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Performances of innovative variable diffusivity membranes integrated within prefabricated timber facades: computer-based modelling and experimental analysis

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Abstract

Vapor barriers and retarders are often needed to improve the hygro-thermal performance of the building envelope. Their use is particularly important in prefabricate timber façade, especially when critical boundary conditions occur. In literature, very little is known on the actual performances of complete envelope packages integrating these membranes, since most of the previous studies focused on the analysis of single components. However, considering the growing interest and use of these timber facade elements, an analysis of the performances of integrated membranes is needed for a correct design of the whole wall structure. Thus, the novelty of this work lies in the validated analysis of a building envelope sample integrating membranes with a variable vapor diffusivity.

The study aimed at investigating the behavior of an envelope component integrating a hygro-variable membrane and a breathable membrane by using computer simulation and experimental facilities.

A thermo-hygrometric analysis of the element has been performed in Delphin, and an experimental activity has been set up, aiming to validate the numerical model, measuring temperature and relative humidity at different layers.Two sets of boundary conditions have been accurately chosen to be critical for the building component in terms of thermal and humidity transmission.

Results show a very good agreement for one test condition. For the second one, the measurement uncertainty has increased. Possible reason is the presence of condensate in the measurement box frame caused by the first test run. The experimental set-up developed is a relatively easy-to-replicate layout for the validation of similar complex packages. Compared to previous studies, the experimental set-up used in this research is indeed simpler and less expensive.

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1 Introduction

Humidity can enter into buildings in different ways: infiltration (caused by rain drainage or due to problems in wall-integrated supply ducts), capillary action (due to rising water from the ground), water vapor stored into materials during the building construction phase, and vapor generated by the occupants.

High levels of humidity combined with low interstitial temperature within the building envelope can cause problems such as superficial and internal condensation, reduction of the insulation capacity of materials, aesthetic degradation and mildew growth [1]. Hence, humidity levels not only influence materials performances, but can also become a problem for the occupants comfort and health.

Therefore, it is crucial to carefully analyse the vapour diffusion within building envelope in order to avoid these uncovenients and to preserve both the building integrity and people wellbeing.

In cold climates and during winter time, problems with excessive humidity are usually caused by poor ventilation of idoor space. The vapour produced within the building goes throughout the building envelope and condenses near colder layers. In order to prevent this behaviour, the humidity rate towards the wall should be reduced, for instance using a vapor retarder membrane on the warm side of the wall.

On the other hand, in hot and humid climates, the main source of vapor can be the outdoor air. In these conditions, condensation problems may occur near the inner layers of the wall, especially if indoor environment is cooled. A possible solution to this issue is the use of breatheble material within the envelope, in order to let the humidity flow through the package, avoiding its storage.

Vapor barriers and retarders are fundamental to control vapour diffusion through the building' walls and therfore to regulate the hygrometric behavior of the whole structure.

Previous research on in situ existing wall and small single-material specimens have already been done [2,3,4], but few examples on more realistic multi-layer building sample integrating variable permeability membranes have not been found in the literature.

Thus, this study aimed at investigating the behavior of an envelope component integrating a hygro-variable ("smart" vapor barrier) membrane named Clima Control 80 [5] and a breathable membrane named Traspir75 [5] , by using computer simulation and experimental facilities.

The experimental set-up developed is a relatively easy-to-replicate layout for the validation of similar complex packages.

2 Metodology

2.1 Experimental set-up

In this work, the behaviour of a building envelope sample (0.5mx0.5m) composed by the layers listed in Table 1 has been analyzed through numerical modeling and experimental investigation. The layout were defined in collaboration with a local supplier of components for timber constructions to ensure the selection of a realistic configuration.

