Humidity buffering of the indoor climate by absorbent walls

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1. INTRODUCTION

The variation in relative humidity (RH) indoors can be moderated by using porous, water absorbent material for covering the walls and ceilings. This method of improving the indoor climate is never deliberately used and most modern building materials have almost no moisture capacity in the usual RH range of the indoor climate. Furthermore, interior wall surfaces are generally impermeable to moisture, usually being covered with paint. On exterior walls an impermeable barrier is often placed just behind the gypsum plaster interior finish. In this article I review the advantages of using absorbent materials as wall plasters, or even as entire walls.

2. SOURCES OF INDOOR HUMIDITY

The indoor relative humidity is generally increased by human activity and, in a cool climate, decreased by ventilation. The modern lifestyle with the family out at work or at school during the day results in a cycle of falling indoor RH during the day and rising RH from the time the family reunites in the evening. The standard for ventilation is set to prevent the development of a high interior RH that will allow mould growth. There is an underlying assumption that the house itself cannot play any significant part in moderating this cycle of RH. There is some published research (Plathner 1998) on the moisture admittance of materials in houses but this is passive, analytical research, taking the house as it is, rather than exploring ways of improving climatic stability.

3. WATER VAPOUR EXCHANGE WITH WALLS

One should think in terms of water production and removal, rather than RH change, because a large RH change is not an inevitable consequence of people breathing or opening the window. The RH indoors is a consequence of water production, or removal, *moderated by absorption and desorption by the materials in the house*. This factor is ignored by designers. The house as it has developed in modern times is less and less absorbent. Nylon carpets replace wool, paint is used in preference to wallpaper, upholstery is polyester stuffing covered with polyester

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cloth, woodwork is varnished. Kitchen surfaces are stainless steel and melamine. The only trends that introduce absorbent elements to the modern house are cotton T shirts and junk mail.

It is therefore no surprise that I have found none among the top ranking models for calculating moisture movement in buildings which include the indoor climate as an active player in the calculation. The indoor climate is taken as a boundary condition which influences water movement through a wall but is not itself influenced by the wall. Rather more serious is the complete lack of physical testing facilities. There are many chambers filled with building materials under test at a controlled RH but no chambers that can inject or remove a known quantity of water and then measure the RH in the chamber that results from the interaction of the test material with the water vapour.

This article describes the principle of operation of a test chamber for evaluating the performance of absorbent materials and refers to a simple model for predicting the consequences of the absorption process on the indoor climate. The technical details and exact calculations are described by Padfield (1998).

4. THE EXPERIMENTAL CHAMBER

The experimental chamber is shown in figure 1. The chamber is airtight. All the liquid water in the system is contained in a weighed tank within the chamber. Water can be evaporated from the tank or condensed into the tank. This process is performed by a thermoelectric heat pump which heats or cools the tank according to the direction and magnitude of the current through it. The waste heat, or cold, from the other surface of the heat pump is removed by a water cooled heat exchanger whose temperature is controlled to be always just above the dew point of the air in the chamber. The chamber as a whole operates at a constant temperature.

At the beginning of an experiment the test material is put into the chamber in the form of a tilted thin slab, or a slab built up from tiles, resting against an impermeable back plate. The tank is half filled with water and the chamber is sealed. The weight of the tank is maintained constant by adjusting the cooling to just prevent evaporation. When the system has reached equilibrium, which can take a week or two, a cyclic flux is imposed by cooling the tank to

