

# Humidity buffer capacity of some building materials

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## Abstract

Unfired clay brick, wood, and cellular concrete have been evaluated as humidity buffers for indoor spaces. Their response to a cyclic variation of RH has been measured and reduced to a figure of merit, the ‘buf’ with symbol **B**. This is defined as the quantity of water exchanged through unit area of surface expressed as the volume of space which will experience the same change in amount of water vapour when exposed to the same relative humidity (RH) cycle. This number is approximately equal to the number of air changes needed to exhaust the buffer moisture reserve in a typical room. The best performance (61 for a daily RH cycle) is provided by a wall consisting of perforated unfired clay bricks, mechanically ventilated through the aligned perforations. The same brick exposed passively with perforations exposed to the climate chamber air had about half the buffer capacity, 27. Wood cut across the grain was next with a value of 15, just ahead of massive unfired brick at 10. Cellular concrete was an unimpressive buffer at 7 but worst of all was fired perforated brick with a buffer value of 3 even for a long RH cycle.

However, even the perforated unfired brick reacted slowly to changing RH, having a buffer capacity nearly doubling from a one-day to a four-day humidity cycle then doubling again for a very long cycle. Even then, the performance was worse than predicted from sorption measurements made on finely divided particles. The effectiveness of all humidity buffering materials is limited by the slow diffusion of water molecules through the material. The steepness of the water vapour sorption curve is therefore only an approximate, and optimistic, indicator of moisture buffer performance.

## Introduction

The moisture content of a hygroscopic material is continually adjusting towards equilibrium with the relative humidity (RH) of the space around it. However, as the air change rate in the space diminishes towards zero, the roles are reversed and the RH becomes determined by the water content of the material. This is the basis for the long established tradition of buffering the RH in showcases and boxes containing art in transit. Without a buffer, air leakage will quickly bring the interior of the package to the same RH as that outside. If the temperature changes in an airtight container, the buffer material will also maintain a nearly constant RH, in contrast to a buffer-free container, in which the RH drops as the temperature rises. This stabilisation of RH can be exploited also in archives, which are stuffed with hygroscopic paper and which do not need a rapid air exchange because people do not work there - only entering to retrieve and to replace documents. There are several examples of archives whose stable RH is mainly due to buffering by the objects they contain, aided by massive walls and low air exchange. These are reviewed by Padfield et al. [1] and by Ryh-Svendsen et al. [2]. Archives can safely be operated without air conditioning in the temperate climate zone, though strict adherence to archival standards, for example British Standard 5454-2000, will force air conditioning. This is not

because the RH specification is difficult to achieve but because only a two degree temperature window is allowed.

There are some archives which do not contain much hygroscopic material exposed to the room air. Film archives are a good example, with rows of steel cans isolating the contained rolls of film from the room air. The film container performs as a small buffered enclosure because the gelatin layer of the film is hygroscopic, but it is a wise precaution to incorporate a humidity buffer into the archive construction and furniture so that one can be sure of the ambient RH to which the individual films will slowly equilibrate through air leakage into the cans.

There are currently no standard building materials explicitly developed to moderate indoor relative humidity. We have studied those industrial products which can without further development be used as humidity buffers: unfired clay brick, wood and porous silicate block.

### **The need for a quantitative description of buffer performance**

Architects and building engineers need some standardised quantity to represent the usefulness of materials and structures as humidity buffers and to allow the incorporation of moisture exchange processes in computer models used to help design buildings. This buffer performance figure cannot be a property of the material because it depends on its form: the limiting factor in speed of response is the surface area exposed, so the same material in a labyrinthine form will react faster. The buffer performance also improves at lower temperature, because the water vapour content in the space is lower and less water exchange is needed to control its RH, while the exchangeable water in materials is scarcely affected by temperature. Buffer performance also improves with increasing RH, because all materials have a steeper sorption curve at high RH.

Current computer programs for modelling indoor climate use two material properties to predict RH: The sorption curve and the diffusion coefficient. The sorption curve is a measure of the total amount of exchangeable water in the material, the diffusion coefficient is a measure of how quickly water molecules can move through the material. The transfer from surface to room air is relatively fast, so its exact rate is not important. In reality, the diffusion coefficient is so small that solid materials do not perform well as humidity buffers. We have to design labyrinthine structures with a large surface area, perhaps even forcing air movement over the surface. Computer models cannot at present cope with this complexity, so experimental measurement of these structures is necessary. The results of these experiments cannot be reduced to fictional values of sorption and diffusion coefficients, imitating solid, homogeneous substances. Some other way of describing buffer performance is needed. Ideally, a single number - a figure of merit for the buffer material or construction.

The relative humidity indoors is constantly changing, reacting to the flux of water vapour from human activity as well as from atmospheric intrusion. A daily cycle of water vapour flux is appropriate for evaluating the performance of materials intended to ameliorate the indoor climate. In the workplace, the daylight hours are the time of increasing moisture production in an office, from people breathing and from steaming coffee cups. An eight hour day is usual. At home, the cycle is different; daytime is a period of dehumidification through ventilation while the evening and night air is humidified by cooking and by the breath of sleepers. This is typically a fourteen hour period (the missing two hours in this simple model of human existence is travel time).

