A NUMERICAL ANALYSIS OF AN EXPERIMENTAL SET-UP FOR EVALUATING MOISTURE BUFFER EFFECTS OF POROUS MATERIAL

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Abstract. *The variation of humidity within the environment is a very important aspect of thermal performance of buildings. The humidity directly affects the thermal comfort, air quality, the health of residents, the durability of materials and energy consumption. The objective of this work is to present a numerical analysis performed on an experimental apparatus to evaluate the hygroscopic inertia of porous building materials. The parameter moisture buffer value (MBV) informs the amount of water absorbed or released by a hygroscopic material when a cyclic step change in RH between high (75%) and low (33%) levels respectively for 8 and 16 h, is directly imposed in the inlet air. This experimental device is numerically analised to determine the physical parameters that take an important role in this caracterization.*

Keywords*: Hygroscopic inertia; air quality; relative humidity; moisture buffer value; porous media; PowerDomus.*

1. INTRODUCTION

It is very important to study the interaction processes of the porous / moisture, since the mechanisms of heat and mass transfer can significantly influence the thermal comfort and building material. In a lot of cases the moisture can accelerating the degradation process of buildings, and the repair solutions are generally expensive. It is also possible to appear human diseases due to the bad air quality caused by mold growth. So it is necessary to determine the ability of materials have to adsorption/desorption with moisture air content.

As building materials are strongly influenced by moisture, then the project NORDTEST, bringing together several Nordic countries, established a test protocol for determining the so-called experimental MBV [kg / m².% RH] (Moisture Buffer Value) for these materials. The principle is based on tests in a chamber (Rode, 2006).

The variation of relative humidity is a very important point for the construction industry. Has a significant effect on thermal comfort, air quality, durability of construction materials and also the energy consumption of buildings.

In the project NORDTEST, practice to get the moisture measurement is made by placing the sample exposed cyclically to a period of 8 to 16 hours with humidity of 75% and 33% respectively. For example, the sample was subjected to a cycle of 8 hours in a high humidity of 75% and 16 hours for a low humidity of 33%, so the interval of each cycle is 42% relative humidity.

The trend of mass increase is due to initial conditions that were far inferior to the quasi-stationary state conditions that emerge after a few cycles (Rode, 2006).

In accordance with the protocol of the Japanese Industrial Standard (JIS 2002), the range of time that the sample was subjected to 24 hours is 53% to 33%, which is also 24 hours for low humidity, the process is repeated for the other bands of moisture that are 75% to 53% and average humidity of 93% to 75% of high humidity.

The Japanese Industrial Standard (JIS), the Draft International Standard (DIS) and Protocol NORDTEST, have similar procedures regarding the use of cyclic tests, where the sample is conditioned to a specific relative humidity and uniform, there are regions where there is no tested this uniformity of high or low humidity. The evolution of the mass of moisture in the sample is recorded and its amplitude sets the Moisture Buffer Potential (MBP), which measures the potential for moisture storage (Janssen, 2008).

Meissner *et al.* (2010) present a full-scale experimental apparatus to evaluate the hygroscopic inertia of porous building materials, whose principle is based on measurements of the changes in a mass of a porous material when its neighboring environment is subjected to daily cyclic variation of relative humidity. Results in terms of the moisture buffer value index (MBV) for a light weight wood construction material are also presented and discussed, considering two sample sizes: a cubic cell with 24 m^2 of mass exchange surface area and a smaller one with a circular exposed area of approximately 0.08 m². They found different MBV values to different sample sizes (24 m^2 and 7.82×10^{-2} m²).

The objective of this work is to analyze the physical parameter that contributed to these differences in measurements. These analyses will allow the established new procedures to determine the parameter MBV in a way that will be easily reproduced.

