Humidity buffering of building interiors by absorbent materials

Tim Padfield, Ph.D. [1]
Lars Aasbjerg Jensen, M.Sc. [2]

[1] United Kingdom
[2] The National Museum, Denmark

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SUMMARY:
Unfired clay brick, wood, and cellular concrete have been evaluated as relative humidity (RH) buffers for indoor spaces. Their response to a cyclic variation of RH has been measured and expressed in a novel unit for describing the buffer capacity, the 'buf' with symbol B. This is defined as the quantity of water vapour exchanged with the material, expressed as the volume of space which will experience the same change in amount of water vapour when exposed to the same RH cycle. Well ventilated unfired perforated brick, 5 cm thick, has a buffer capacity of 27 m^3 per square metre of surface for a daily RH cycle. One can regard the sum of the buffer values of the wall lining and the furnishing as a virtual (larger) volume of a room, into which water vapour from infiltration and internal generation has to disperse, with a consequently smaller RH variation. The buffer value is dependent on cycle period, temperature and air velocity over the surface.

1. Introduction

Stabilisation of the interior climate by moisture-active building materials and furnishing is of great value to museums and archives. Humidity buffering by absorbent materials has long been used to stabilise the microclimate in showcases and transport boxes. In this article we explore the potential for extending the benefits of humidity buffering to better ventilated enclosures: stores, archives and even museum galleries. For these large spaces the buffer material must be cheap and available through large scale production. We have investigated the few common building materials which have a significant water sorption capacity at moderate RH. These are unfired brick, wood and cellular concrete.

We know that buildings which are heavily loaded with water absorbent materials keep their internal RH remarkably stable, even over a whole year. The Suffolk Record Office in Ipswich UK was unventilated and only heated in winter. Its microclimate is shown in figure 1. The RH varies between 52% and 58% in a gentle annual cycle. The winter heating drives the RH down a little. During the summer the tendency of infiltrating air to raise the RH is resisted by water absorption by the paper.

Other museum stores, and particularly museum galleries, have the same need for RH stability, but do not have the buffer capacity provided by densely packed paper records. Can this lack of buffering be compensated by building, or lining the walls, with moisture absorbent materials?

2. Experimental evaluation of buffering by building materials

The materials were exposed to a cyclic RH variation between 50% and 60%. The resulting exchange of water vapour with the surrounding space was measured. The experimental technique is described by Padfield et al. (2002). The apparatus, with a perforated brick specimen, is shown in figure 2A. It is a sealed chamber in which the RH is controlled by the temperature of water in a weighed reservoir. The water temperature is adjusted by a thermoelectric heat pump. By weighing the water container, specimens of different geometry and weight can be tested conveniently. In a separate experiment, the materials were finely divided for measurement of their equilibrium sorption curves over a repeated cycle of 40% to 60% RH, to find the maximum exchangeable water over this limited RH range.