To approximate in a single rhythm these two daily cycles, we subjected the test materials to a 10% sinusoidal variation in RH around the average value 55%, at which most materials have a nearly linear sorption curve. The results from this cycle can be extended approximately to any RH variation from 10% to 70%. The apparatus is described in detail in an appendix. Briefly, the specimen is enclosed by a sealed container held at constant temperature. The RH is changed by alternately heating and cooling a water reservoir within the container. The water vapour exchanged between the chamber space and the specimen is found by weighing the water reservoir, rather than the specimen. The variation in water vapour content of the chamber volume, which is about  $0.25 \text{ m}^3$ , is negligible, so one can assume that what is lost from the water reservoir is gained by the specimen. This allows convenient testing of assemblies which are difficult to weigh directly. The reason for using a sinusoidal variation, rather than a step change in RH, as used in existing and proposed standards (summarised and compared by Roels and Janssen [3]), is that imposing a sudden increase in RH on a highly absorbent material requires a large water flux and releases heat of condensation which lowers the surface RH at the specimen, and raises it on the reverse step, so the thermal conductivity and capacity become significant factors influencing the result. In reality, people generate a flux of water vapour which raises the RH steadily, rather than causing a step in RH, which requires a huge sudden injection of water vapour, only encountered in real life in a shower cubicle or a sauna.

### Defining a single number to describe buffer capacity

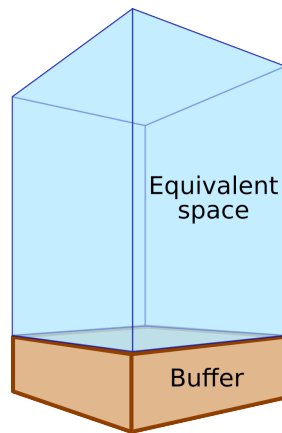


Figure 1: A visual display of the ‘equivalent air column’ principle for defining a figure of merit for a buffer material or construction. The horizontal area of the buffer is one square metre. Suppose that the RH is increased by 1%. The buffer material will absorb water vapour through its surface as it moves towards achieving equilibrium at this higher RH. The volume of the column is defined as that volume which will also increase by 1% RH when injected with exactly the same amount of water which enters the buffer. A highly buffering material will absorb a lot of water, so its equivalent air column will be high. This unit of buffer capacity is, naturally, called the ‘buf’ (B) with dimension length.

We suggest that the equivalent air volume per square metre of active surface is a useful measure of performance, encapsulated in a single number. This is explained visually in figure 1. A horizontal square metre of active surface is the

base for a column of air (strictly speaking a column of space). The height of the column is such that when the air space is subjected to a change of RH, from 50% to 60% for example, the surface will react to this new RH by absorbing exactly the same amount of water vapour as would have to be added to the air column alone to give it the same RH increase. This unit we call the ‘buf’, with symbol **B**, so as not to be confused with ‘b’, which is used in building physics to represent thermal effusivity and in nuclear physics is a measure of the effective cross section area for particle capture.

This B-value will change with temperature. It will approximately double with every 10°C drop in temperature. This is because the amount of water vapour required to cause a certain change of RH in space diminishes with temperature, while the equilibrium moisture content of materials is dependent on RH, approximately independently of temperature. The buffer capacity of absorbent materials in a cold store will therefore be significantly larger than at human comfort temperature. The value also changes with the time allowed for equilibrium, because for all buffer materials, diffusion from the surface through the bulk of the material is the process limiting the rate of change of water content. Only in the case of an infinitely long cycle time does the value represent equilibrium between the material and the surrounding space. This dependency on cycle time makes the buffer value fundamentally different from the sorption and diffusion parameters, which are measured after the specimen has attained equilibrium. The equivalent air column height B must therefore be accompanied by a statement of the temperature, the RH cycle time, as well as the nature of the specimen, which can be a complicated laminate or a mechanically ventilated labyrinthine construction. Note that the column height is independent of the magnitude of the change of RH, assuming linear sorption by the material, which is approximately true between 10% and 70% RH. This differentiates the B-value from other proposed standards which define a particular RH step sequence and measure the consequent weight of water transferred through unit area of surface.

This concept of air volume equivalent per unit area of sorbent surface can usefully be extended to surfaces which are entirely unabsorbent but which conceal a buffer mechanism. A simple example would be a wall made of vertical cardboard tubes embedded in plaster to give a smooth surface which is painted. The tubes are open near the foot of the wall and at the top, so that room air gently convects through the tubes. The performance of such a wall can still be expressed as the equivalent air column per unit area of wall exposed to the room, even though it is working like an air conditioning system with ducted air and supply and return vents. Such a labyrinthine buffer device could also be in the form of the plinth for a showcase or the support for a raised platform. At some point, however, it becomes more useful to quote the equivalent air volume to the buffering device, without reference to its surface area.