2. ANALYSIS

The index MBV allows estimating the moisture storage capacity of one material to a daily cycle of variation of relative humidity. The MBV is defined as the ratio of the measured amount of moisture exchanged per unit surface area exposed during a certain period in the experimental apparatus, where the material is exposed to a high relative humidity for 8 hours and a low relative humidity for 16 hours (Meisssner *et al*., 2007). The MBV is defined by Eq. 1, according to the protocol NORDTEST (Rode, 2006), which involves the variation of mass, surface area and the change in relative humidity.

$$MBV = \frac{\Delta m}{A.\Delta\%UR} \quad (1)$$

where Δm is the change in mass [kg]; A is the surface area [m²] and $\Delta\%UR$ is the change in relative humidity.

The MBV depend of several factors like the moisture diffusivity, vapor permeability, cycle times, density, roughness, thickness, surface quality, ventilation rate and air temperature (Meisssner, 2008). Thus a numerical analysis may bring us additional information on the sensibility of these parameters for the calculation of MBV and the deviations and sources of uncertainties.

To realize these analyses are used a simulation in buildings software called: POWERDOMUS. It uses dynamic model for analyzing the hydrothermal behavior (Mendes, 2003). The PowerDomus software is the first national software simulation and hydrothermal building energy that was developed to meet the needs of energy saving, thermal comfort and sustainability issues. Its interface is easy to use, allowing designers of systems to determine environment heat exchanges much more quickly and accurately. There are several benefits that the software provides:

- Analysis of different strategies to reduce energy consumption in buildings by remembering that these are responsible for about 48% of total electricity consumed in the country;
- Technical support professionals to energy planning in the design, construction and evaluation of programs for energy conservation;
- Support for affordable housing projects for low-cost and low power consumption;
- Creation of building designs "green" and energy efficient, improving health and productivity of occupants;
- Analysis of coupling with HVAC systems, providing an overall assessment of each end-use energy in buildings;
- Improvement projects of HVAC systems using simulation analysis of alternative schedules and transient. Typically, projects are made based on critical conditions and without taking into account the thermal inertia of the components that makes equipment to be oversized, and over time, with control problems, spend much more energy than they should;
- Inclusion of output files for analysis of costs from the pricing structure established by ANEEL (National Electric Energy Agency, Brazil).

The PowerDomus is software that provides profiles of temperature and moisture on the walls for any length of time beyond the present values of these properties for each zone of one or more buildings, considering not only the heat transfer, but also the vapor transport and liquid through the building wrap.

2.1 BOUNDARIES CONDITIONS

The domains are the same that presented by Meissner *et al*. (2010) that describes the experimental apparatus. It is analyzed a cubic test-cell of 8 m^3 made of the material being tested connected to a supply air tunnel with controlled temperature and moisture. The wall is divided into layers to be applied to the finite volume method for discretization of governing differential equations. The PowerDomus software can also display the hydrothermal properties of the materials present in its database. An important feature is the equilibrium isotherm. The Fig. 1 shows this feature of the light weight wood, the material used in this experiment work.

The properties are based on the percentage of saturation, thermal conductivity; moisture transport coefficient associated with a temperature gradient, moisture transport coefficient associated with a moisture gradient, vapor transport coefficient associated with a temperature gradient, vapor transport coefficient associated with a moisture gradient.

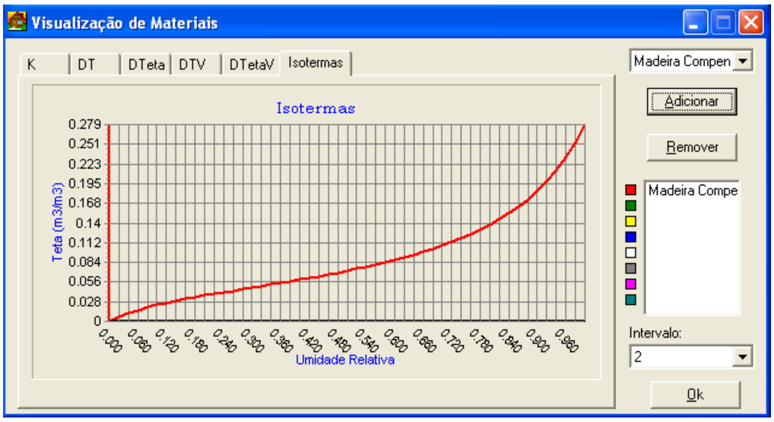

Figure 1. Isotherm of the light weight wood.