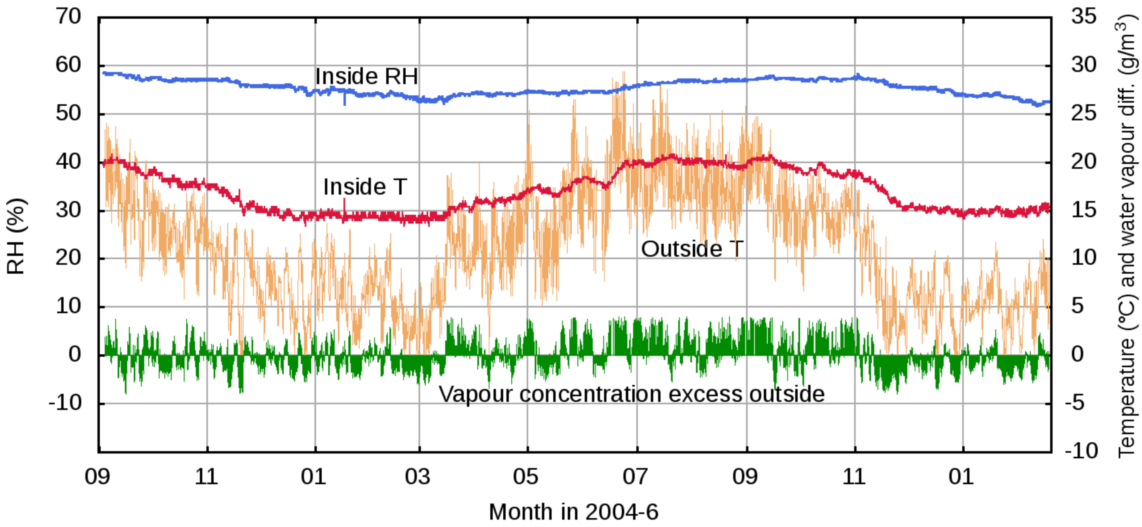

FIG 1. The annual cycle of temperature and relative humidity in the Suffolk Record Office. The lowest trace indicates the difference between the concentration of water vapour inside and outside. During the winter the inside RH is driven down by air exchange; during the summer the outside air has a higher water vapour concentration, as shown by the lowest trace being mostly above the zero line, but buffering by the archived documents slows the rise of indoor RH.

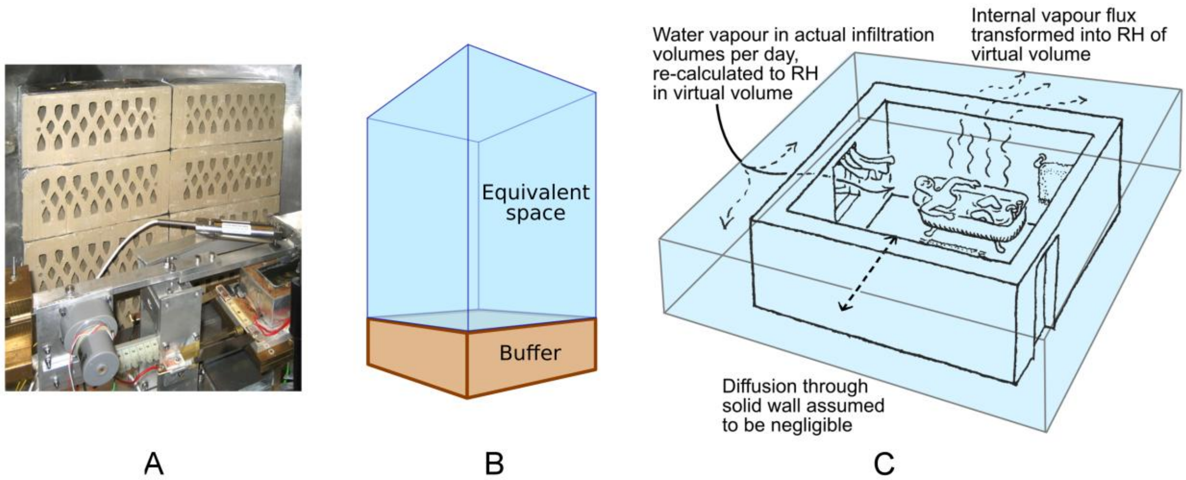

FIG 2. A: Water is exchanged back and forth through the surface of the perforated brick wall as a consequence of an imposed RH cycle between 50% and 60%. B: This weight of water is transformed into the equivalent air volume (the B-value) which would experience the same change in water content for the same RH cycle. C: The equivalent air volumes for all buffering components in a room are added to the actual room volume to give a 'virtual volume' for the room. It is this volume whose RH change is calculated from the water vapour flux from infiltration and internal generation.

3. The quantitative description of buffer performance

The experimental apparatus measures the weight of water transferred between the test object and the reservoir as a consequence of a change of ambient RH applied over a defined cycle time, at a constant temperature. Given the diversity of materials and forms which combine to influence the microclimate of a room, we need to find a way of expressing their performance which can be summed conveniently to predict how the room will react to the exchange of water vapour with outside air and to the generation of water vapour by human activity within the room.

We transform the measured water exchange of our specimens to the equivalent volume of air (strictly speaking the volume of space) which will experience the same cyclic change in RH with the same water vapour transfer. This concept is illustrated in figure 2B. This equivalent volume is labelled the B-value for the material. For construction materials, the volume is calculated per square metre of exposed surface. For irregular shaped buffering objects, such as a sofa, the B-value can be defined as the equivalent air volume for the entire object. For a library the equivalent volume per linear metre of shelving would be appropriate.