It is good for a unit of measurement in building physics to have an easy intuitive interpretation, to unite home builders, architects and air conditioning engineers in comprehending a useful concept in home comfort. The equivalent air column height is approximately the number of air changes in a room which will exhaust the buffer capacity of the material. This is so because many rooms have a wall area to volume ratio which is approximately unity. So a B-value of 15, for example, means that 15 air changes are needed to bring the buffer surface to equilibrium, so that it can no longer defy the different RH of the incoming air. For a modern house with half an air change per hour, the buffer performance will substantially reduce the expected RH variation through leakage, since it would take 30 hours to exhaust the buffer capacity, which is longer than the daily cycle.

The buffer performance against moisture generated indoors can only be guessed, because it depends on the lifestyle of the inhabitants.

## Experimental results for perforated unfired clay brick

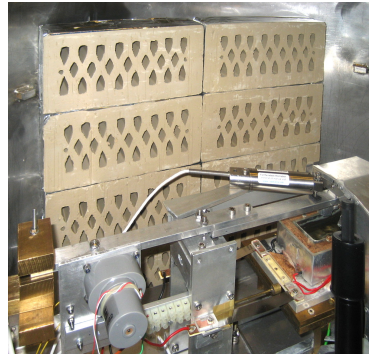


Figure 2: Eight perforated unfired bricks, exposed in the climate chamber. The apparatus controlling the RH and measuring the weight of water moving into the specimen is at the bottom of the picture. The climate chamber is described in detail in the appendix. The exposed area of the brick wall is  $0.2 \text{ m}^2$ , its depth is 53 mm. The sides and back are sealed with aluminium foil so the perforations are exposed to the chamber air as blind tubes.

This concept of buffer value will be illustrated using experimental results for the unfired perforated brick specimen shown in figure 2. The weight changes following the imposed RH cycles are shown in figure 3 for sinusoidal cycles lasting one day and four days and for a long period imposed by step changes of RH.

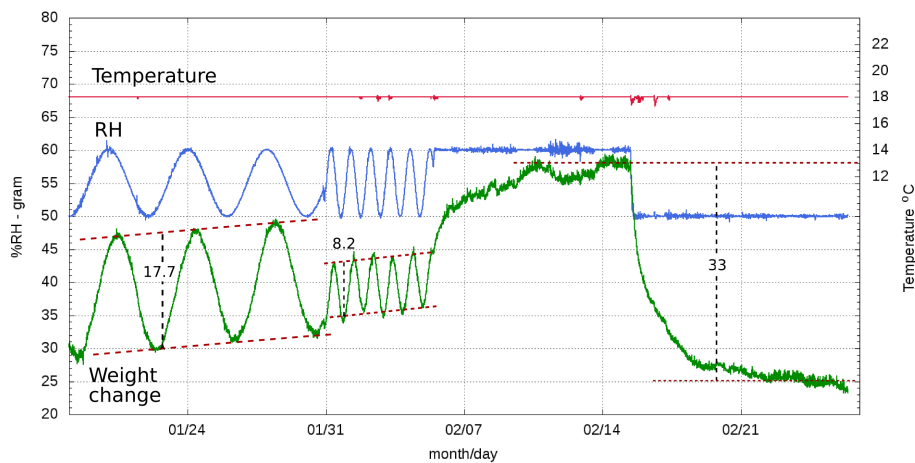


Figure 3: The perforated unfired brick, exposed successively to three 96 hour RH cycles, then 24 hour cycles and finally to steady chamber RH. Parallel lines mark the envelope of the cycles. The numbers indicate the weight of water in grams absorbed through the  $0.2 \text{ m}^2$  exposed area of the bricks.

The numbers on the graph are the actual weight of water in grams transferred back and forth through the specimen surface in reaction to the cycling relative humidity in the chamber. For the 12 hour, 96 hour and ‘infinite’ cycles, the

weights are 8.2, 17.7 and 33 g respectively. These numbers are first recalculated to one square metre of wall, giving 41, 88.5 and 165 grams respectively for the 24 hour, the 96 hour and the ‘infinite’ RH cycles. This is in response to a 10% RH cycle amplitude but the cycle amplitude is arbitrary and its value disappears when the water sorption is converted into the air column equivalent.

Turning now to the space column calculation, the saturation water vapour content for one cubic metre of space at 18°C is 15.29 g, so a 10% RH change will cause a 1.53 g change in water content per cubic metre. Using data from the 24 hour cycle, 41 g water will raise the RH by 10% in 26.8 cubic metres of air. Rounding to a whole number,  $B = 27$  m is the figure of merit of the material, at the defined temperature and cycle time. A room, 5 x 4 m, has a wall surface to volume ratio of 0.9, but corridors and small rooms bring the ratio to about unity for a typical dwelling. For a public building like a museum the ratio will be smaller. Windows are not absorbent. Even so, as a very rough guide, the figure of merit indicates the number of air changes during the humidity half cycle that will bring the absorber to equilibrium with the RH of the invading air stream. In this case an air exchange rate of over twice per hour will be necessary to exhaust the buffer. Another way of looking at the matter is that the humidity buffering effect will be just noticeable even in a house subjected to this quite large air exchange rate. In a store room with an exchange rate of once per day, the buffering will be the main influence on the interior RH.

