DYNAMIC WATER VAPOUR SORPTION: MEASUREMENT AND MODELLING

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ABSTRACT

The objectives of this investigation were to examine the dynamic water vapour sorption of various building and furnishing materials and to compare the experimental results with predictions obtained from the Moisture Admittance Model. Dynamic sorption measurements were carried out for common building materials. The measurements were made by placing specimens of the materials in a humidity chamber and varying the ambient humidity between 46% and 90% RH at constant 22°C. The weight of the specimens was monitored in situ during this procedure. The materials included carpet, vinyl strips, MDF, chipboard, parquet tiles, plywood, untreated timber and gypsum board. The experiments showed that the damping effect of materials on air humidity in daily cycles of high-low humidity is determined by the speed at which moisture can be absorbed and cannot be predicted by using sorption isotherm data. However, the results were then used to obtain material parameters for the Moisture Admittance Model (MAM). The investigation showed good agreement between model and experiment.

INTRODUCTION

Almost all furnishing and building materials are, to a certain extent, capable of taking up water in its vapour form. The amount of absorbed water vapour depends on the surface structure, the porosity of the material and the moisture content of the surrounding air. If the material is exposed to a constant air humidity long enough, an equilibrium between air and material humidity will be reached. If the moisture content of the air is then lowered, the material will give off moisture to the air (desorption). If the moisture content of the air is increased, the material will take up moisture (absorption).

In a steady-state situation the material specific relationship between air and material moisture content at constant temperature are represented by the well established sorption-isotherm curve[1] . Analogous to this, an equilibrium state is reached in an occupied dwelling. Depending on occupant behaviour, air tightness and external climate, an equilibrium between average moisture content of the air and the furnishing and building materials is established. In this equilibrium state no moisture is exchanged between air and material. Should this equilibrium be upset by a sudden increase in moisture production in the house, the increase in air humidity will depend on the ability of the furnishing and building materials to absorb water vapour.[2] Sorption isotherms can be used to determine if moisture will be absorbed. Information about the speed at which the moisture is absorbed, which is of particular interest in this case, is not given in the sorption isotherms.

If the room humidity rises to such a level that the dew point temperature of the air exceeds the temperature of the surfaces in the room, condensation will occur. The furnishing and building materials should be able to absorb enough water fast enough to prevent condensation under normal occupation behaviour.

Once the air humidity levels start to fall, the water that was absorbed by the materials is released back into the air. To investigate the moderating effect of hygroscopic furniture on indoor humidity levels in detail, more primary data on the dynamic behaviour of individual material types is needed.

EXPERIMENTAL METHODS

The main experimental system consists of two environmental chambers, a digital balance and samples of building and furnishing materials. The two chambers were set to operate at constant temperature of 22°C and 46%RH and 90% RH respectively. This investigation developed primary data on the dynamic response of selected building construction and furnishing materials subjected to a step change in air relative humidity at constant temperature. The testing was performed on 8 different material types. The sample edges and backs were sealed where they would not normally be exposed to ambient air or where they represent a small element of a larger area. Table 1 presents a summary of the test specimens used.

Table 1: Summary of test specimens

Test material description	Dimension (cm x cm x cm)	Equilibrium weight at 46% RH (g)	Exposed surface area cm^2
Parquet tile 1	10.5 x 9.9 x 0.7	48.47	103.95
Parquet tile 3	10.3 x 9.9 x 0.7	48.75	101.97
Gypsum board 1	15.9 x 9.9 x 1.0	129.14	157.41
Gypsum board 3	16.0 x 9.8 x 1.0	124.94	156.80
untreated wood (pine)	17.3 x 7.0 x 3.7	210.39	358.01
plywood 2	10.0 x 7.8 x 0.6	23.6	78.00
chipboard 1	10.0 x 9.9 x 2.2	156.9	186.56
chipboard 3	10.0 x 10.0 x 2.2	152.85	100.00
carpet a1	10.3 x 9.9 x 0.6	39.99	101.97
carpet a3	10.3 x 9.7 x 0.6	39.47	99.91
carpet c1	10.0 x 10.0 x 0.5	9.3	100.00
MDF 1	10.0 x 9.8 x 1.3	32.81	98.00
MDF 3	9.9 x 10.0 x 1.3	33.71	99.00

Prior to testing the specimen were placed in the environmental chamber set to 22°C and 46% RH and stored for 2 months. Regularly weighing the samples during this period ensured that they had reached equilibrium with these conditions. The samples were then placed in the chamber set to 22°C and 90% RH and the weight increase due to moisture absorption was monitored in situ for 3 hours at 10 minute intervals.