The sum of the B-values for all wall surfaces and all sorptive components within a room, expressed in cubic metres of space, is added to the actual volume of the room to give a larger, virtual volume (figure 2C). To calculate the effect of moisture generation and air exchange, one uses the actual air exchange, and the actual moisture production, but calculates the resulting change of RH caused by these fluxes dispersing into the larger virtual volume.

4. Experimental results

Table 1 shows the B-values, expressed in metres, for a one day sinusoidal cycle, a four day sinusoidal cycle and a long cycle represented by holding the RH steady at each of the extreme values, 50% and 60%, for long enough for the specimen to reach equilibrium, but not longer than two weeks. The last column shows the theoretical B-value on the assumption that all the exchangeable water is available for movement between the material and its surroundings. This value is derived from the gradient of the equilibrium sorption curves between 40% and 60% RH, which are shown in figure 3.

TABLE 1. Buffer values, in metres, of building materials at 18°C. The second column is the specimen thickness. The next columns are the B-values for 24 hour, 96 hour and 'long' cycle time (a square wave with minimum 7 days settling time). 'B-static' is the value calculated for complete moisture equilibrium throughout the thickness of the specimen.

Material	mm	B-24	B-96	B-long	B-static
Unfired massive brick	53	10	21	-	165
Unfired perforated brick	53	27	58	108	136
Unfired perforated brick, double depth	106	39	95	196	272
Unfired perforated brick, double depth, low airflow	106	10	21	-	272
Unfired perforated brick, double depth, paper cover	106	10	26	98	272
Unfired perforated brick, fan ventilated	110	61	108	243	271
End grain wood	40	15	34	-	122
Cellular concrete	50	7	9	-	17
Fired perforated brick	52	-	-	3	12

The measurement precision was such that for the poorly absorbent materials, B-values less than 3 are omitted from the table. For more absorbent materials the variation between specimens of different wood species, or different clay pits, would be greater than the experimental error. The values given here are therefore indicative rather than exact.

For the perforated specimens, the B-value depends greatly on the air turbulence at the surface. The effect of ventilation vigour on the performance of the perforated brick was checked in a room-sized chamber with a much gentler air circulation system, more typical of a dwelling. The 24 hour B-value sank from 39 to 10, illustrating the importance of air circulation around highly absorbent materials.

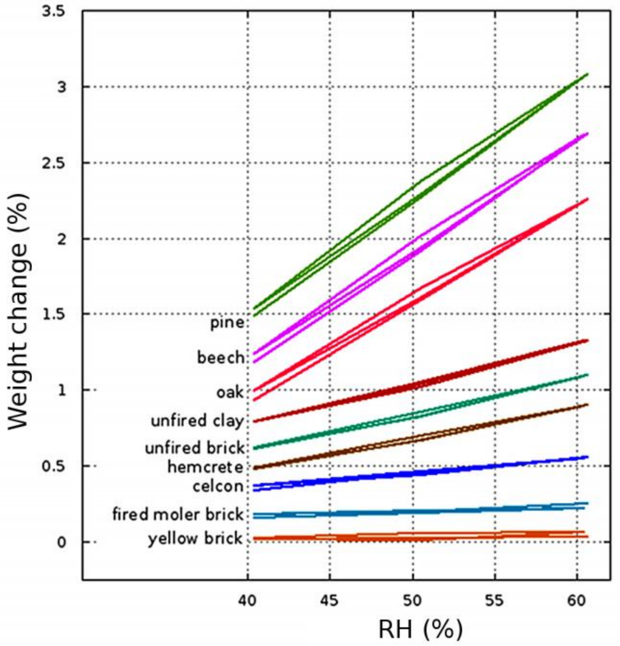

FIG 3. Sorption of water vapour over a limited RH range. The plots show the response to cyclic step changes of RH between 40%, 50% and 60%. The hysteresis loops are insignificant over this moderate RH range. The sorption cycles for each material are offset vertically for clarity. 'Moler' is a clay rich 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 Helsinge, Denmark.

4.1 The effect of cycle time on the exchangeable water supply

The B-value increases with the RH cycle time because deeper layers of the material become involved in the diffusion process. A 24 hour cycle matches the pattern of human activity, but a longer cycle time would be appropriate for designing an archive, which has a slower air exchange and very little human generated water vapour. The B-values roughly double from the 24 hour to the 96 hour cycle, then double again for the slow cycle.