It is interesting to note that the four day cycle gives about twice the buffer capacity and the ‘infinite’ cycle gives about four times the 24 hour capacity. The theoretical maximum B-value, calculated from sorption measurement on finely powdered material is even greater. This shows that even with perforated clay brick presenting a very large surface area, slow diffusion within the material limits the buffer performance. If the surface area of the brick were to be increased, the sorbent density per unit of wall area would decrease, so there is an optimal degree of perforation.

Massive unfired brick, made from the same clay mix, has a notably inferior performance, showing a B-value 10 for the 24 hour cycle, less than half that of the perforated version though it has much more mass per unit area, both test walls being 53 mm thick.

In contrast, thermal buffering of the daily temperature cycle by solid earth brick involves about a half metre depth within the wall, giving an amelioration of indoor temperature which has been exploited and appreciated for millenia by the inhabitants of hot countries.

## The performance of a mechanically ventilated structure

The solution to the limit set by diffusion rate is to perforate the wall and force air through narrow tubes. An alternative construction for a buffer wall is to pile up the bricks so their perforations are aligned within the wall and are ventilated mechanically. The surface of the wall can be entirely non-absorbent, which allows a much greater choice of decorative surface treatment. Such an arrangement is shown in figure 4. The corresponding response graph is figure 5. After normalisation to the smaller wall area (0.097 m<sup>2</sup>), the figures of merit are  $B = 61, 108$  and 243 respectively for 24 hour, 96 hour and ‘infinite’ periods. This is about twice the buffer capacity of the wall made of bricks stacked with perforations exposed, but the wall is also twice as thick. The forced ventilation seems not to have increased performance over that of the blind perforations ventilated by the moving air of the chamber. One can conceive of labyrinthine walls like this being ventilated by thermal convection, without mechanical devices.



Figure 4: The eight perforated unfired bricks are here assembled with their perforations in line, ventilated by a fan. The outside surfaces were sealed before exposure in the chamber. The wall surface area was  $0.1 \text{ m}^2$ , the thickness  $108 \text{ mm}$ .

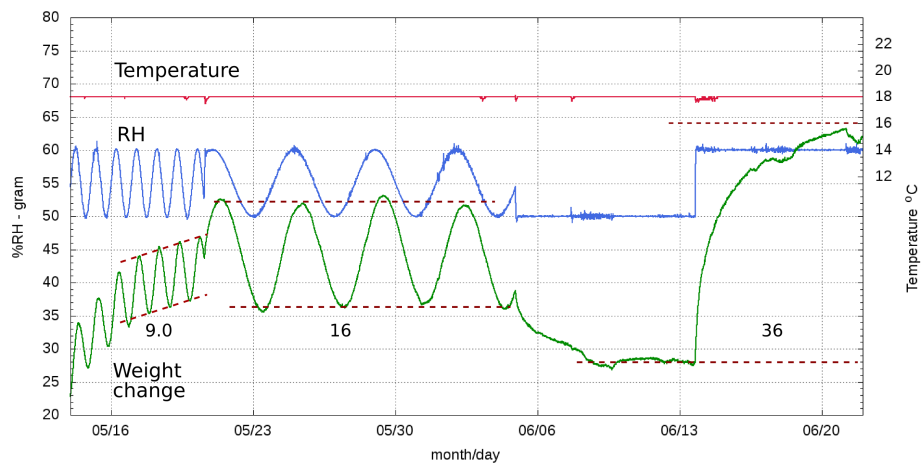


Figure 5: The buffer performance of the perforated unfired bricks with internal ventilation through the perforations. The wall area is  $0.1 \text{ m}^2$ .

## Other buffer materials

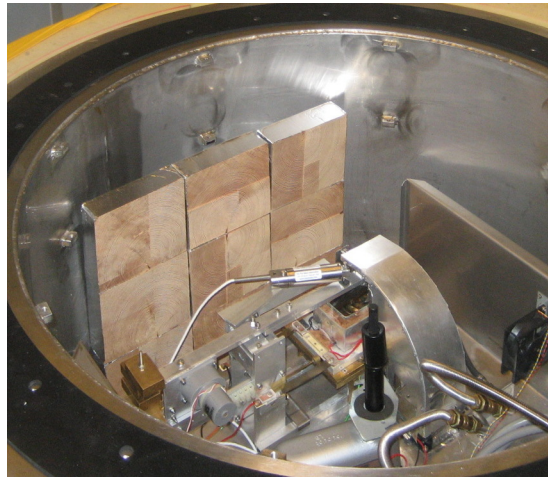


Figure 6: Wooden blocks cut from a beam with the end grain exposed on one face. The wall area is  $0.2 \text{ m}^2$ .

