The influence of surface treatment on mass transfer between air and building material

Kwiatkowski, Jerzy; Rode, Carsten; Hansen, Kurt Kielsgaard; Woloszyn, Monika; Roux, Jean-Jacques

Published in:
Proceedings of the 8th Symposium on Building Physics in the Nordic Countries

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Kwiatkowski, J., Rode, C., Hansen, K. K., Woloszyn, M., & Roux, J-J. (2008). The influence of surface treatment on mass transfer between air and building material. In Proceedings of the 8th Symposium on Building Physics in the Nordic Countries (Vol. Volume 1, pp. 661-668). Kgs. Lyngby, Denmark: Technical University of Denmark, Department of Civil Engineering.

The influence of surface treatment on mass transfer between air and building material

Jerzy Kwiatkowski, Ph.D. Student,
CETHIL, Universite de Lyon, CNRS UMR5008, Universite Lyon 1, INSA de Lyon;
jerzy.kwiatkowski@insa-lyon.fr

Carsten Rode, Assoc. Professor,
Department of Civil Engineering, Technical University of Denmark;
car@byg.dtu.dk

Kurt Kielsgaard Hansen, Assoc. Professor,
Department of Civil Engineering, Technical University of Denmark;
kkh@byg.dtu.dk

Monika Woloszyn, Assoc. Professor,
CETHIL, Universite de Lyon, CNRS UMR5008, Universite Lyon 1, INSA de Lyon;
monika.woloszyn@insa-lyon.fr

Jean-Jacques Roux, Professor,
CETHIL, Universite de Lyon, CNRS UMR5008, Universite Lyon 1, INSA de Lyon;
jean-jacques.roux@insa-lyon.fr

KEYWORDS: *Mass transfer measurements, surface treatment, climatic chamber.*

SUMMARY:
The processes of mass transfer between air and building structure and in the material influence not only the conditions within the material but also inside the connected air spaces. The material which absorbs and desorbs water vapour can be used to moderate the amplitude of indoor relative humidity and therefore to participate in the improvement of the indoor air quality and energy saving. Many parameters influence water vapour exchange between indoor air and building material. The aim of this work is to present the change of mass transfer under different climatic and material conditions. The measurements were performed at the Technical University of Denmark (DTU), Department of Civil Engineering. Two climatic chambers were used for the tests, the first one for dynamic and the second for steady state conditions. Two commonly used building materials exposed to the indoor environment were chosen for the experiments: gypsum board and calcium silicate. The wallpaper and paint were used as finishing materials. Impact of the following parameters for changes of RH was studied: coating, temperature and air movement.

The measurements showed that acryl paint (diffusion open) can significantly decrease mass uptake. It was shown also that higher air velocity speeds up the process of mass exchange between indoor air and materials but apparently decreases the total amount of exchanged water after a longer period. The experiment allows not only to check the influence of surface treatment on mass transfer, but can be used also as validation for simulation programs. At the end of the article, a mass uptake calculation using the HUMIMUR model is presented.

1. Introduction

The water vapour exchange between indoor air and materials influences many aspects of indoor climate. The relative humidity is one of the most important parameters influencing perceived indoor air quality and the human comfort. Moisture is also needed to initiate microbiological growth at the surface of building envelope. Most of the building materials have ability to absorb and desorb water vapour; therefore it is important to study mass transfer between them and the surrounding air. In reality in dwellings we will not find any pure building material. In most of the cases they are covered with some finishing materials. Also the indoor conditions are not always the same but change every day, hour and even minute. In order to study water vapour exchange between indoor air and building materials at minimum the following parameters should be taking into account: material, coating, temperature and air velocity, in addition to the hygric condition in the air and within the building material.

A lot of measurements of mass exchange between air and materials have been presented in the literature. In some experiments a few parameters influencing water vapour transfer were examined. May and Woloszyn (2006) performed test of mass absorption for two building materials: gypsum board and red brick, in order to study the link between sorption mechanism and microstructure. The influence of temperature for gypsum board was also checked in this work. Osanyintola and Simonson (2006) investigated moisture buffering capacity of plywood. Their studies were done for two cases: the first without air movement in a sealed jar and the second with fully developed, forced convection air flow in a small wind tunnel. The moisture buffer value and the influence of two kinds of paint have been investigated by Peuhkuri and Rode (2005).