2.2 THE CONVERGENCE CRITERIA

They are three parameters take in account:

- Convergence Criteria for Temperature (T): defines the value of the minimum error adopted so that the software can go to the next time step without having to make any further iteration on the internal temperature of the area or building elements;
- Convergence Criterion for Moisture (W): sets the value adopted for the minimum error that the software can go to the next time step without having to make any further iteration on the absolute humidity inside the zone or the moisture content of wall;
- Maximum Number of Iterations: sets the maximum number of iterations for the software if it cannot converge to the value of convergence.

The tests performed in software PowerDomus it was created a weather file to simulate the experimental conditions. Figure 2 presents the box created with for this analysis.

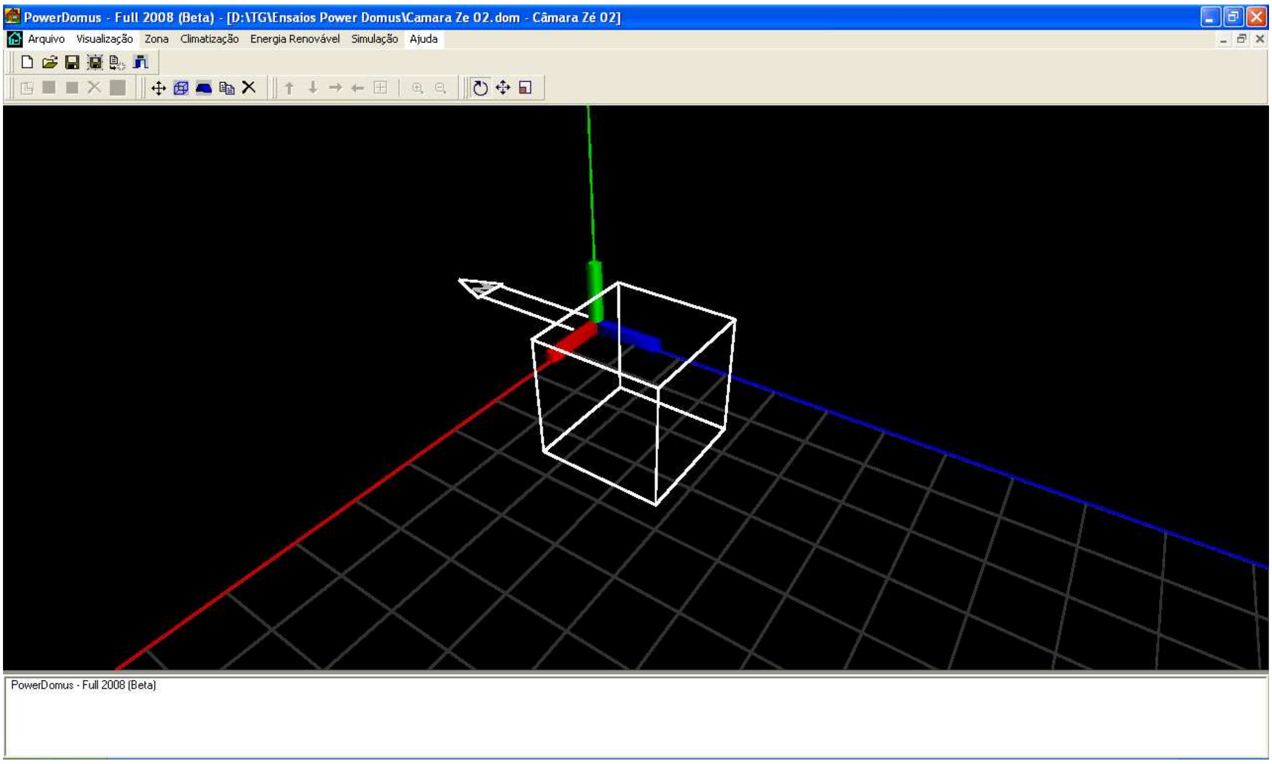

Figure 2. Geometry used in the analysis.