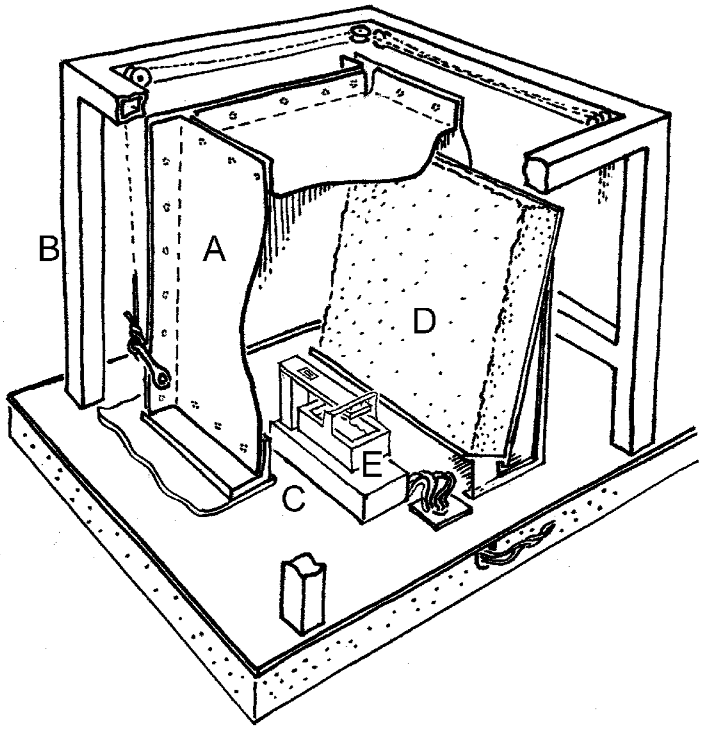

Figure 1 A schematic diagram of the climate chamber. A is a stainless steel box without a base, about 1 m high. It can be raised within the frame B but normally seals against the base plate C. The test material D rests tilted against a metal backrest. Water vapour is released or absorbed by the weighed water tank E.

condense water and then heating to re-evaporate it, typically with a 24 hour cycle. By the third cycle the system has usually reached a constantly repeating pattern. The flux is designed to be of the same order of magnitude as that of a house in a cool climate with about half an air change per hour. The downward half cycle imitates ventilation, the upward half cycle represents water production from breathing, cooking and bathing. This flux imposed on the empty chamber would give a RH cycle of about 10% to 90% RH. The test material reduces this RH amplitude by absorbing or emitting water vapour in a manner closely analagous to a heat store. The exposed area of test material is 0.6 square metres per cubic metre of chamber volume, which is a typical ratio for wall and ceiling area to volume of a house.

A sensor measures the chamber RH at 100 mm from the test surface. A second RH sensor is mounted in a shallow recess in the back of the test specimen. Whenever possible, sensors are also mounted within the test specimen to give an approximate indication of the active depth of the specimen for a given cycle time.

5. THE THEORETICAL MODEL

The damping of the RH cycle depends on three factors: the surface resistance to water vapour movement, the water capacity of the material and the speed of water vapour diffusion through it. These last two quantities are sometimes combined into the moisture diffusivity, by analogy with heat flow, but here they are kept separate.

The *surface resistance* is taken as a constant depending only on the air speed at the surface (Wadsö 1993).

The *water capacity* of the material is simplified to a constant: the slope of the tangent to the sorption curve at 55%RH. If the steeply increasing slope of the sorption curve at high RH needs to be taken into account then the material is not working as a buffer! In any case, the steepening of the sorption curve at both low and high RH will always give a better than calculated buffering at high fluxes which push the RH to extreme values.

The *porosity* of the material controls the depth of material that is active for a given cycle time. The water vapour diffusion coefficient is normally measured after the water absorbed in the material has reached a steady state. The diffusion constant measured in this way is basically the ease with which water molecules can navigate through the pore spaces. In the continually changing conditions of a daily flux cycle the situation is more complicated, because water can absorb into and disengage itself from the material at different rates according to different mechanisms. This has been conclusively demonstrated for wood (Wadsö 1993) and seems to apply also to some inorganic absorbers such as clay.

6. THE MATERIALS

The materials that best buffer the indoor climate are never used! The best material is wood cut across the grain, that is horizontally across the tree trunk, exposing the extremely open pore structure. The next best performer among those tested is a montmorillonite clay plaster, with a perlite filler. The best of the orthodox building materials is cellular concrete. The other standard building materials have negligible buffer capacity at moderate RH. Figure 2 summarises the characteristics of several building materials. Note that the water capacity is expressed by volume rather than by weight, because the factor limiting the use of these moisture buffers is the area exposed to the room interior. The water capacity by volume and the diffusion coefficient are combined to give a figure of merit for the various materials.

