Dynamic Moisture Behaviour of Materials for Integration into Whole Building Heat Air and Moisture Simulation

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ABSTRACT

Indoor humidity is an important parameter influencing the occupants' perception of indoor air quality, and is also a cause of harmful processes that may occur on surfaces of materials, such as cracking of walls or microbiological growth. Building materials used in contact with indoor air may have a positive effect to moderate the variations of indoor humidity, and may be used to improve indoor comfort and decrease energy consumption. This work deals with dynamic hygric characterization of civil engineering materials: red clay brick and gypsum board. First the structural physical characteristics of the materials are studied. The different microstructures are described using scanning electron microscopy, apparent density measurements and mercury porosimetry. Then, the vapour buffering effect of both materials for two different relative humidity steps is analysed. The results show significant differences in the hygric behaviour of both materials.

KEYWORDS

Moisture, building, dynamic, gypsum board, brick, measurements

INTRODUCTION

Moisture flows in buildings are closely related to heat and air transfers in the envelope and indoor air. The importance of latent heat of water introduced the idea to use moisture to control the thermal environment, for example using direct on indirect evaporative cooling techniques. Needless to say that the indoor temperature decrease is proportional to the amount of the evaporated water. In practice however the quantity of evaporated water depends upon resulting indoor conditions and mainly upon relative humidity, which is a significant limitation of the performance of such cooling techniques. Indeed, too high relative indoor humidity values are the cause of moisture damage in buildings, such as for example microbiological growth. Materials that absorb and desorb moisture can be used to moderate the amplitude of indoor moisture variation and therefore to participate in the improvement of the indoor climate and in the energy savings (Padfield, 1999).

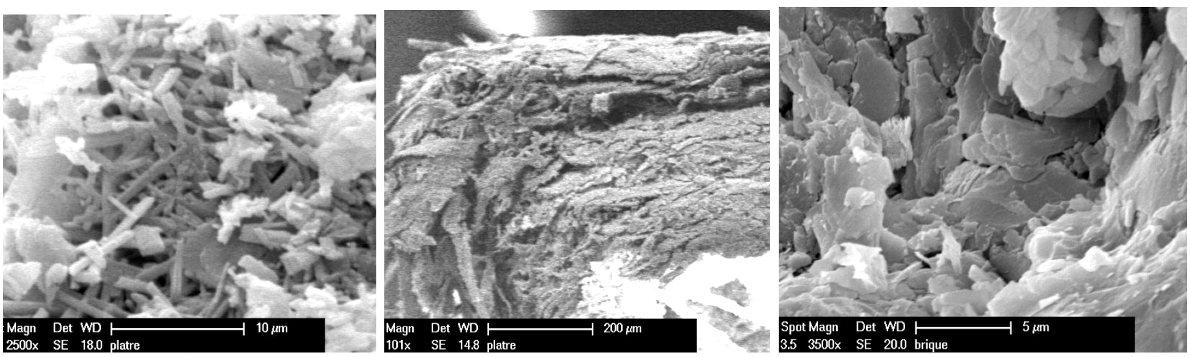
Hygric properties of building material have been deeply studied in the past, and values of water vapour permeability and sorption isotherms are rather known for many materials. However, those properties apply for stationary conditions, which almost never occur in real buildings. Moreover the difficulty to predict correctly dynamic moisture behaviour of materials using only steady-state properties was pointed out by several authors (see for example Peuhkuri, 2003). Some very recent research project are interested in dynamic characterisation of moisture behaviour of materials (called also "moisture buffering"), such as Nordtest project (Rode et al. 2005) from Nordic European countries, that proposed a standard experimental method.

In this project dynamic measurements were performed in a climatic chamber on two types of building materials: gypsum board and red ceramic brick. Numerous tests were performed to check the importance of different boundary conditions on exchanged mass flow: size of the sample, its position in the climatic chamber (which influences air velocities close to the sample), its position (vertical, horizontal…) and also the impact of ambient temperature. Experimental results are analysed using additional information obtained using mercury porosimeter and electron microscopy.