DISCUSSION OF EXPERIMENTAL RESULTS

In Figure 1 the weight measurements of the samples are shown for a step-change from 46% RH to 90% RH. On this graph the most obvious feature is that all materials show a distinct increase in weight over the whole monitoring period. The group of 4 materials (the two carpets, plywood and wood) at the bottom end of the graph, gained about 0.002 g/cm^2 of exposed surface area after 3 hours. Looking closer at those 4 samples we can see that, in the first hour, the two carpet samples show faster weight gain than the wood and plywood, which then slows down after 1.5 hours and actually drops below the weight gained by the wood and plywood after 2 hours. This shows that the carpet reaches equilibrium with the surrounding air quicker than the wood samples. The other 4 samples show considerably more absorbed water vapour, the MDF sample has increased by more than 0.005 g/cm^2 after almost 3 hours, followed by the parquet tile with 0.0048 g/cm^2, followed by gypsum with 0.0039 g/cm^2 and finally chipboard with 0.003 g/cm^2. A vinyl tile was also tested and it showed no measurable weight gain and can thus be assumed not to absorb any significant amount of water vapour.

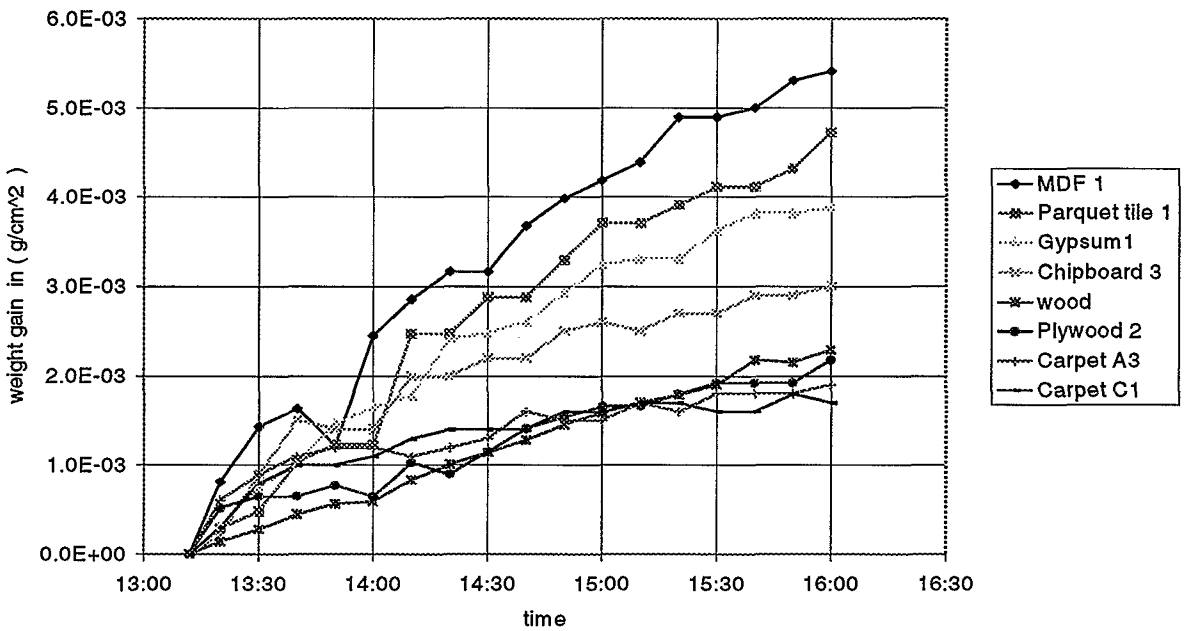

Figure 1. Specific weight gain per cm^2 exposed surface area in a step change from 46% RH to 90% RH

MOISTURE ADMITTANCE MODEL

A Moisture Admittance Model was introduced by the authors to simulate the dynamic absorption and desorption of water vapour by common building and furnishing materials[3]. The sorption model is based on the assumption that the rate of moisture transfer between the air and material is proportional to the difference between the material and air moisture content. The constant of proportionality, k, is a material dependent parameter.