Table 1 Layer composition and characteristics

	Material name	Thickness	Density	Specific heat	Thermal conductivity	Vapor diffusion resistance	Equivalent air layer thickness (SD)	U- value
INDOOR		[mm]	[kg/m^3]	[J/(kg*K)]	[W/(m*K)]	-	[mm]	[W/(m^2*K)]
Layer 1	Gypsum fiber board	12.5	1133.35	1228.37	0.34	16.83	0.21	0.23
Layer 2	Wood fiber insulation board	60	150	2000	0.04	3	0.18	
Layer 3	Clima Control 80 membrane	0.2	400	1700	0.20	1000÷25000	0.2÷5	
Layer 4	Wood fiber insulation board	100	150	2000	0.04	3	0.3	
Layer 5	OSB board	18	630	1880	0.13	280	5.04	
Layer 6	Traspir75 membrane	0.3	250	1800	0.30	67	0.02	
OUTDOOR								

The Clima Control 80 is a particular type of vapor barrier that can adapt its diffusion resistance based on the sorrounding relative humidity. In particular, the membrane vapor resistance increases with a decreasing sourrounding relative humidity (Fig. 1).

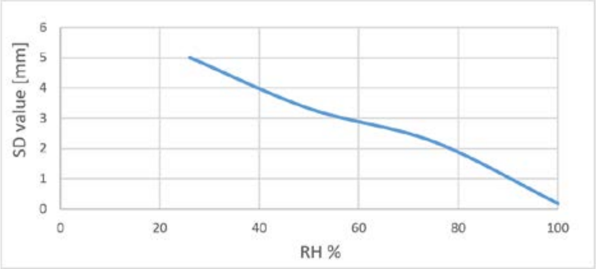

Figure 1 Clima Control 80 membrane relation between surrounding RH and SD-value

EE08 by E+E sensors (RH→0÷100% ± 2%; T→-40÷80°C ± 0.2°C) have been placed between specimen layers for temperature and relative humidity monitoring. Fig. 2 shows the sensors' position within the materials. In particular, four internal sensors have been embedded into small cavities inside the wood fiber insulation boards: position **1** is at gypsum – insulation (60mm) interface; position **2** is at insulation (100mm) – Clima Control 80; position **3** is at OSB – insulation (100mm) interface; position **4** is at Clima Control 80– insulation (60mm) interface.

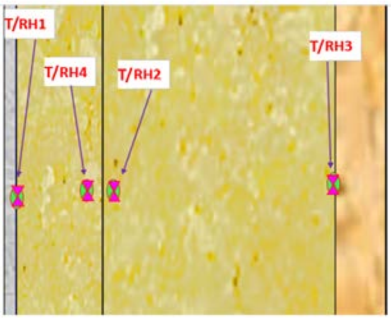

Figure 2 Sensors' position inside the specimen

Two different boundary conditions have been created on the different sides of the speciment during the analyses.
On one side, the temperature and relative humidiy level were mantained by a mono-zonal climatic chamber. On the other side, it has been decided to use a dummy woden made climatic chamber, very well insulated both thermally and for vapor diffusion. This box has been made of OSB panels (18mm thickness), internally covered by pressed insulation material (Styrodur 2500C, 60mm thickness).
During the two performed tests, the box was plugged by the specimen on one side, as shown in Fig. 3, and the whole block was inserted in the main climatic chamber. The desired temperature inside the box has been set using a thermal resistance, while the air relative humidity has been set using salt solutions.
In this way it has been possible to impose a thermal and vapor flux from one side to the other of the tested component.

Figure 3 Specimen closing the box

2.2 Boundary conditions

In order to analyze the behavior of the component under critical temperature and high humidity conditions, two tests have been done. In the first one, typical hot and humid conditions for the outdoor environment has been used. In particular, the temperature has been set to such a high value (Fig. 4 - left) to take into account the possible effect of direct sun irradiation on the façade.
In the second test, typical cold and very humid winter conditions have been used (Fig. 4 – right).

Figure 4 Boundary conditions TEST 1 (left) (hot/humid summer outdoor conditions) & TEST 2 (right) (cold/humid winter outdoor conditions)

The duration of each test has been determined after considering the necessary time for reaching the thermal and humidity flux steady-state conditions in the specimen, accepting a difference respectively of 0.1 W/m² (heat flux) and 0.1 g/m²h (humidity flux) between entering and exiting fluxes. These values have been assessed through a preliminary simulated numerical model. Finally, it has been decided to let each test run for almost 15 days.

In the following figures (Fig. 5, Fig. 6), the monitored boundary conditions for the second test are reported.