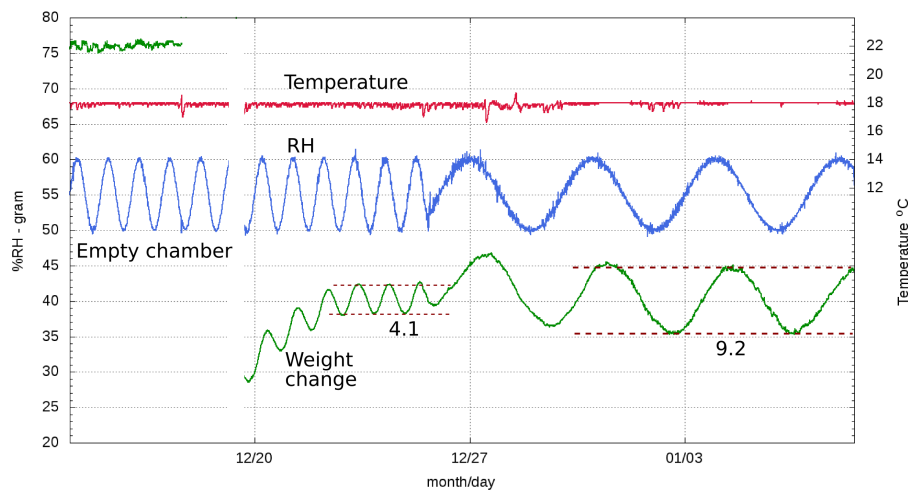


Figure 7: Buffer performance of wood cut across the grain. On the left is the weight change of the empty chamber. The exposed wall area is  $0.2 \text{ m}^2$ . The thickness is 40 mm.

Soft wood cut across the grain is shown in figure 6. The corresponding graph is figure 7. The diffusion rate of water vapour in the lengthways direction of wood is about four times the rate across the fibre direction. Nevertheless, on the 24 hour cycle, wood is a mediocre humidity buffer. Its figure of merit is 15 and 34 for the 24 and 96 hour cycles respectively.

Cellular concrete is a rather imprecise name covering a range of lightweight building blocks. Our specimen is the variety known as ‘gasbeton’. It is a calcium aluminium silicate made by reacting water, sand, lime and aluminium powder. The structure is a finely porous mass of silicate needles interspersed with larger spherical spaces, originally hydrogen gas bubbles. The buffer performance of this specimen is quite poor, shown in figure 8. B is 7 for the 24 hour cycle and the scarcely better 9 for the 96 hour cycle.



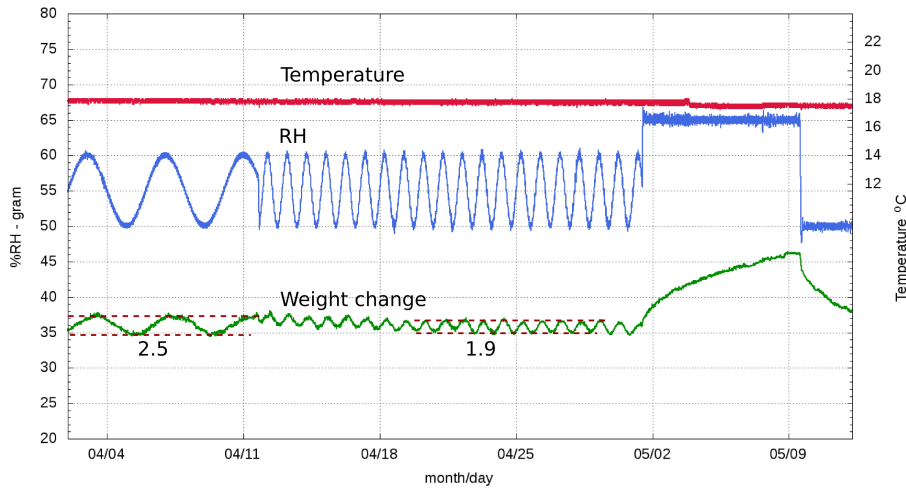


Figure 8: Buffer performance of cellular concrete. The exposed wall area is  $0.2 \text{ m}^2$ . The thickness is 50 mm.

## Comparison of the materials and constructions

The buffer values for the tested materials are summarised in table 1. The contrast between the good performance of unfired brick and the scarcely measurable buffer capacity of brick from the same source after firing is very striking. Unfired brick has a moisture stabilising ability entirely lacking in fired brick. The sorption is mainly due to the clay component. Clay varies in its sorptive power, with sodium montmorillonite showing high sorption and kaolinite low sorption. Most brick clays have a mixture of clay species. These unfired bricks are from a calcareous clay deposit in northern Denmark.

End grain wood, though visually attractive, for a while at least, is disappointing, having too slow a response. For museum use its outgassing of organic acids and many other volatile chemicals is a serious disadvantage.

Cellular concrete has a poor buffer performance, though it is the easiest to specify for the purpose, since it comes in large slabs. It is entirely mineral and does not outgas vapours. It is certainly better than fired brick.

Specimen description	Thickness	B-24	B-96	B-long	B-sorp
unfired perforated brick	53	27	58	108	130
unfired massive brick	53	10	21	–	173
unfired perf. brick ventilated	110	61	108	243	271
End-grain wood	40	15	34	–	122
Cellular concrete	50	7	9	–	18
fired perforated brick	52	–	–	3	15

Table 1: Buffer values (B) of building materials at  $18^\circ\text{C}$  for 24 hour, 96 hour and ‘long’ cycle time (a square wave with minimum 7 days settling time). B-sorp is the value calculated for complete moisture equilibrium throughout the thickness of the specimen, based on the measured sorption curve shown in figure 10. The wall thickness is in mm. Buffer values are in equivalent metres of air column (see text for explanation).