It is used a thickness of 100 control volumes to the wall with a thickness of 65 mm.

The time step was defined to lower steps of time (less than 1min). It was choice the Model 0 in PowerDomus that consider the moisture in the wrap.

3. THE EXPERIMENTAL APPARATUS

Figure 3 shows the experimental apparatus presented by (Meissner, 2008) to MBV measurements. The apparatus use a calorimeter, which is composed of two chambers: one in which is installed a psychometric bench, Fig. 4, that it controlled the temperature, humidity and air velocity and the second one that housing the test cell made of wood. These chambers are connected by a window through which passes air blown by the psychometric bench and that air then enters the test cell. The first chamber will control the air conditions that will enter the test cell while the second chamber will simulate the conditions of air outside the test cell. The psychometric bench consists of a fan, two heating systems, two systems of humidification by a steam generator and a sprinkler and a cooling system. The data are measured by thermocouples and sensors installed in the chambers.

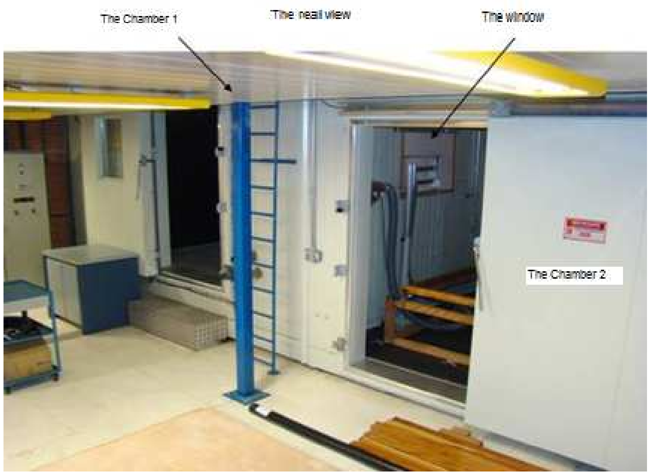

Figure 3. Calorimeter apparatus containing two chambers.

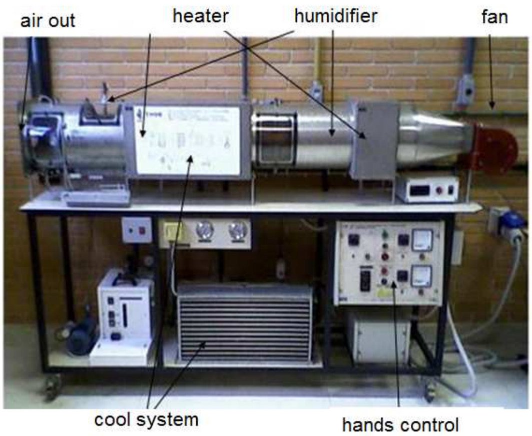

Figure 4. Psychometric bench.

A 100 mm diameter flexible duct is used to conduct the air between the two chambers. It has an additional layer of glass wool thermal insulation, reducing losses and improving control of temperature inside the duct. A 3 m length duct is used to measure the flow meter using an anemometer in fully development conditions. The air flow is calculated by the air velocity measurement at the midpoint of the duct, Eq. 2.

$$\dot{V} = \bar{V} A \tag{2}$$

where: $\dot{V}$ is the volume flow [m³/s]; $\bar{V}$ is the average speed in the duct [m/s]; A is area [m²].

A typically Reynolds number is 9296.57 (considering the air density of 1.29 g/l and viscosity $182{,}675.10^{-7}$ Ns / m), characterizing the turbulent flow. A tax of 3 changes per hour to the air renewal was determined assured. The average velocity of the air flow is determined by: (Fox and McDonald, 1998)

$$\bar{v} = U\left(\frac{2n^2}{(n+1)(2n+1)}\right)$$

$$n = -1{,}7 + 1{,}8 \log(Re) \tag{3}$$

The U is the velocity at the midpoint measured in m/s and the Reynolds number is based on average speed. The Reynolds number is calculated according to the psychometric conditions of the air, so the speed sensor may vary.