In this paper the influence of the finishing material (diffusion open paint and wallpaper), temperature (20 and 24 °C) and air movement (tests with and without fan working in the chamber) on mass uptake is presented. Also the water vapour transfer under dynamic changes of relative humidity is shown. Finally an example of mass uptake calculation using HUMIMUR model (Kwiatkowski et al. 2008) is presented.

The experimental measurements were divided into two parts. In the first the part the change of mass transfer between indoor air and building material with step-change of the relative humidity has been examined. The second part of the measurements concerns water vapour uptake under dynamic changes of relative humidity. In the experiments two building materials exposed to the indoor environment were used. In the tests with step-change of relative humidity level also the influence of paint and wallpaper has been investigated.

2. Samples description

For the measurements two different commonly used building materials in contact with indoor air were chosen: gypsum board and calcium silicate. Three variants of gypsum board were used: naked gypsum board, gypsum board with paint layer and gypsum board with wallpaper. For calcium silicate only naked samples and samples with a paint layer were used. The size of the samples was 200x200 ±1 [mm]. The thickness of the specimens was 12.5 ±0.5 [mm] for gypsum and 10 ±0.5 [mm] for calcium silicate. Five sides of the samples were sealed with the aluminium tape and only one side was exposed to the outside conditions. As coating materials wallpaper and a diffusion open paint were chosen. Wallpaper paste was used to coat the samples with the wallpaper. The specimens with paint layer were primed and then painted with two layers of paint. The total permeability of the paint coating was equal to $1.6481*10^{-11}$ [kg/m.s.Pa]. Prepared specimens were used in tests few days after being coated in order to avoid influence of drying of the glue and paint on measurements.

3. Tests with step-change of relative humidity

In the experiment with step-change of the relative humidity it was sought to examine the influence on moisture exchange of each of the two finishing materials, of different temperatures and of air movement over the samples. The tests were carried in a climatic chamber with precise control of temperature and relative humidity. There was no possibility to cool the air in the chamber so the lower limit of temperature depended on the ambient temperature in the room. In order to get as high range of temperatures the room was cooled down to 18.5 ±0.5 °C. The upper limit of temperature was 25-26 °C. The relative humidity could be varied between 4-5% and 96-98%. A photo and schematic drawing of the climatic chamber is presented in FIG. 1.

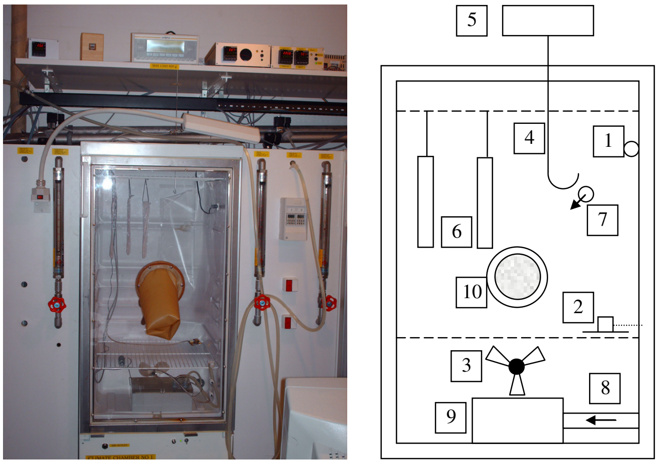

FIG. 1: Photo and scheme of the climatic chamber used in the measurements.

Relative humidity inside the chamber is controlled by a PID controller with humidity sensor (1) and regulated by mixing of dry and 100% saturated air in the chamber. The injection of dry air into chamber was by a small pipe (7). The saturated air was achieved by injection air by a pipe (8) into water tank (9). The temperature is also controlled by a PID controller but regulated by electric resistance heater (2) placed inside the chamber. A fan (3) is placed in the lower part of the chamber, to mix the air and thereby avoid temperature and humidity stratification inside the chamber. A wire (4) comes into the chamber through the upper part, connecting accurate balance (5) with the hook in the chamber. During weighing of the specimen (6), the air-conditioning system is stopped (in order to not to influence weighing) and the specimen is hung on the hook. The precision of the sensors is ±0.003 g for the balance, ±0.3 °C for the temperature sensor and ±1.0 % for relative humidity sensor.