INVESTIGATED MATERIALS

Two materials with very different microstructure and chemical composition were chosen: gypsum board and red brick. The gypsum board BA13 from Lafarge, non coated, and red brick from Téréal-Guiraud were used. The gypsum board is a composite “sandwich” material with about 11 mm of plaster in between two 1 mm thick paper layers. For sorption experiments the samples were approximately $100x100x13mm^3$. Five faces were sealed with aluminium tape. Therefore, only one face exposed to the varying indoor conditions was tested.

The porous structure of the samples has been investigated using electron microscopy, after coating of the samples using gold. The results can be seen in figure 1. The needle-formed crystals of gypsum, described in the literature (Meille, 2001) can be clearly seen in figure 1. Its final structure includes numerous empty spaces in between the surfaces. Such porous structure has many open pores communicating with the ambient conditions. Figure 1 shows also the vegetal cellulose fibbers forming the paper.



gypsum needles (10 μm) paper fibers (200 μm) detail of clay layers (5 μm)

Figure 1. Gypsum board and brick microscopy

Very different porous structure of brick can be seen in figure 1. The structural matrix forms superposed layers (formed by silicates - tetraedrical silex). The empty spaces in between the clay layers are mainly small closed pores. The differences are due to very different constitution: bricks are inorganic material formed mainly by clay and sand, with both vitrous and crystal phases existing (Alviset, 1994).

The pore distribution and material density were also investigated using mercury porosimeter. Results of density measurements are presented in Table 1. Gypsum board apparent density in mercury porosimeter measurements was calculated supposing that the gypsum board is composed of 15.4% of paper (2 mm thickness) and of 84.6% of gypsum (11 mm thickness). Apparent M/V density was measured using a measured mass to measured volume ratio.

TABLE 1
Density measurements of different materials

Density (g/ cm^3)	Paper	Gypsum	Gypsum board	Brick
apparent. M/V			0,69 ± 0,04	2,09 ± 0,09
apparent porosim (Hg)	0,45 ± 0,02	0,75 ± 0,02	0,70 ± 0,04	2,03 ± 0,04
matrix porosim (Hg)	1,60 ± 0,15	2,18 ± 0 ,03		2,80 ± 0,30

The open porosity of 71,4 % was found for the paper, 65,8 % for gypsum and 27,7 % for the brick. Therefore the gypsum board porosity is about twice as high as the brick. Also, the pore distribution was investigated using mercury porosimetry and is presented in figure 2. The brick has much less pores than paper and gypsum. Main pores diameters for brick are: 0.4, 0.7 et 5.6 µm, for the plaster 1.1 et 33.4 µm and for the paper de 6.9, 58.0 and 122.6µm (±3%).