Under normal occupant behaviour with daily cycles of high-low humidity only the inner surface layer of a material interacts with the air and diffusion further into the material is not taken into account. Since the moisture content of a material is not normally known, the material moisture content is related to the history of the humidity of the indoor air via an exponentially weighted time averaging term, controlled by a material-dependent time-parameter τ. This time parameter determines the memory of a material, such that events that happened more than $4*\tau$ before time t have no affect on the sorption at time t.

MATERIAL PARAMETERS

Since the sorption isotherms are unable to give information about the dynamic sorption behaviour of materials the Moisture Admittance Model (MAM) is suggested to classify and describe the dynamic response of materials to air humidity changes. A 3-D optimisation was chosen to obtain the two parameters k and τ for each tested specimen. Figure 2 shows the experimental data with error bars from the weight measurement for the sample MDF 3 and the optimised modelled data (mamweight).

It can be seen that all but two points of the modelled data are within the error limits of the experimental data and all the modelled points show a deviation of less than 1% from the measured weight. The determined material parameters k=2.74 (g/m^2.hr) and τ=0.09 (days) in conjunction with the Moisture Admittance Model can thus be used to describe the dynamic behaviour of an MDF sample.

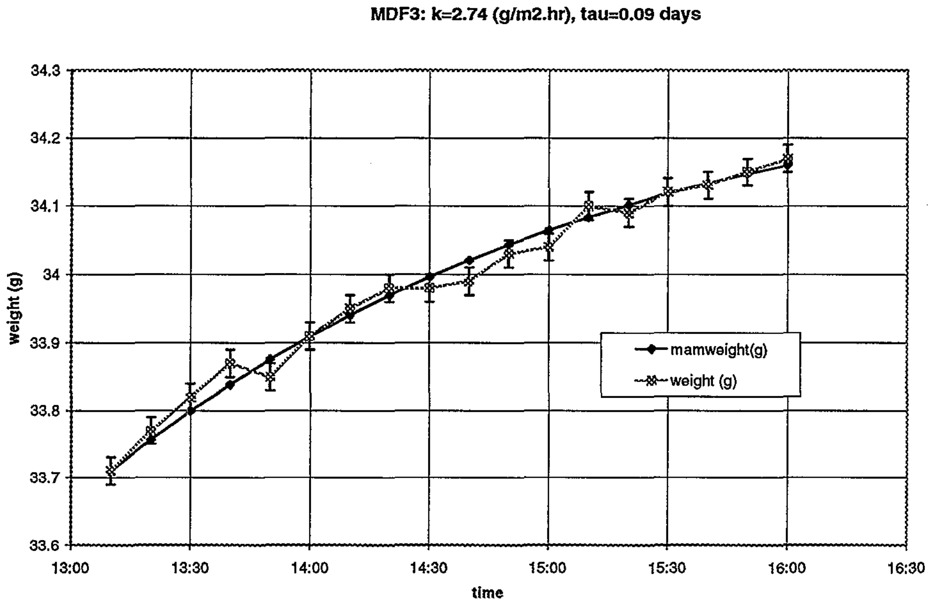

Figure 2. Material sample MDF3, step change 46% RH to 90% RH, measured and modelled weight change

Table 2 shows a summary of the parameters for the other material samples found using the same 3-D optimisation routine. We can see that the transfer parameter k varies between 0.9 g/m^2.hr for wood and 2.74 g/m^2.hr for the MDF3 sample. The time parameter τ varies between 0.04 days for the carpets and 0.35 days for the wood. This suggests that carpets reach equilibrium with their surrounding air humidity after about 4 hours, whereas wood can absorb and desorb water in excess of 34 hours. But both wood and carpet samples had absorbed about 0.002 g/cm^2 after 4 hours, thus it is the combined effects of storage capacity and speed of sorption that determine the usefulness of a material to moderate air humidity levels.

The question arises, are the obtained material parameters really parameters of the tested material or are they parameters typical for this specific step change experiment.