The measurements of mass uptake in the chamber were divided into four parts. For each part, the samples of material were preconditioned at constant temperature of 20 or 24 °C (depending on the test) and in constant relative humidity of 35% for two days. At the beginning of each test the relative humidity was set to 75% and then after 24h again to 35%. The parameters describing each test are presented in TABLE 1.

TABLE 1. Parameters in the Tests 1-4.

	Test 1	Test 2	Test 3	Test 4
Temperature [°C]	20	20	24	24
Fan	On	Off	On	Off

In the Test 1 and 2 the temperature was fixed to 20 °C, and in Test 3 and 4 to 24 °C. In order to check the influence of air movement on mass uptake, the fan in the chamber has been switched off in the Test 2 and 4. Additional measurements have been made of the air velocity inside the chamber when fan was working. The velocity has been measured in six points between the hanging specimens (see FIG.2).

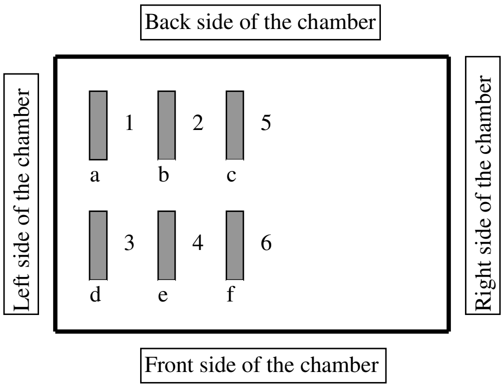

FIG. 2: Scheme of the velocity measurement points distribution in the climatic chamber, seen from above.

The velocity under condition from Test 1 was measured using Brüel & Kjær Indoor Climate Analyzer Type 1213 with the precision of 2 [cm/s] and the results of the measurements are presented in TABLE 2. For each point the mean, maximal and minimal velocity was measured over five minute periods. Also the standard deviation for each point was calculated.

TABLE 2. Results of the velocity measurements inside the climatic chamber (Test 1).

Velocity [cm/s]	Position of the measuring point					
	1	2	3	4	5	6
Mean	1.5	1.0	2.0	3.0	5.0	4.0
Max	3.0	2.0	5.0	7.0	8.0	6.0
Min	0.0	0.0	0.0	1.0	3.0	1.0
Std. dev.	2.0	1.0	2.0	4.0	4.0	4.0

The measurements showed that even when the fan was working well, the velocities in the chamber were lower then 10 [cm/s]. It can be noticed that the velocity profile was not uniform, and the variation between the different measuring points was high. Also the temporal deviations for each point are high.

The water vapour exchange between air and materials was measured by weighing the samples and calculating the difference in weight. From the beginning of each experiment (step-change of the relative humidity in the chamber) the measurements were done according to the following scheme: for the first 2 hour every 15 minutes, for the next 2 hours every 30 minutes and later every one hour. The last measuring point was taken after 24h from the change of the relative humidity.

3.1 Influence of coatings on mass uptake

The influence of different coatings for gypsum board and for calcium silicate is presented in FIG. 3. For the gypsum, diffusion paint and wallpaper have been used as finishing. For the calcium silicate only paint has been used as coating.

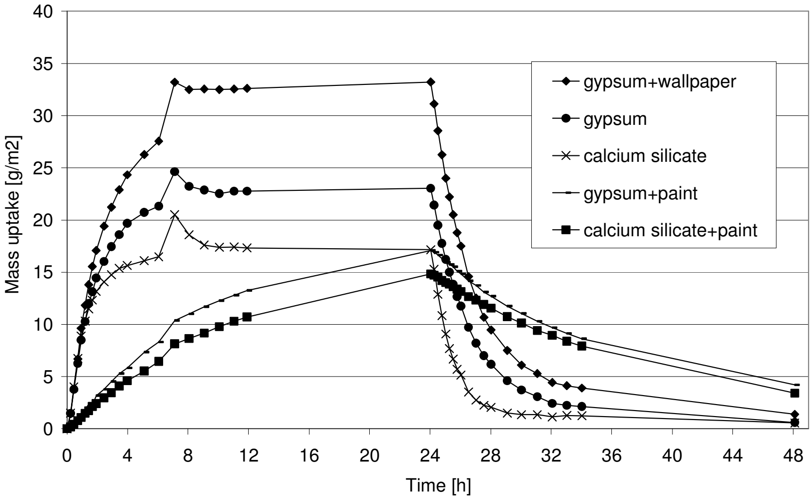

FIG. 3: The chart of the mass uptake for the all variation of samples for the TEST 1.