## Sorption properties of the materials

A useful screening test for identifying suitable buffering materials is to measure the equilibrium sorption curve. This is customarily expressed as water absorption per unit dry weight of material. In the last column of table 1 the sorption property, measured as described in appendix 1, is transformed into a theoretical maximum B-value for comparison with the direct experimental results for finite cycle times. The comparison shows that a high sorption does not automatically give a high buffer value but low sorption cannot be compensated by rapid response.

In the RH range between 40% and 60% the sorption curve of every material is nearly linear. By measuring the change in weight in both increasing and decreasing RH within this range, the effect of hysteresis was found to be very small. The raw data are shown in figure 10 in appendix 1. Notice the lack of correlation between water sorption at equilibrium and the buffer capacity expressed by massive materials during a short cycle time. The sorption coefficient defines the performance of the material when it has reached equilibrium, but the equilibration time is too long to be useful for ameliorating the RH in a building ventilated for human habitation. A 50 mm thick book, for example, takes several weeks to come half way to equilibrium after a change of ambient RH. So in spite of the huge exchangeable water reserve in a library, most of it is not accessible to buffer the daily cycle of humidity.

The buffer performance promised by the sorption curve is linked to the actual buffer performance through the diffusion coefficient. In principle it should be possible to use the sorption coefficient and the diffusion coefficient to bypass the tedious measurements described in this article. However, there are two problems with using measured diffusion coefficients. One is that the usual method of determining the diffusion rate of water vapour through a material is to set up a steady state movement of water molecules through the material, under the influence of a fixed RH difference across it. This does not allow for time dependent sorption chemistry in a varying environment, so the measurement really gives a value for the diffusion of an unreactive gas with the molecular weight of water. The other problem with diffusion coefficients is that they cannot be used in complicated labyrinthine geometries, which will surely be necessary in practical humidity-stabilising walls.

## Discussion

The revelation of the good moisture absorption of unfired clay brick will not come as a surprise to the large fraction of mankind which lives in earthen houses, but this article will serve as a reminder to engineers and architects in rich nations of the benefits of cheap and unfashionable building materials.

Since quantification of physical properties is required for the approval of building materials in technically regulated societies we offer a simple measure of the buffer potential of a wall surface exposed within a room: the volume of space which has the same water exchange capacity as unit area of the surface under test. This measure of performance is simple and independent of the amplitude of RH variation (within the limits of the normal indoor environment), but it is considerably different from the two already established tests discussed by Roels and Janssen [3]. These two tests are empirical protocols designed to suit simple climate chambers and the customary working hours of their operators. The ‘Nordtest’ protocol specifies 8 hours at 75% RH followed by 16 hours at 33% RH. The RH values were surely decided by the availability of cheap saturated salt solutions to control them. The Japanese test ‘JIS A 1470-1 (2002)’ has a more

elaborate protocol involving a 24 hour exposure to each fixed RH, abandoning the natural daily cycle in the interest of the operators' convenience. Both these tests define the performance as the weight of water exchanged per unit area per percent RH change, a number which has no immediately understandable significance, though it allows comparison between materials.

It is not clear how any of these quantitative statements of buffer performance can be incorporated into the heat and moisture programs used to aid modern construction. These programs use a combination of the statically measured sorption coefficient and diffusion coefficient of the material. This is probably adequate for solid walls, but will surely not work for materials whose absorptive area is enhanced by intricate surface detail or by deep perforations thinly protected by moisture transparent coatings.

The few materials we have measured are the commonest immediately available, but they are not the only promising candidates. Cement bonded earth bricks, usually made on site, should perform well, since the cement gel has a very high water vapour sorption. Hemcrete is a lime-sand mixture filled with hemp (*Cannabis sativa*) fragments left over from processing for fibre. This material also is usually mixed and applied immediately on site. Among wood-based materials found in building suppliers there are cement bonded wood chip boards and compressed wood chip boards with similar properties to plywood but with more cut fibres exposed at the surface. We would not expect these to perform better than end grain wood.

An immediate use for buffer materials is in bathrooms subjected to intermittent bursts of water vapour which are currently exhausted through ducts by fans. A test in an unfired brick house built by Tom Morton [4] showed that walls of unfired brick worked as well as mechanical ventilation in reducing condensation. Bedrooms are another target for humidity buffering, since asthmatics sensitive to dust mites need to keep the RH below 60%.

A more speculative use for perforated unfired bricks is in solar powered dehumidifiers in which outside air is passed through sun warmed bricks during the day, to remove moisture. At dusk the air flow is cut and the bricks are allowed to cool. At night, the air flow is switched to pass room air through the bricks, which maintain the low equilibrium RH they achieved during the daytime flush of warm air and therefore dehumidify the room air.

### Appendix 1: measured values

The entire sequence of measurements is shown, unedited, in figure 9. Note that the weight is here shown as diminishing with increasing RH. This is because the weight change recorded is that of the water in the reservoir rather than in the specimen.