4. RESULTS

The numerical analyses demonstrate the behavior of moisture function of the time, the mass flow of adsorbed/desorbed and MBV.

Figures 5 and 6 show the humidity, the adsorbed/desorbed mass and the MBV and $h_m = 2.75\ 10^{-3}$ m/s and a number of nodes equal to 100.

Figure 7, was held on 10 test days in order to observe the behavior of moisture and especially where the mass flux approaches to the steady state, as shown in Fig. 8.

Figure 9 it is used $h_m = 2.75\ 10^{-4}$ m/s, number of nodes equal to 65, the test time equal to 15 days, starting at 10% humidity and a time step equal to 30 seconds. It can be observed that there was a change in the cycle of water vapor, the adsorbed mass flow is very close to the value of mass desorbed, Fig. 10.

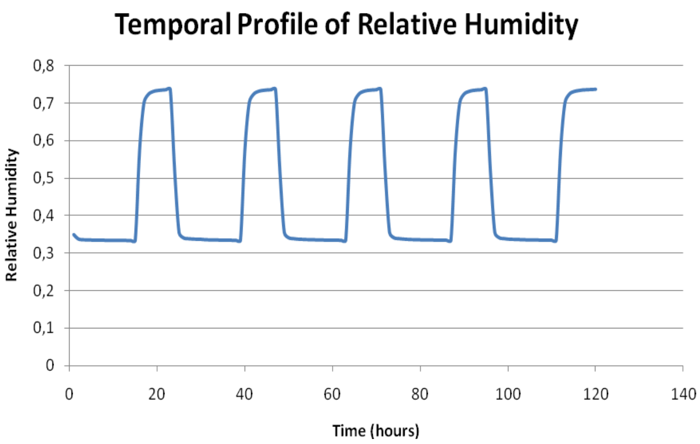

Figure 5. Moisture variation to $h_m = 2.7510^{-3}$ m/s and number of nodes equal to 100.

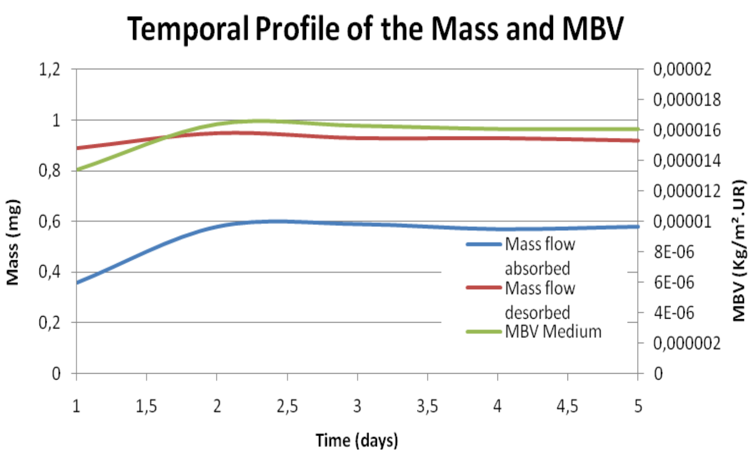

Figure 6. Mass flow Adsorbed/desorbed and MBV to $h_m = 2.75.10^{-3}$ m/s and number of nodes equal to 100.

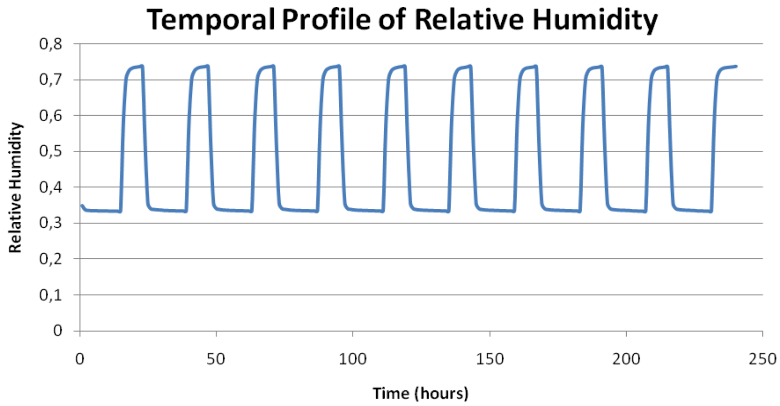

Figure 7. Moisture variation to h_m= 2.75 10^{-3} m/s and number of nodes equal to 100,10 days of testing.