As it can be noticed, the mass uptake for various materials and coatings differs a lot. The gypsum board and calcium silicate are rather diffusion open materials, and the speed of absorbing/desorbing of mass in the first stage of the process is almost the same for both of them. The difference can be seen in the amount of water vapour absorbed by materials. The calcium silicate has less hygroscopic structure than gypsum board and therefore the amount of absorbed water is smaller.

It can be noticed that for both materials covered with paint the process of adsorption/desorption is slower. The dispersion in mass uptake between specimens without and with paint layer can be well seen on FIG. 3. Even after 24h the samples with paint layer could not get to equilibrium with the surrounding air.

There is no difference in the initial rate of adsorption/desorption between the gypsum board without and with wallpaper. The difference occurs in the amount of exchanged water, what is a result of the hygric properties of wallpaper. Wallpaper is very hygroscopic material so it can absorb an additional amount of water.

Between the seventh and eighth hour of test, there appears a peak in the mass uptake profile. This peak is the result of a short dysfunction of the air conditioning system in the climatic chamber.

3.2 Influence of temperature on mass uptake

In order to check the influence of temperatures on water vapour uptake similar tests but for different temperatures have been performed (see TABLE 1). The results of the measurements are presented in FIG. 4.

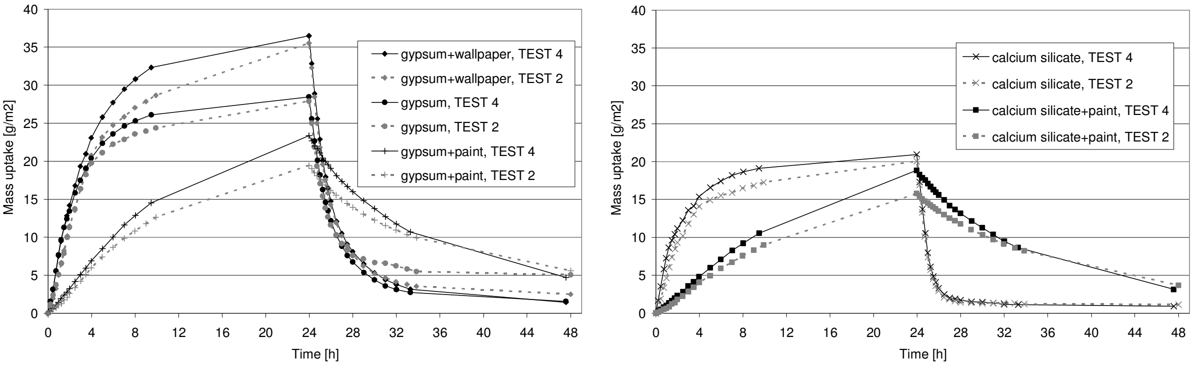

FIG. 4: Mass uptake comparison for TEST 2 (20 °C) and 4 (24°C).

TEST 2 was performed at the temperature 20 °C and TEST 4 at 24 °C. The slight differences between results from both tests can be noticed for all variants of the materials. It can be seen that the initial rate of the absorption/desorption process in the first part of measurements is slightly higher in the temperature of 24 °C than in 20 °C. Eight hours after the step-change of relative humidity the relationship between rate of the process and the temperature is inversed. The mass uptake is growing faster at 20 °C than at 24 °C. The reason is that the samples got closer to equilibrium already within the first 8 hours when the temperature was higher. Therefore it is obvious they could not absorb so much more in the next 16 hours. Similar results were presented by May and Woloszyn (2006) for 20 and 30 °C. The only exception are the samples with paint layer, when the process of absorption/desorption is faster at 24 °C for whole duration of the experiment (24 hours). The reason is that the diffusion paint has high resistance on water vapour transfer and slows down the mass exchange process.