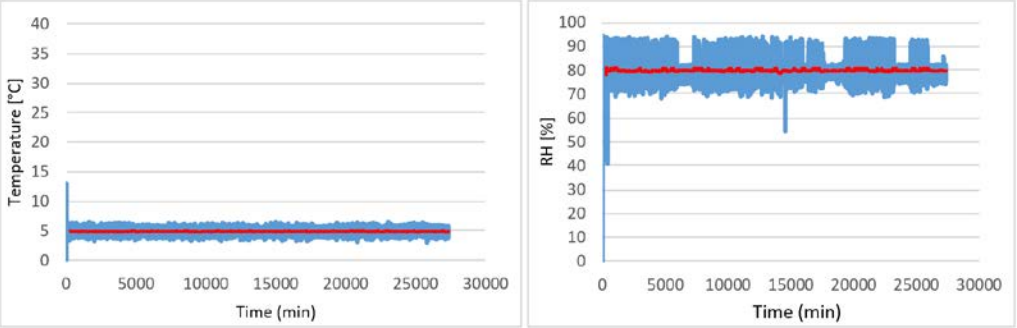

Figure 5 Climatic Chamber Temperature (left) & RH (right) - TEST 2

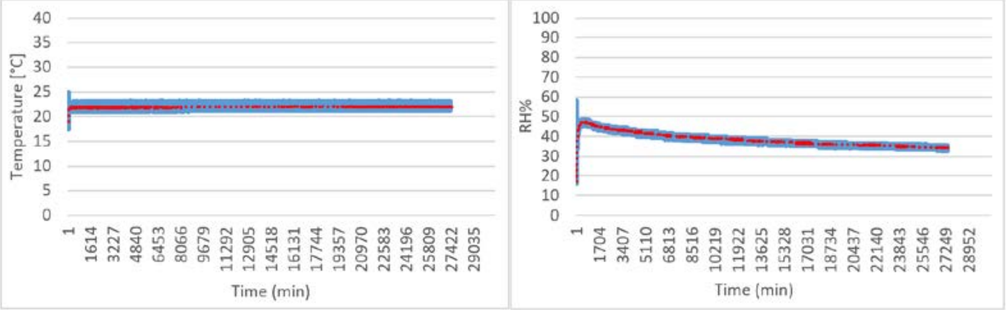

Figure 6 BOX Temperature (left) & RH (right) - TEST 2

3 Results

In this section, the results of the monitoring campaign are compared with those calculated by the numerical model built in Delphin 5.8.

The presented values obtained with the model have been reached after a calibration process on some uncertain parameters, mainly related to humidity transfer function of those materials whose technical sheet was not available.

3.1 TEST 1 – hot/humid outdoor conditions

In this test, NaCl solution has been used within the BOX to generate the desired humidity rate (RH=70%).

In Fig. 7 and Fig. 8, the monitored and measured trends for temperature and relative humidity at each material interface are presented.

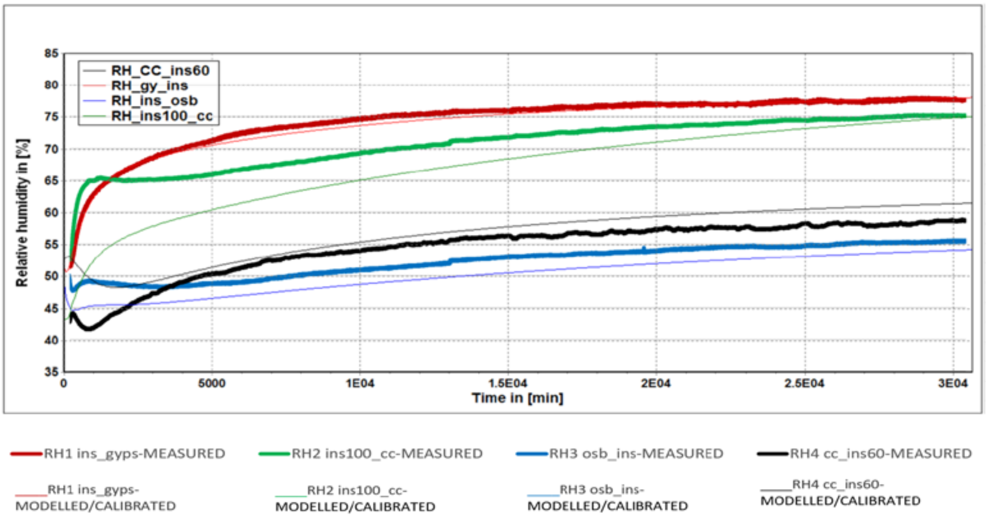

Figure 7 Relative humidity trends – measured data (thick line) & modelled data (thin line) – TEST 1