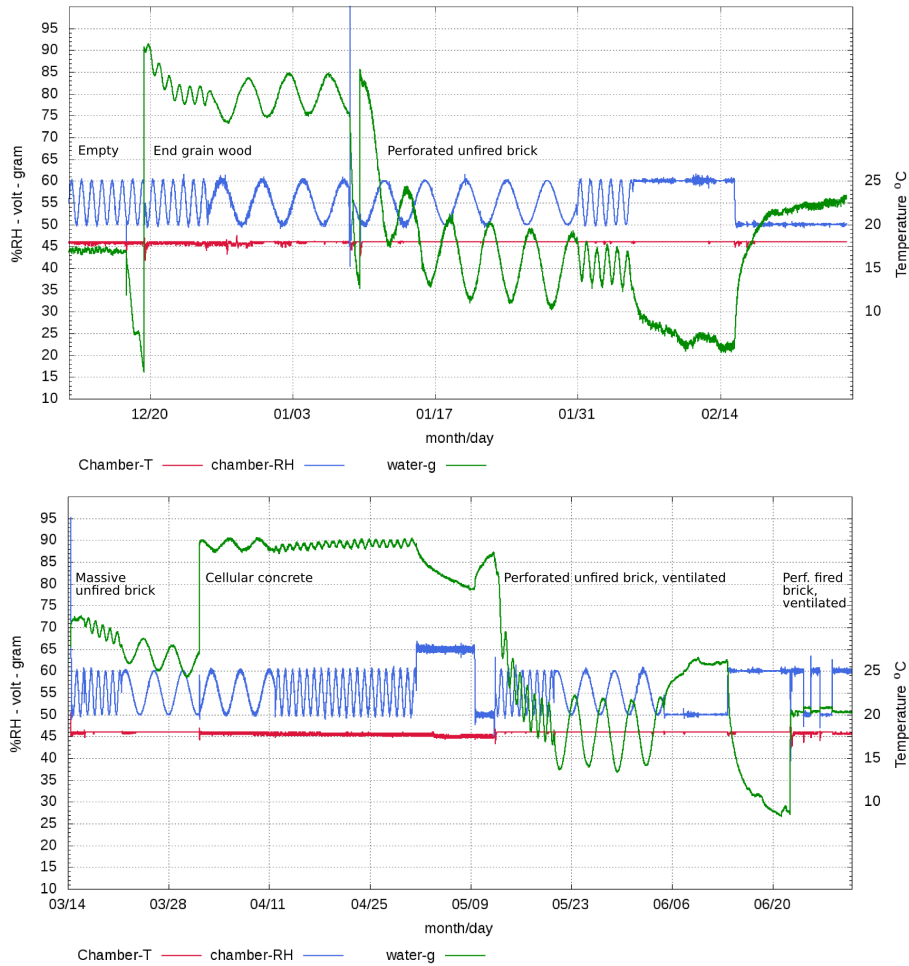


Figure 9: Unedited climate data from the experiment.

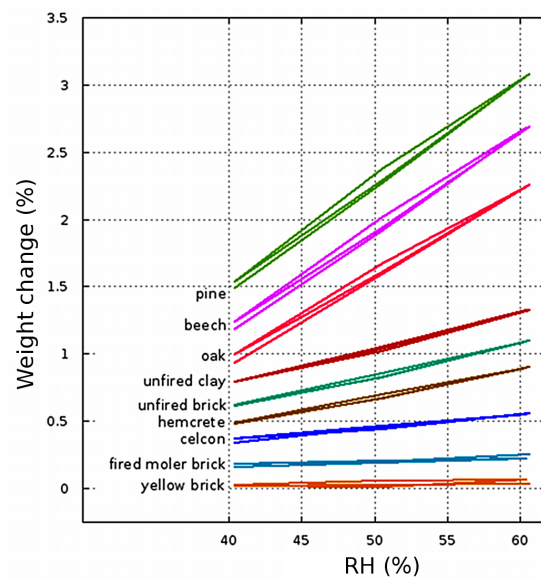


Figure 10: Sorption of water vapour by materials over a limited RH range. The plots show the response to cyclic change of RH measured at 40, 50 and 60% RH. The hysteresis loops are insignificant over a moderate RH range. The sorption cycles for each material are offset vertically for clarity. ‘Moler’ is a clay rich diatomaceous earth quarried in western Denmark. ‘Hemcrete’ is lime mortar mixed with hemp residues. ‘Celcon’ is a porous calcium-aluminium silicate block. The clay products are from Wienerberger brickworks in Helsingør, Denmark.

## Appendix 2: the climate chamber

The climate chamber is shown in figure 11. The annular temperature control system is shown in cutaway in figure 12. The flux control device is shown in figure 13 and explained in figure 14. Normally, the top is closed with an airtight stainless steel lid and covered with 200 mm of wool insulation.