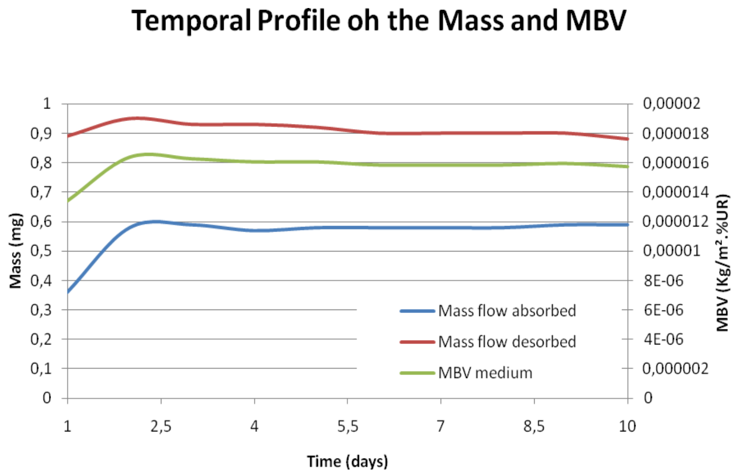

Figure 8. Mass flow Adsorbed/desorbed and MBV to h_m = 2.75.10^{-3} m/s and number of nodes equal to 100. 10 days of testing.

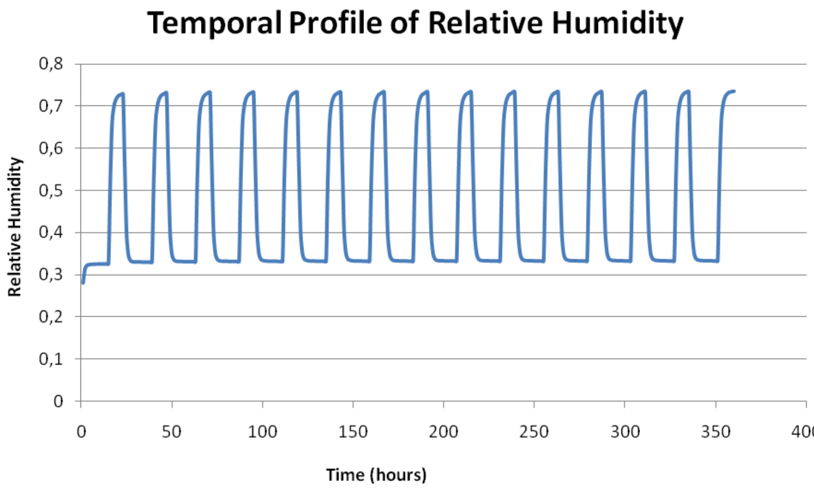

Figure 9. Moisture variation to h_m = 2.75 10^{-4} m/s and number of nodes equal to 65 and 15 days of testing, starting at 10% RH and with time step of 30s.

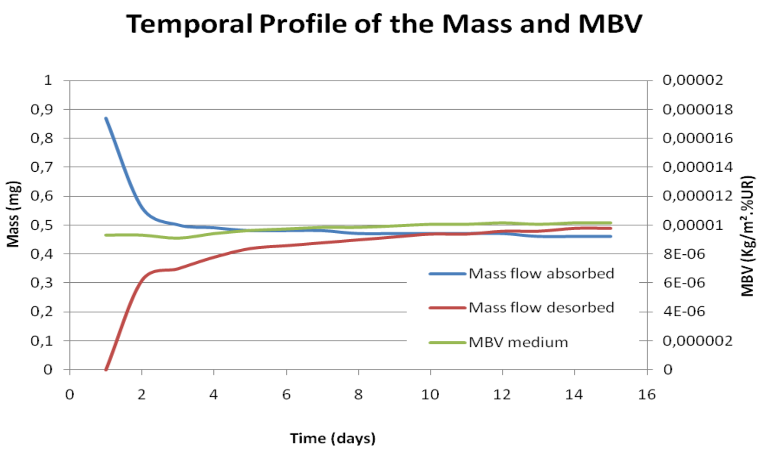

Figure 10. Mass flow Adsorbed/desorbed and MBV to $h_m = 2.75\ 10^{-4}$ m/s and number of nodes equal to 65 and 15 days of testing, starting at 10% RH and with time step of 30s.