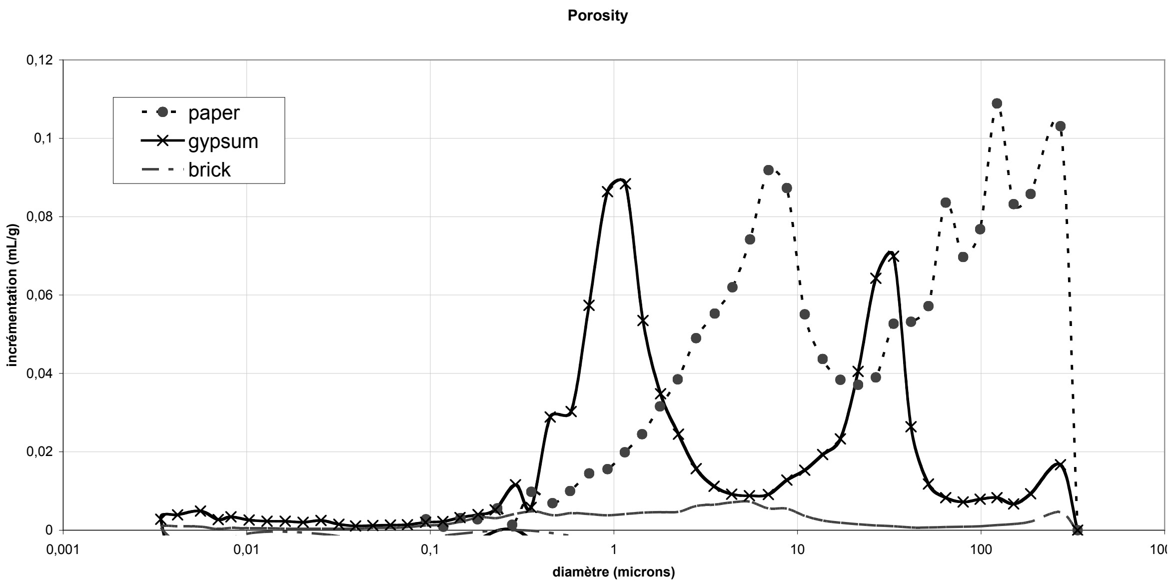


Figure 2. Porosimetry measurements

EXPERIMENTAL MEASUREMENTS OF SORPTION KINETICS

Climatic chamber with precise control of relative humidity and temperature was used to measure the sorption kinetics. The measurements were made by controlling samples' weight over experimental period. The samples were put into hermetic bags and weighed out of the climatic chamber. Preliminary experiments validated the approach – the fact that samples were weighted outside of the climatic chamber had no impact on results. As the air in the climatic chamber was well mixed by a continuously operating fan, homogenous air conditions were assumed in the chamber, which was verified by preliminary experiments. Moreover the position of the sample (horizontal, vertical, etc.) was found to have no impact on the results (Woloszyn et al. 2006). Also the moisture uptake was proportional to the exposed surface.

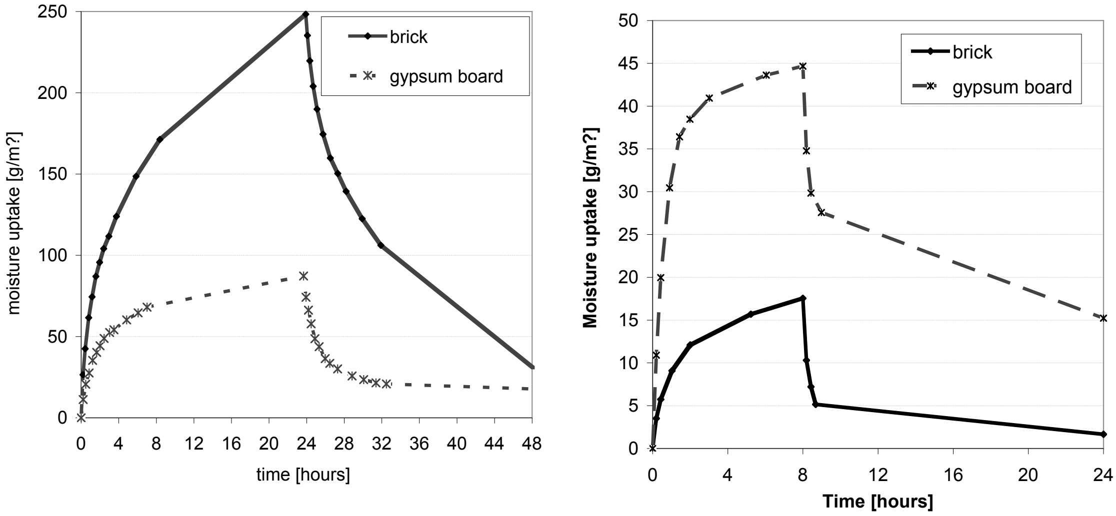
All the experiments were isothermal; for the reference case the temperature was kept at 20°C. First, the samples were preconditioned over a minimal period of 24h at 35% of RH (relative humidity), and then a step variation of RH was applied: 95% for exactly 24 hours. At last, a step decrease of RH was applied: back to 35% over at least 24 hours.

Moreover cyclic moisture loading (16h at 33% - 8 h at 75% at 23°C, over 5 to 6 days) were performed in order to meet the requirement proposed by Rode et al. (2005) for standard measurements of moisture buffering capacity of materials.

5 samples were used in each experiment – the results presented in the following are the mean of the 5 samples. The results are given in g/m² of moisture exchanged with the air. A good agreement between the 5 samples was found in all the experiments. The uncertainty of results is estimated at ±2.5g/m².