3.3 Influence of air movement on mass uptake

The influence of air movement on water vapour exchange has been checked by performing similar tests but with and without the fan in operation in the climatic chamber. The measured velocities in the chamber with the running fan were presented in the TABLE 2. When the fan was off the velocity measurements showed that there was no air motion in the chamber. The differences in mass uptake for both situations are presented in FIG. 5.

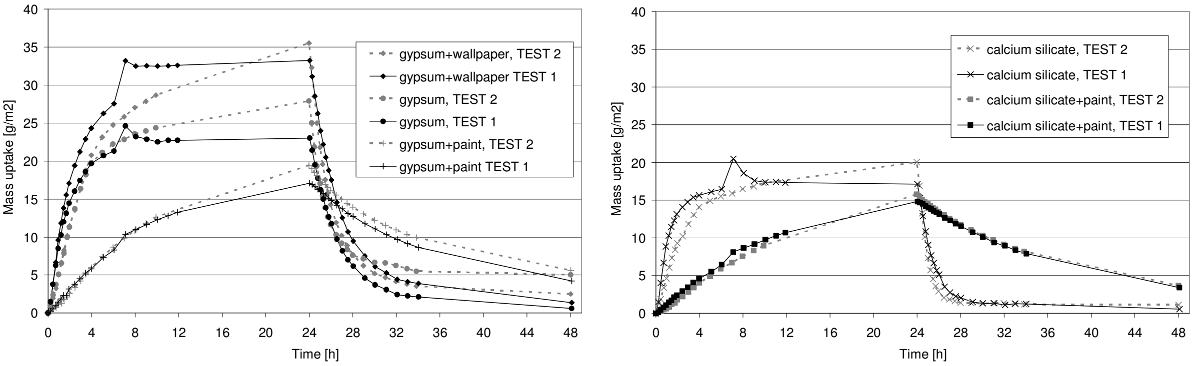

FIG. 5: Mass uptake comparison for TEST 1(fan on) and TEST 2 (fan off).

TEST 1 represents the measurements with the fan on, and TEST 2 with the fan off. It can be noticed that for all materials and finishing, except the samples with paint layer, the difference in the rate of adsorption process is significant. The mass uptake during the first 7-8 hours is faster in the TEST 1 than in TEST 2. Then the situation is inversed: mass uptake rate is faster in the TEST 2 than in The TEST 1. In the desorption process this dependency is opposite, first the process of desorption is faster in the TEST 2 but after few hours it is slower than in the TEST1. The measurements show that the amount of absorbed water after 24 hours for the test with fan off is higher than for test with fan on. This behaviour can be connected with hygric properties of the materials, however some additional investigations are needed to explain the origin of this phenomena. The difference in the speed of the mass absorption/desorption for the samples with paint layer is not so significant, which is a result of paint high resistance on water vapour transfer.

4. Tests with sinusoidal oscillation of relative humidity

The climatic chamber called Mega-Cup (Padfield et al. 2002) was used for the experiment with sinusoidal changes of relative humidity. The climatic chamber is an open topped cylinder of stainless steel with a double-wall. The top can be sealed with a metal plate so that the cylinder encloses the specimen under test in an airtight space. The climatic chamber is well insulated and the inside temperature and relative humidity can be controlled between 8 and 30 °C and from 30 to 95% of relative humidity. The temperature is controlled by air circulating in the annular space of the double-wall. The air in the chamber is cooled by water circulating in a ribbed copper coil and is heated by an electric resistive element. The relative humidity in the chamber is controlled by condensating water into, or evaporating water from a small water tank placed inside the chamber. The temperature of the water is controlled by a thermostatic device fixed beneath the tank. The water vapour flux to and from the tank is measured by checking the weight of the tank.

The tests with dynamic, sinusoidal oscillations of relative humidity from 30 to 70% with a time cycle of 24h were performed for gypsum board without any coating. The measurements were done at two different temperatures: 20 and 24 °C. Before each test the specimens were preconditioned in the temperature of 20/24 °C and 50% relative humidity. The results of the experiment are presented in FIG. 6 and FIG. 7.