Table 2 showing a summary of MAM parameters of k and τ

Sample	k (g/m2.hr)	τ (days)	τ (hours : mins)
Carpet a1	1.84	0.04	0:57
carpet c1	1.84	0.04	0:57
chipboard3	2.5	0.05	1:12
gypsum 1	2.5	0.07	1:40
MDF 3	2.74	0.09	2:09
parquet tile	1.15	0.12	2:52
chipboard1	1.25	0.15	3:36
wood	0.9	0.35	8:24

To test the validity of the MAM a second experiment was conducted, again using two environmental test chambers, one set to 47% RH the second to 70% RH, both at 21°C. The materials were placed in the low humidity chamber until they had stopped changing weight and then placed into the 70%RH chamber for 1 1/2 hour, then returned to the 47%RH chamber for another 1 1/2 hours. During these 3 hours the weight was monitored at 10 minute intervals. Figure 3 shows the results for the weight change of the MDF3 sample (weight) and in comparison the MAM prediction of the weight change (Mamweight) using the same material parameters as obtained from the first experiment.

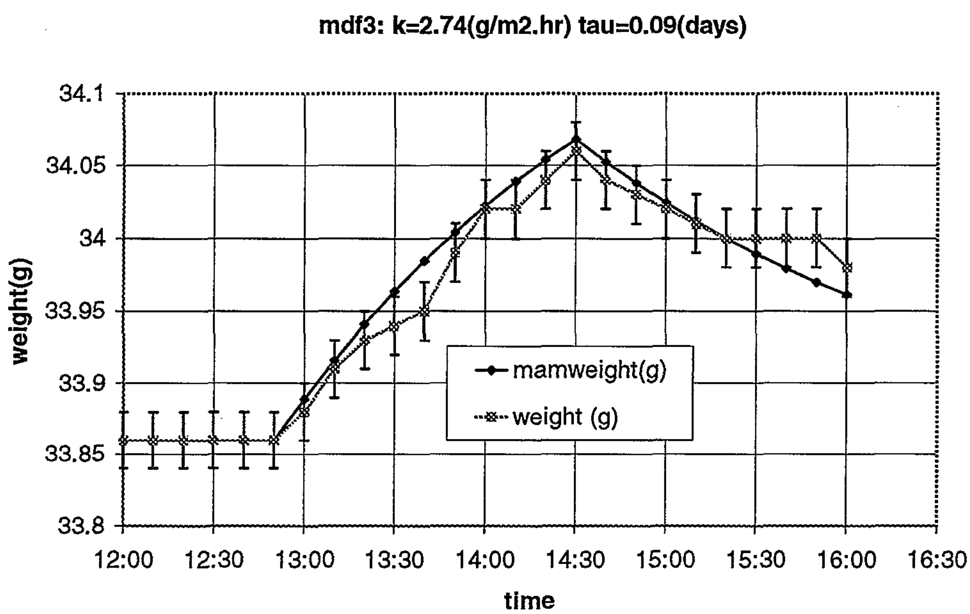

Figure 3. Showing the measured and modelled weight change of the MDF 3 sample due to a 47%RH to 70%RH to 47% RH step change

Again we can see that the weight of the material sample increases as soon as it is placed into the 70% RH chamber, and the specimen starts desorbing moisture as soon as it is placed back into the 47% RH chamber. The comparison with the MAM shows that all but two of the data points are within the error margins of the experimental values thus showing good agreement with the same parameters obtained from the first experiment.

CONCLUSION

The objectives of this investigation were to examine the dynamic water vapour sorption of various building and furnishing materials and to compare the experimental results with predictions obtained from the Moisture Admittance Model. The experiments showed that the damping effect of materials on air humidity in daily cycles of high-low humidity is determined by the speed at which moisture can be absorbed and cannot be predicted by using sorption isotherm data.

In the first 4 hours of a step change from 46% RH to 90%RH the MDF sample absorbed the most water vapour per exposed surface area at 0.005g/cm, followed by the parquet tile, gypsum board and chipboard. The wood, plywood and the two carpet samples had all gained less than half the weight the MDF sample had and showed an increase of 0.002 g/cm^2 after 4 hours.

Comparison with predictions obtained from the Moisture Admittance Model showed good agreement with experimental results. A second experiment showed that the MAM is also capable of simulating the combined effects of ab- and desorption and can thus be used in future investigations to calculate the moderating effect of furnishing and building materials on indoor humidity levels.

ACKNOWLEDGEMENT

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