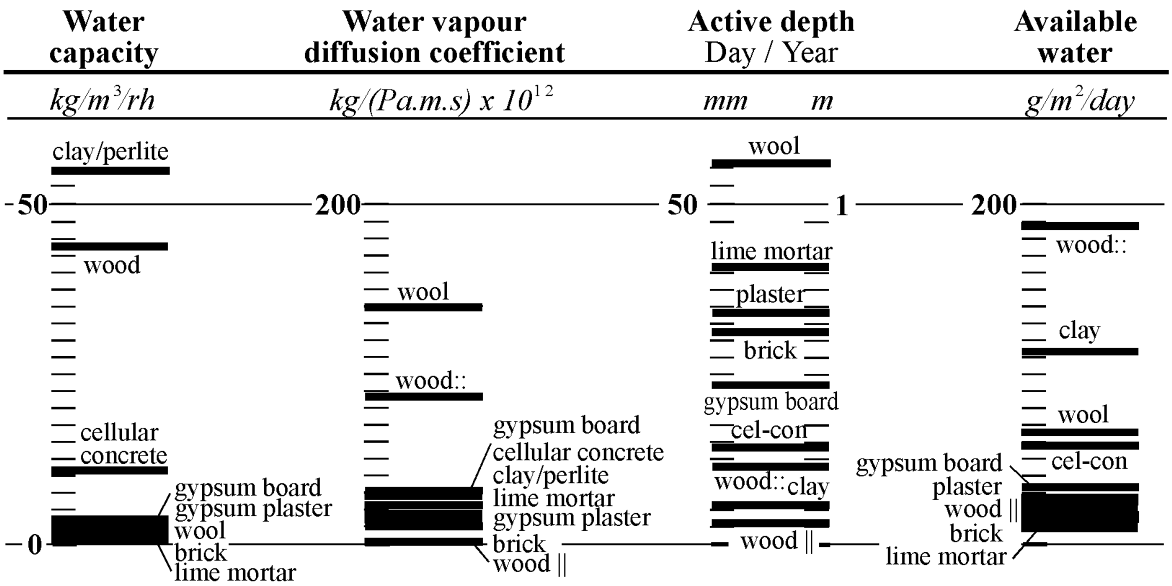

Figure 2 The ability of various building materials to buffer the RH variation in a house is built up diagrammatically above. The "order of merit" in the column on the right is derived from the volumetric water capacity **c** combined with the water vapour diffusion coefficient **k**. First the active depth **d** is calculated for a given sinusoidal cycle time **t**: $d = \sqrt{(kt/c\pi)}$. The active depth multiplied by the water capacity gives the water available for buffering, shown in the column on the right and expressed in grams of water per square metre per day that will pass through the surface if the RH is forced from zero to 100% (using the water capacity at 55% RH).

wood:: is wood cut across the cell direction
wood || is normal plank wood
cel-con is cellular concrete

Table 1 The material properties used in figure 2.

Material	**water capacity** $kg.m^{-3}.Pa^{-1}$	**Water vapour diffusion coefficient** $kg.Pa^{-1}.m^{-1}.s^{-1} \times 10^{12}$	**24hr penetration mm**	**360 day penetration m**	**24 hr. penetration x water cap. x 100**
wool insulation	0.00110	140	59.1	1.12	6.5
wood, radial/tangential	0.01445	2	2.0	0.04	2.8
wood, longitudinal	0.01445	88	12.9	0.25	18.7
Light clay	0.02092	22	5.4	0.10	11.3
Cellular concrete	0.00418	30	14.0	0.27	5.9
Gypsum board	0.00126	25	23.4	0.44	2.9
Cast gypsum	0.00076	32	34.0	0.65	2.6
Lime plaster	0.00027	16	40.7	0.77	1.1
Brick, Falkenlowe	0.00038	13	30.7	0.58	1.2

Notes: The water capacity is here quoted per Pascal of water vapour pressure at 23°C, to conform with the SI units. The water capacity is, however, rather insensitive to temperature and is therefore quoted per unit of RH (0 - 100%) in figure 2.
The water vapour diffusion coefficients were measured with a RH gradient of 50% to 76%. The water capacity is the tangent to the sorption curve at 55% RH and 23°C.

Figure 3 (left) shows the daily cycle with clay plaster as humidity buffer. The expected RH cycle for the empty chamber is shown for comparison. The RH cycle amplitude is very much less than that of the empty chamber subject to the same flux. At this cycle time only the surface layer of the plaster is reacting and the performance is limited by the surface resistance. This is shown by the almost equally good stabilisation of a four day cycle with four times the flux amplitude (figure 3, right). The RH record from within the specimen shows that at this cycle time the 40 mm thick tiles are reacting right through and are therefore performing at their optimum.