The figures 11, 12 and 13 show a comparison of temporal profile of the mass adsorbed, desorbed and the MBV, for different values of h_m, using spatial discretization of the wall equal to 100, with test time equal to 5 days, with initial moisture of 50% and initial temperature of 23 ° C.

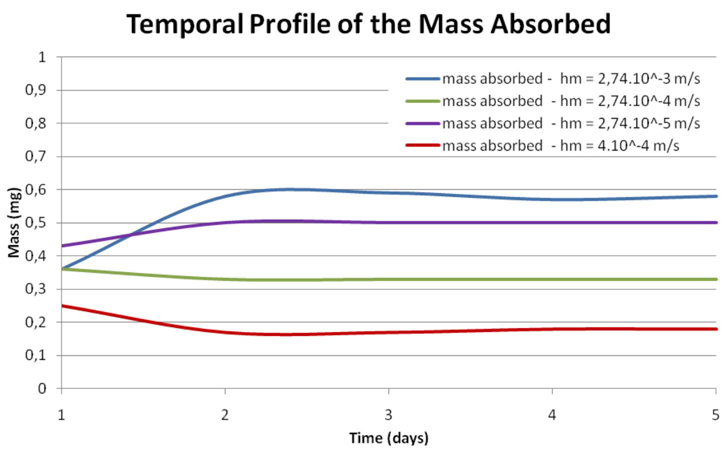

Figure 11. Adsorbed moisture mass variation for several mass transfer coefficients.

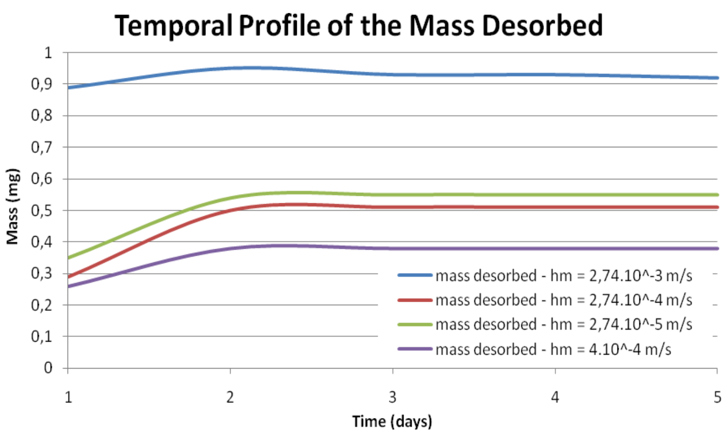

Figure 12. Adsorbed moisture mass variation for several mass transfer coefficients.

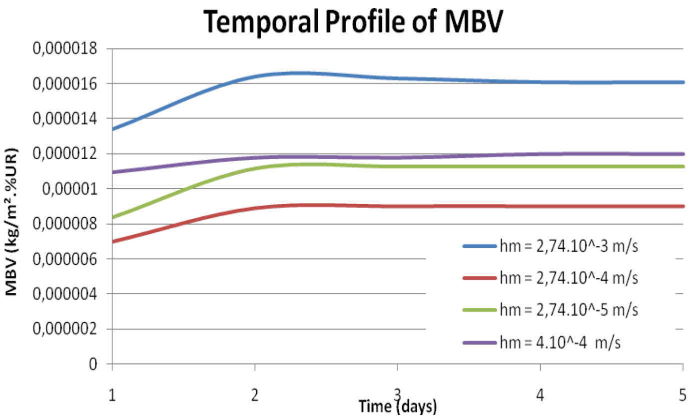

Figure 13. MBV variation for several mass transfer coefficients.