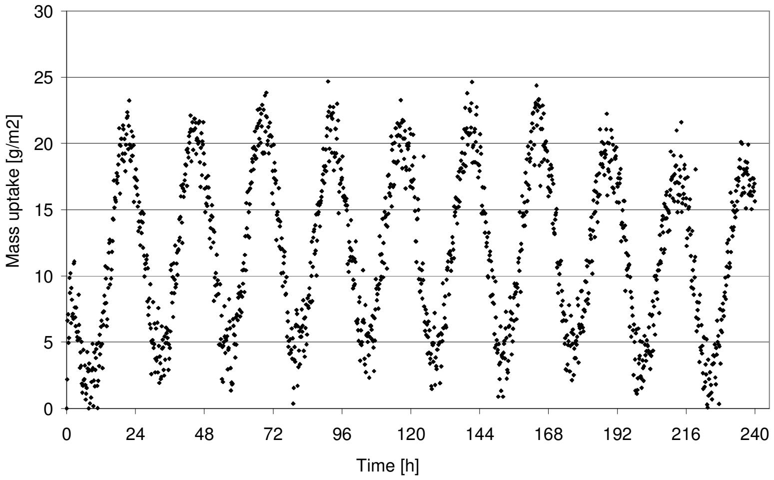

FIG.6: Mass uptake under dynamic changes of relative humidity for gypsum board in 20 °C.

The measurements of mass transfer between air and gypsum board under dynamic changes of relative humidity were done for a period of some days. The test in the temperature of 20 °C was performed over ten days and the results are presented on the FIG. 6. It can be noticed that the amplitude of water vapour exchange is almost the same as in the test with the step change of relative humidity (TEST 1) after 12 hours. It can also be seen that the mass uptake profile is slightly changing with the time. This phenomenon is better seen for the longer experiments. Therefore the measurements in 24 °C were done for 25 days and the results are presented in FIG. 7.

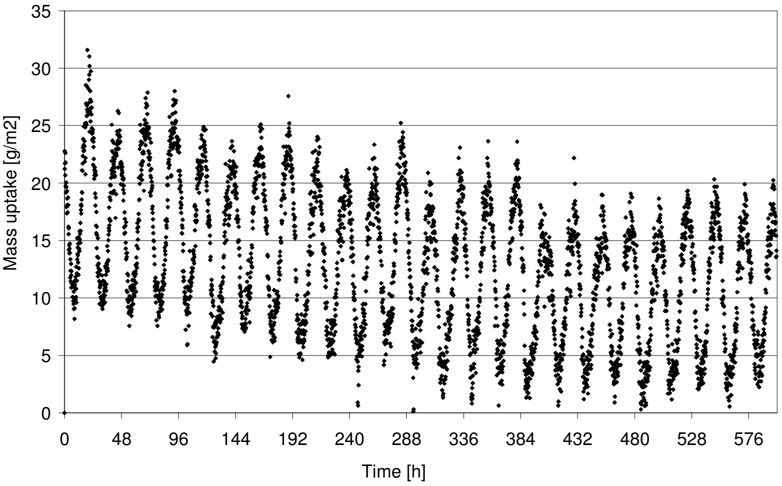

FIG.7: Mass uptake under dynamic changes of relative humidity for gypsum board in 24 °C.

As for the test at 20 °C also here the amplitude of mass uptake profile is approximately constant for the whole time of the experiment and equal to the mass uptake from measurements with the step-change of relative humidity (TEST 3) after 12 hours. It can be noticed that the change of the mass uptake profile is more significant here than for the test at 20 °C. It can also be seen that for the last few days of the experiment the mass uptake profile is not changing. This might indicate that the hygric condition in the material reached oscillatory equilibrium for this sorption/desorption process. The slight decline in mass might be due to too short preconditioning of the specimen.

5. HUMIMUR simulations

The experiments of water vapour exchange between air and building material can be used as validation for simulation programs. Some preliminary results of TEST 1 from HUMIMUR simulation are presented hereafter. The HUMIMUR program was elaborated in order to simulate isothermal water vapour transfer between air and material and the moisture flow inside the material (Kwiatkowski et al. 2008). The simulations are performed using Control Volume Method (CVM) with 1-D model and a first order explicit time scheme. For the calculation the measured water vapour permeability and the sorption curves of gypsum board were implemented into model. The results of calculation for TEST 1 are presented in the FIG. 8.