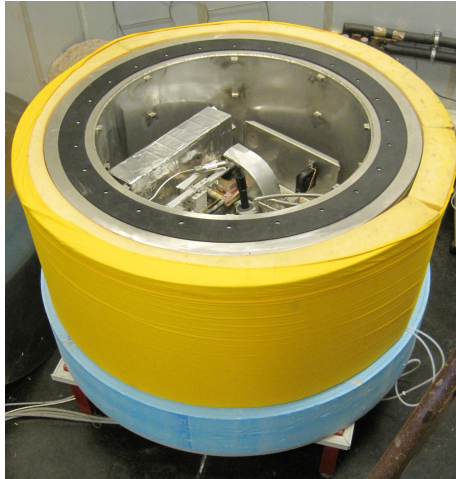


Figure 11: The buffer measurement chamber with lid removed, showing the ventilated brick test specimen and the top of the flux generating apparatus. The inner cylindrical space is 793 mm diameter, 500 mm deep.

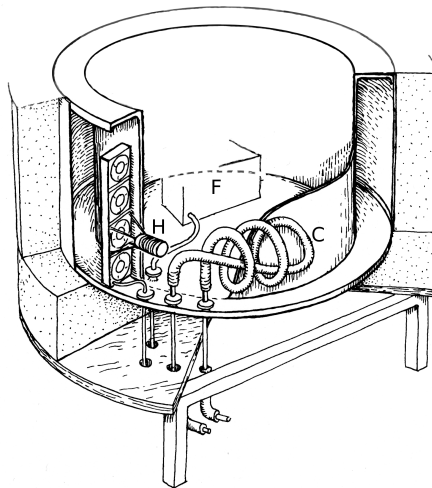


Figure 12: The chamber temperature is controlled by air blowing around the annular space. The electric heating element is marked **H**, the water cooling is marked **C**. Both heating and cooling are switched by the computer program. The flux generator within the inner chamber, **F**, is also supplied with cooling water to its heat exchanger.

The chamber climate is managed and measured through a computer program written in Python, running on a PC with Debian Linux operating system. This program controls a Hewlett Packard programmable data control and acquisition unit which in turns operates various valves and relays to govern the operation of the chamber. For this experiment the chamber had a controlled RH, with

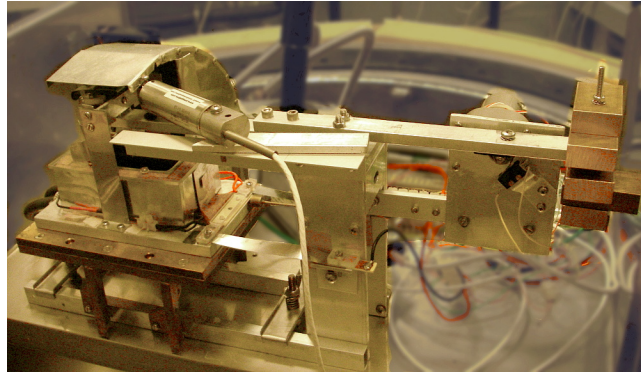


Figure 13: The flux generator. See figure 14 for the explanation.

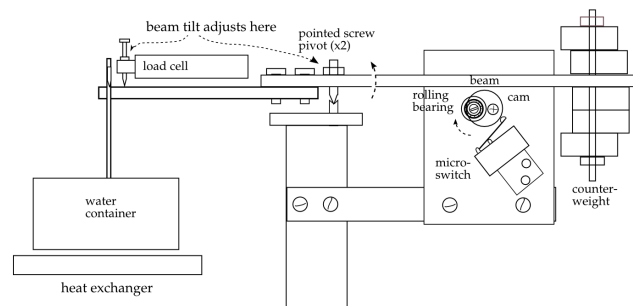


Figure 14: The flux generator heats or cools the water reservoir on the left, alternately evaporating and condensing water. The weight of the full reservoir is just overbalanced by the counterweight at the other end of the beam, which is pivoted in the middle. In normal operation, the raised cam tilts the beam so the reservoir rests on the heat exchanger, which is held at 2 degrees above the chamber dewpoint. At one minute intervals, the chamber fans are stopped and the cam rotates to release the beam to rotate freely up against the load cell which is placed close to the knife edge holding the reservoir. Not illustrated (but visible in figure 13) are the flexible stainless steel strips which supply current to the Peltier elements which control the water temperature in the reservoir. Various adjustments to the bearing points and to the counterweight blocks allow the beam to be balanced so that the exact tilt has no influence on the weighing process.

feedback from a dew point sensor. The chamber can also operate by controlling the water vapour flux, measuring the RH as a consequential value. It is clear from figure 9 that there was intermittent instability in the RH control.

This is a slightly modified version of the apparatus described in detail by Padfield et al. [5].

The sorption experiments were made in an apparatus which mixes a wet and a dry air stream within a chamber held at constant temperature. The specimens are suspended within the chamber on an automatic carousel which drops each specimen in turn onto a hook suspended from an external balance. The chamber need not be opened during the process, so cyclic RH steps can be applied with complete assurance that there is not a moment of exposure to an unregulated RH. The instrument is shown in figure 15.



Figure 15: The sorption measuring device. Finely divided specimens are loosely packed in polyester mesh bags which are suspended from a carousel which rotates them in turn to be hooked to a rod, connected via a briefly open tube to a balance mounted out of sight above the picture. The climate is controlled by mixing two air streams, one saturated, the other dry. The entire assembly is held at a constant temperature in a double enclosure.

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