Figure 14 presents numerical and experimental results compared for the same conditions. Only the convective mass transfer h_m is changed. The numerical results present a good concordance with the experimental measurements.

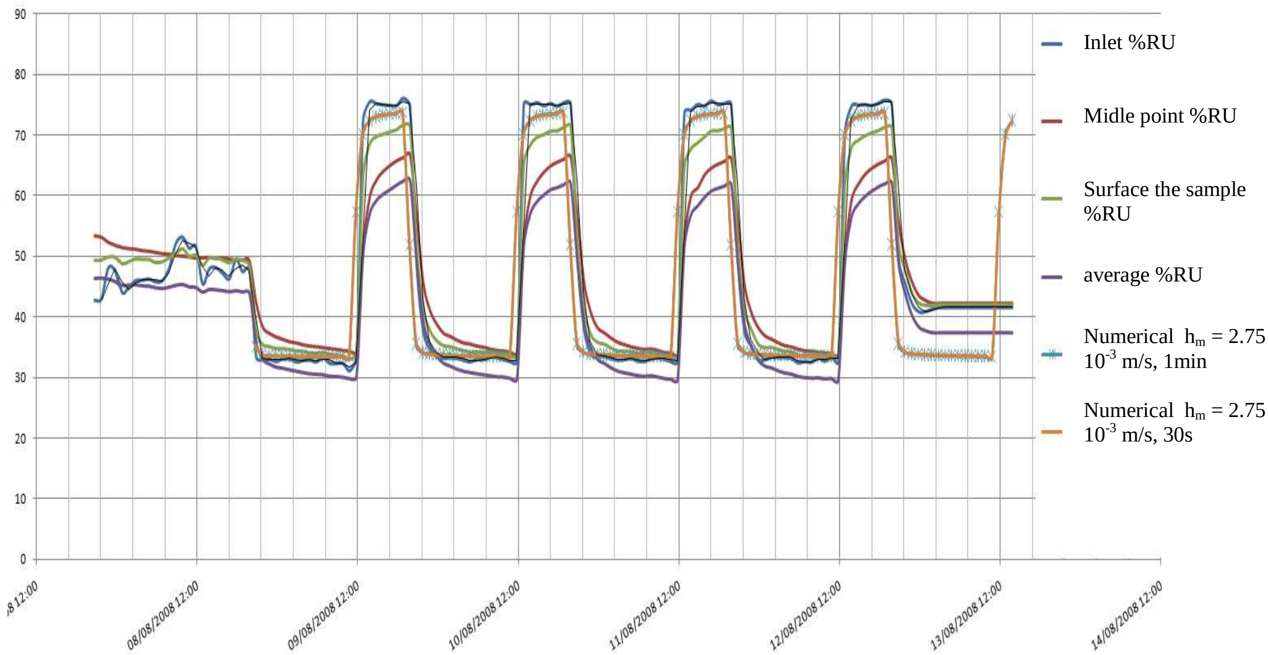

Figure 14. Moisture variation to $h_m = 2.75\ 10^{-3}$ m/s compared to experimental values of the moisture in the test-cell.

5. CONCLUSIONS

To the numerical analysis using the PowerDomus software the variation of pre-established parameters such as time step, the test day, number of nodes and the initial relative humidity, there is a difference with respect to the mass flow of vapor adsorbed/desorbed and the values of MBV. It can be conclude that the value of MBV has ranged over five days, as shown in the comparison of Figure 10 and more experimental days is necessary. The convective heat mass transfer plays an important role in the MBV parameter. Changes in the air flow velocities can modify the convective heat mass transfer and consequently the estimated MBV. New investigations must be performed to determine a possible region unless dependent of the convective heat mass transfer.

Previous works uses 3 days measurements to determine the MBV parameter. The numerical results show that it is necessary more days to accomplish the quasi-stationary state conditions.

For future work it is suggested to perform more tests varying the parameters mentioned above and especially the time trial, leaving more than 1 month.

6. ACKNOWLEDGEMENTS

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