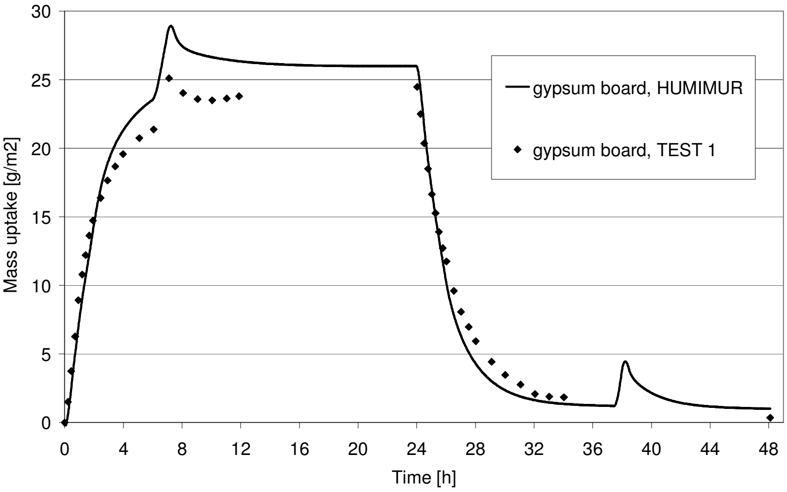

FIG.8: HUMIMUR calculation of the TEST 1.

Although some differences can be noticed the HUMIMUR model gave results close to the measurements. The shape of the calculated mass uptake profile is similar to the experimental data. The difference between calculation and test can be due to experimental uncertainty on the material and climatic data implemented into model. The differences between simulation and measurements show how important precise material and climatic data are for mathematical models.

6. Conclusions

This paper presented the influence of different parameters on mass transfe. It was shown that even diffusion open paint significantly decreases the rate of the mass transfer. The wallpaper does not change the rate of the absorption/desorption but increases the amount of buffered water. It was pointed out that the change of the temperature from 20 to 24 °C is changing the rate of adsorption/desorption process for the specimens with wallpaper and without any coatings, making it faster in the first part and slower in the second part. For the specimens covered with paint, the change of the temperature causes a uniform change of water vapour transfer rate for the whole duration of the experiment. In the test with higher temperature (24 °C) the mass uptake rate is higher than in the test with lower temperature (20 °C). Also investigations of the mass transfer for different air movements have been presented. In the tests without any air movement, the rate of mass uptake for the first part of the absorption/desorption process was first lower, but after 7-8 hours from the step-change of the relative humidity, higher than in the test with air movement in the chamber. The measurements under dynamic changes of relative humidity showed that the oscillatory equilibrium for adsorption/desorption process are obtained after few days from the start of the experiment and might depend on initial condition in the material.

Finally the preliminary results from HUMIMUR simulation were presented. Despite differences, the calculations gave similar results to experimental data. Some more simulations for other test with step-change of relative humidity and tests with sinusoidal oscillations of relative humidity will be done in the near future.

7. References

Kwiatkowski J., Woloszyn M. and Roux J-J. (2008). Modelling of hysteresis influence on mass transfer in building materials, Submitted for publication.

May M. and Woloszyn M. (2006). A41-T2-F-06-3 Dynamic moisture behaviour of building materials links with microstructure, *Annex 41 Working meeting*, Kyoto 3-5 April.

Osanyintola O. F. and Simonson C. J. (2006). Moisture buffering capacity of hygroscopic building materials: Experimental facilities and energy impact, *Energy and Buildings*, 38. 1270-1282.

Padfield T., Peuhkuri R., Rode C. and Hansen K. K. (2002). Non-isothermal water vapour transmission through porous insulation. Part 1: the climatic chamber, *Proceedings of the 6th Symposium on Building Physics in the Nordic Countries*, Trondheim, Norway.

Peuhkuri R. and Rode C. (2005). A41-T2-Dk-05-1 Using dynamic moisture loading tests for determination of moisture buffer value, *Annex 41 Working meeting*, Montreal 16-18 May.