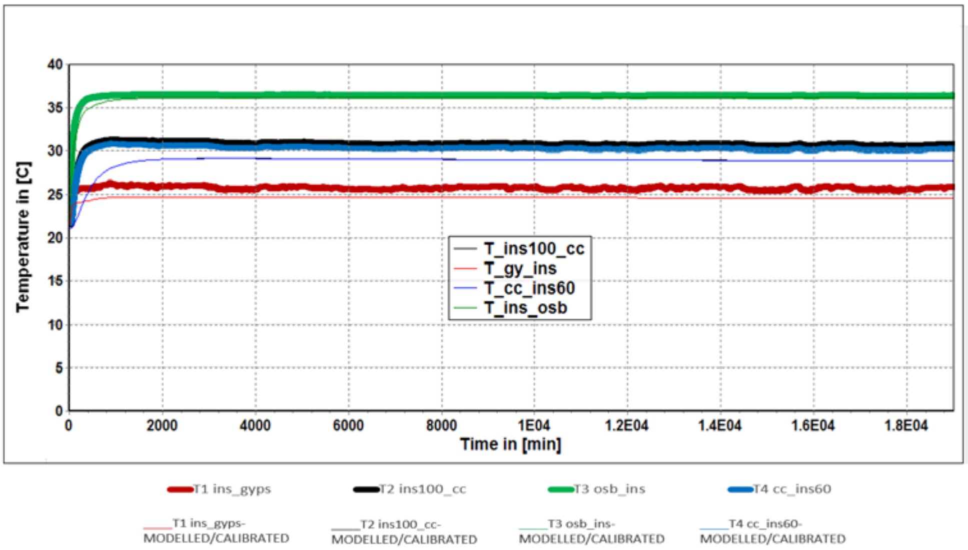

Figure 8 Temperature – measured data (thick line) & modelled data (thin line) – TEST 1

In Fig. 9 it is presented the comparison between measured (both calibrated and not) and calculated relative humidity, after having reached stationary conditions for vapor flux across the specimen.

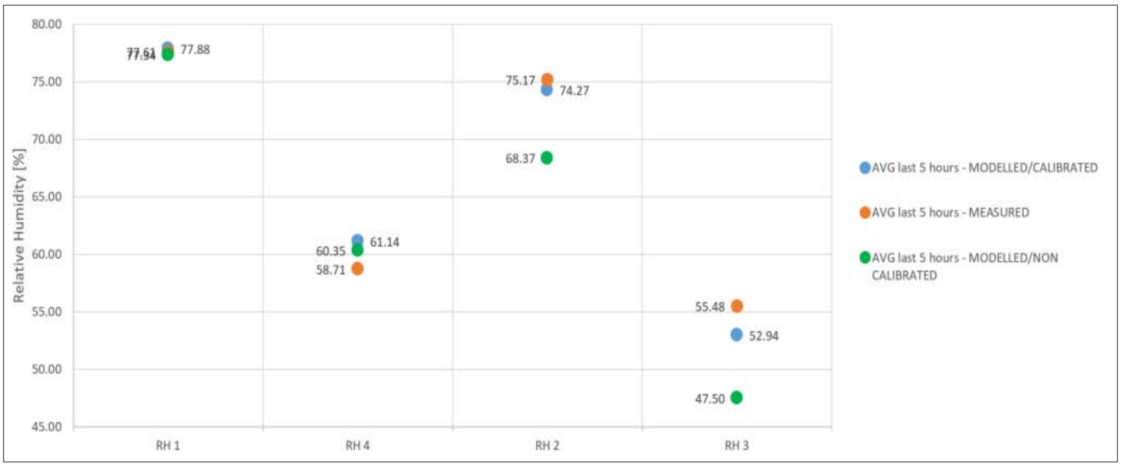

Figure 9 Comparison between RH values measured & modelled, after stationary conditions (averaged on last 5 hours) – TEST 1

Table 2 and Table 3 present the standard deviation and the absolute value between calculated and monitored values for each sensor in the last hours of simulation (after stationary conditions occurred).