RESULTS AND DISCUSSION

The results under both reference conditions and cyclic loading for gypsum board and bricks can be seen in figure 6. The difference between both materials is significant. For high RH step (35-95%) moisture uptake for brick is about 2.5 times higher than moisture uptake for gypsum board. However the situation is very different for medium RH step (33-75%). In this case moisture uptake for brick is about 2.5 times lower than moisture uptake for gypsum board. Naturally the maximum moisture uptake is higher for both materials for high RH step than for the medium RH step.



35-95-35%RH, 20°C, 24h-step　　35-95-35%RH, 20°C, 8h-step

Figure 3: Sorption kinetics for brick and gypsum board

Experimental results were also analysed on terms of Moisture Buffer Value (MBV), proposed by Rode et al. (2005). The Moisture Buffer Value is given in [g/(m².Δ%HR)] by the following :

$$MBV = \frac{M_{8h} - M_0}{S.(\%HR_{\max} - \%HR_{\min})}$$

The MBV value for cyclic moisture load was calculated as proposed by Rode et al. (2005). The same formula was also extrapolated to the step reference load. The results are given in table 2 for gypsum board and in table 3 for brick.

TABLE 2
MBV and its extrapolation for gypsum board

Temperature	20°C	23°C	20°C
RH step	35-95-35%	33-75-33%	35-75-35%
RH step interval	48h	8h, cyclic	24h
MBV [g/(m².Δ%HR)]	1,06	1,06	0,65

TABLE 3
MBV and its extrapolation for brick

Temperature	20°C	20°C	23°C
RH step	35-95-35%	35-95-35%	33-75-33%
RH step interval	24h	24h	8h, cyclic
MBV [g/(m².Δ%HR)]	2,42	2,82	0,43

The results from tables 2 and 3 are globally in agreement with presented sorption kinetics: Higher values are obtained for high step of RH and lower values for medium step of RH. Moreover for the gypsum board the “MBV” for 95% is about twice as high as for 75%. For the brick the corresponding ratio is about 5. This confirms that brick and gypsum board have a very different behaviour with respect to moisture. This difference can be explained by corresponding micro-structures. Far from saturations pressures, at RH equal to 75%, the porosity of materials seem to play an important role. In this case the ratio of moisture uptake by gypsum board to the uptake by the brick is slightly more than 2, which corresponds to the ratio of porosities of both materials. This relationship is not valid however for vapour pressures close to saturation pressure. Indeed, as presented in figure 2, brick’s pores are very small and are accessible to moisture at vapour pressures close to saturation pressure, when the capillary pressure is very high (Bories and Prat, 1995). As the pores in gypsum board have larger diameters, the behaviour is different.

Besides, the middle result for gypsum board from table 2 is rather surprising. Indeed, the results from rather different conditions give the same value (35%-95%HR at 20°C and 33-75%HR at 23°C). It seems that in this case the impact of moisture step can be partially removed by a change in the temperature. Indeed the first two results are almost identical, even if the test results were more similar for the two last cases (almost identical RH values, with different temperature and duration).

CONCLUSION AND PERSPECTIVES

The work presented here is the first step of a bigger project, which objective is to use moisture in order to reduce energy consumption of buildings (Padfield, 1999). This can be done for example by the use of moisture buffering materials to optimise the ventilation system (Woloszyn et al. 2005). Better knowledge of sorption phenomena in building materials is a very important issue in this context.

Performed measurements showed that for high relative humidity steps (35-95%), brick shows a better performance than gypsum board for moderating the changes in indoor relative humidity. This seems related to the microstructure of the material. However, the behaviour is very different at medium relative humidity steps (33-75%). In this case moisture uptake by gypsum board is about twice as high as for the brick, which seems correlated with the higher porosity of gypsum board.

As the next step of this project a numerical model is currently being developed in order to represent moisture response of materials in isothermal and non-isothermal conditions. After validation the model is aimed to be implemented in building simulation software in order to predict the energy impact of moisture buffering materials. This is developed on whole building level using heat, air and moisture approach developed within Annex 41 project of ECBCS program of International Energy Agency (Hens, 2005). Moreover some additional experiments will be conducted in order to asses the effect of finishing materials, such as wall papers, paintings on the dynamic moisture performance of construction materials.

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