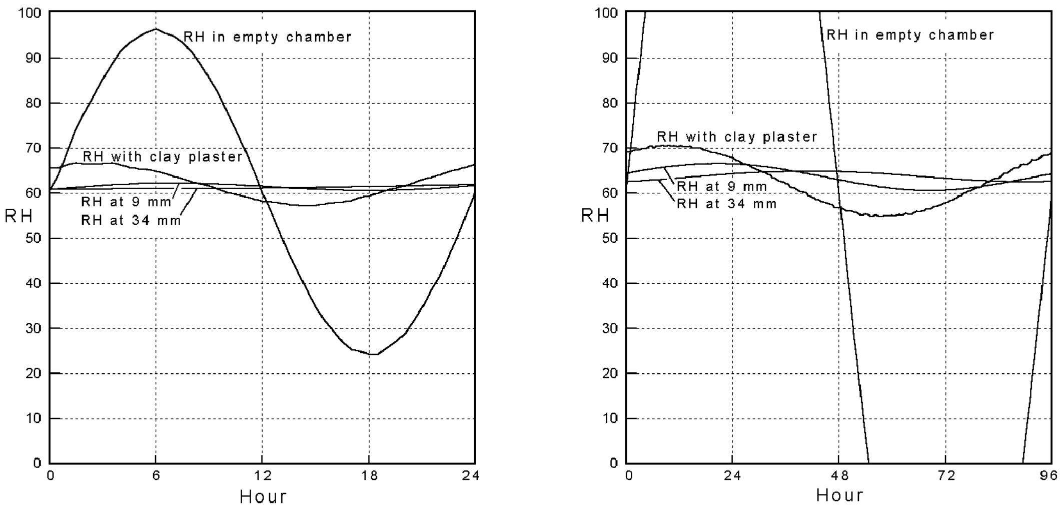

Figure 3 RH buffering by a lightweight clay plaster, 880 kg/m^3, 40 mm thick, 0.65 m^2 of exposed area per cubic metre of air. The wide cycle is the calculated RH in the empty chamber. The flatter curve is the measured RH with the plaster in the chamber. The RH is also measured at two depths within the plaster

The graph on the left shows the daily cycle, which only affects the surface of the plaster. The right hand graph shows a four day cycle, which engages the entire depth of the plaster. Notice that the flux amplitude, which is also four times that in the daily cycle, would cause condensation in the empty chamber.

This data from dynamic experiments with different cycle times can in principle be used to derive both the water capacity and the diffusion coefficient. When this is done with the clay plaster the best fit to the experimental data is with a water capacity roughly equal to the statically determined value but with a diffusion coefficient almost three times the value measured by the steady state method. The material is therefore a better buffer than expected at short cycle times.

The daily cycle of water vapour flux is moderated by at most 20 mm of plaster; more does not help, because the water vapour does not penetrate. The yearly cycle of water vapour is best buffered by about 400 mm of the same material but this is only effective if the air exchange rate is rather low: about 0.1 air changes per hour. This is attainable only in specialised buildings with little human activity, such as store rooms and archives.

7. DISCUSSION

One can expect a real improvement in the indoor climate with the use of absorbent surfaces. They should be particularly useful in kitchens and bathrooms, where the moisture flux is extreme but only for short periods. Transient condensation on the coldest parts of the walls will be much rarer than on impermeable walls. There are anti-condensation paints available, but these act on a different principle, holding liquid water by capillary force in a thin fibrous surface layer.

Absorbent wall surfaces will become dirty more easily. There are a few porous surfaces that can be cleaned, such as silicate paint, but generally one must expect a penalty in the form of more frequent renewal of the surface finish. Suitable finishes are wallpaper, paints based on water soluble cellulosic or glue binders, limewash and even fresco, if it is not burnished too hard during the painting process.

Absorbent interior walls have no other disadvantages compared with conventional structures. Absorbent surfaces on the inside of outer walls can be considered as performing exactly like internal walls if there is an air barrier at about 20 mm behind the surface. The need for an air barrier requires a more profound discussion than there is space for here. Absorbent materials in a wall without a barrier slow down the movement of water vapour until a steady state is reached. This means that such a wall is more resistant than a conventional wall to condensation due to transient cold weather, or brief periods of excessive vapour generation indoors. But there is no advantage over conventional walls when the condensation risk is caused by a long cold winter. The correct design principles for a porous outer wall are therefore still controversial. The performance of porous absorbent walls subject to a temperature gradient is also not reliably predictable at the moment, because there is some doubt about the nature of the potential driving water movement.

8. CONCLUSIONS

Water absorbent plasters can contribute to ameliorating the relative humidity fluctuation caused by ventilation and by human activities in houses. A 20 mm layer of clay plaster will substantially moderate the daily cycle of indoor RH. Thicker layers will be effective over longer cycles but only if the air exchange rate is low. The use of absorbent plasters on interior walls, or as the entire thickness of interior walls, requires surface coatings of high permeability but has no other limitations. Absorbent inner surfaces to outer walls are also non-controversial if an air barrier is placed a few centimetres behind the surface. Outer walls that are porous right through require further investigation to define the limits of their performance in resisting condensation.

9. ACKNOWLEDGEMENTS

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