Table 2 Root mean square error RH values - TEST 1

RMSE(RH1)	RMSE(RH2)	RMSE(RH3)	RMSE(RH4)
0.18	1.11	2.56	2.38

Table 3 Mean absolute error RH values – TEST 1

MAE(RH1)	MAE(RH2)	MAE(RH3)	MAE(RH4)
0.17	1.11	2.56	2.38

3.2 TEST 2 – cold/humid outdoor conditions

In the second test, $MgCl_2$ solution has been used in order to create the desired humidity conditions within the BOX (RH=40%).

In Fig. 10, Fig. 11, Fig. 12 and Table 4, the results of the comparison between monitored and calculated data are reported for the TEST 2.

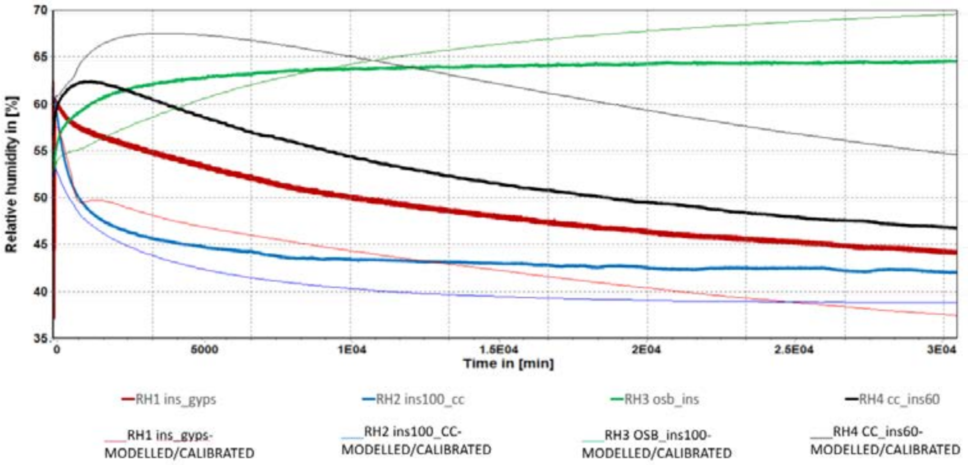

Figure 10 Relative humidity trends – measured data (thick line) & modelled data (thin line) – TEST 2

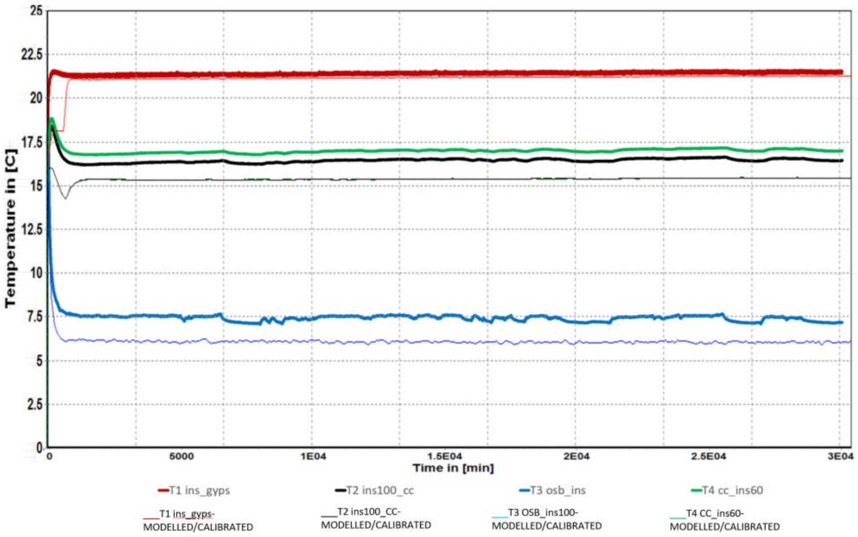

Figure 11 Temperature – measured data (thick line) & modelled data (thin line) – TEST 2

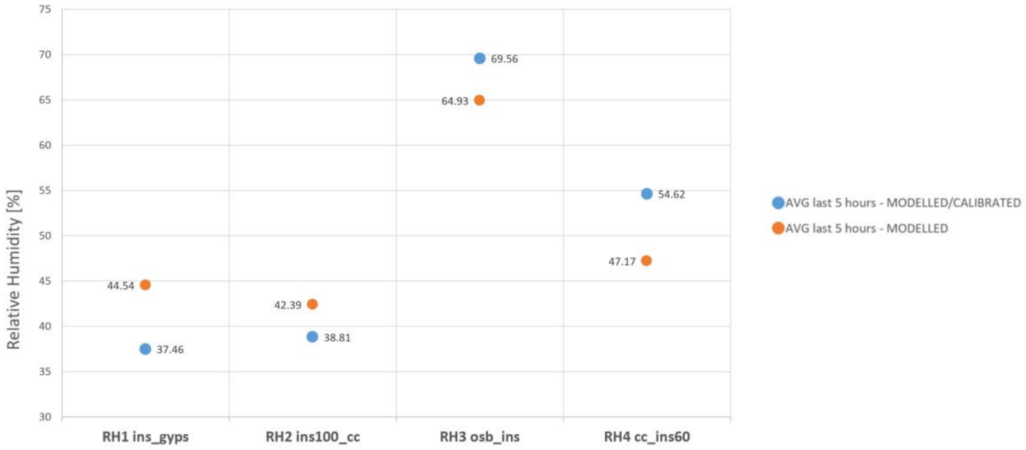

Figure 12 Comparison between RH values measured & modelled, after stationary conditions (averaged on last 5 hours) – TEST 2

Table 4 Root mean square error & Mean absolute error RH values - TEST 2

RMSE, MAE (RH1)	RMSE, MAE (RH2)	RMSE, MAE (RH3)	RMSE, MAE (RH4)
10.1	4.89	4.61	8.39

4 Discussion

In both tests, the measured temperature values are in agreement with the model results. This is due to minor uncertainties resting on the heat transfer process. The only small issues regarding the temperature is caused by the climatic chamber`s difficulty in maintaining conditions around 0°C in a stable way during the test 2.

On the other hand, the relative humidity results (especially in the test 2) show more discrepancies between the model and the reality. Possible explanations to this aspect are as follows.

Firstly, it is noticeable from Fig. 6 that the relative humidity boundary conditions, both in the box and in the climatic chamber, have quite low stability: for the box, this can be due to a non-optimal dosage of the salt solution. Regarding the instability of RH level in the climatic chamber, the main problem is related with the too low operative temperature set in the machine (~ 0°C).

Although the results of the first test are in good agreement with the simulation, another source of errors in the tests can be related to the sensor positioning inside the specimen. In fact, while RH simulations results from Delphin represent the moisture contained in material`s pores, the E+E sensors that have been used in this experimental activity measures the humidity level in the small air cavity within the material where they are inserted.

Another cause of uncertainty that is likely to have affected the second test is the non-adequate drying time estimation. Some humidity, trapped in the sample form the previous test, can have slightly influenced the results of the second test.

Finally, it should be taken into account that all the materials` propriety function used by the model, in particular for less known materials within our specimen (e.g. OSB layer and vapor retarders), can present themselves small uncertainties.

5 Conclusions

It can be concluded that, in the first test, there is a better result in terms of matching between simulation and calculated data, with a maximum difference in stationary condition (value assumed as the average in the last 5 simulation hours) of 4% for RH and 1°C for temperature.

The lower agreement of the second test is likely to have been caused by the above-mentioned possible reasons. Thus, considering the overall results of the performed analyses, it can be concluded that the modelling of the smart vapor barrier was successfully. In general, the methodology applied to this study, although with a limited budget, revealed as a solid approach for the investigation of thermal and hygrometric phenomena in a building's envelope sample.

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