4.2 The effect of air movement on water exchange through the surface

Most of the experiments were conducted with a high air speed, by indoor standards, between 0.2 and 1.2 m/s. This was fast enough to make diffusion through the specimen the rate determining step. Some experiments were conducted at low air velocity - less than 0.1 m/s, and some experiments were made with a permeable surface coating over the specimen (figure 4). Air velocity variation, within the range commonly encountered indoors, has a large effect on the B-value.

4.3 The effect of temperature on the B-value

The B-value is temperature dependent. As a general rule, the B-value for long cycles will double with a ten degree fall in temperature. This is because the buffer material retains almost the same water content for a given RH, independent of temperature. However, the water content of space, at constant RH, diminishes considerably with falling temperature. For short cycle times, slower diffusion will result in a smaller increase in B-value.

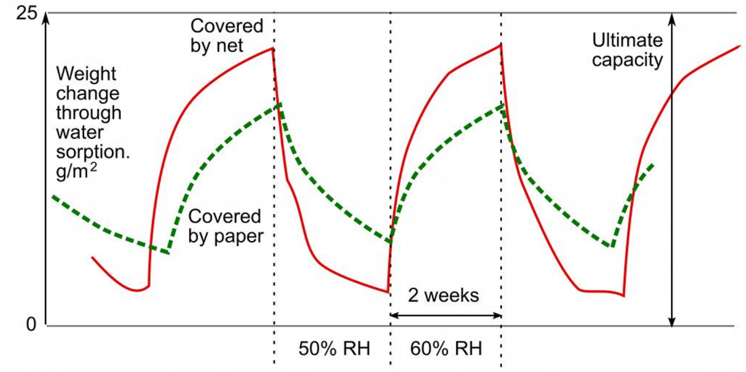

FIG 4. The effect of covering unfired perforated brick with a single layer of filter paper. The response curves to a four week square wave RH cycle are plotted superimposed. The top and bottom boundary lines indicate the ultimate buffer capacity derived from the static sorption measurement. The net had mesh openings 1.2 mm square, the paper was Whatman no.1, 88 g/m^2.

5. Using the B-value in the design process

We don't know of a building that has been deliberately constructed to minimise the variation of RH caused by infiltration and internal generation of water vapour, and whose performance has been measured. We have to resort to simulation based on an existing museum storage building that is currently dehumidified to control its RH. This building, in Ribe, South Denmark, is described by Ryhl-Svendsen et al. (2010). For the simulation we modify the single space of this building to contain three equal rooms, each 14 x 24 x 6.5 m high, lined on all walls with 50 mm unfired perforated brick. We combine this imagined construction with the actual air exchange rate of the Ribe building, 0.03 per hour, and the measured room temperature and outside climate during one year. Assuming a B-value of 100 for the unfired brick, the total B-value for the room is 50,000 m^3, while the room volume is 2184 m^3. The virtual volume is 52184, which is 24 times the actual volume. To calculate the effect of infiltration, we reduce the infiltration rate to 0.03/24 = 0.00125. The outside vapour concentration is calculated every hour. This concentration is multiplied by the virtual exchange rate and brought into the interior while an equal volume of internal air is expelled. The new vapour concentration and the interior temperature are used to calculate the interior RH.

For a typical dwelling or office, this is all that needs to be done to simulate the effect of humidity buffers, because one can assume a fairly constant temperature through the year. In the case of the Ribe museum store the temperature is uncontrolled and varies in an annual cycle. An extra calculation stage is needed. Consider the case where the temperature declines from hour to hour. The buffer will maintain the RH, but the water vapour concentration in the air space will diminish. Therefore, one calculates from the RH a new water vapour concentration at this lower temperature. This modified concentration is used in the next iteration of the simulation.

The result of this calculation process is shown in figure 5, which predicts what would happen were the dehumidification stopped. The traces show the subsequent course of the RH in a building with no buffer capacity (B=1), and in the buffered building (B=24). The B-value is very dependent on air flow over the surface. In a quiet interior the value may be just a fraction of the well-ventilated value. The curve for B=10 may well be more realistic for a museum store. The calculation predicts that in this specialised application, moisture buffering is very effective and will delay serious consequences of mechanical dehumidification failure for at least two months.

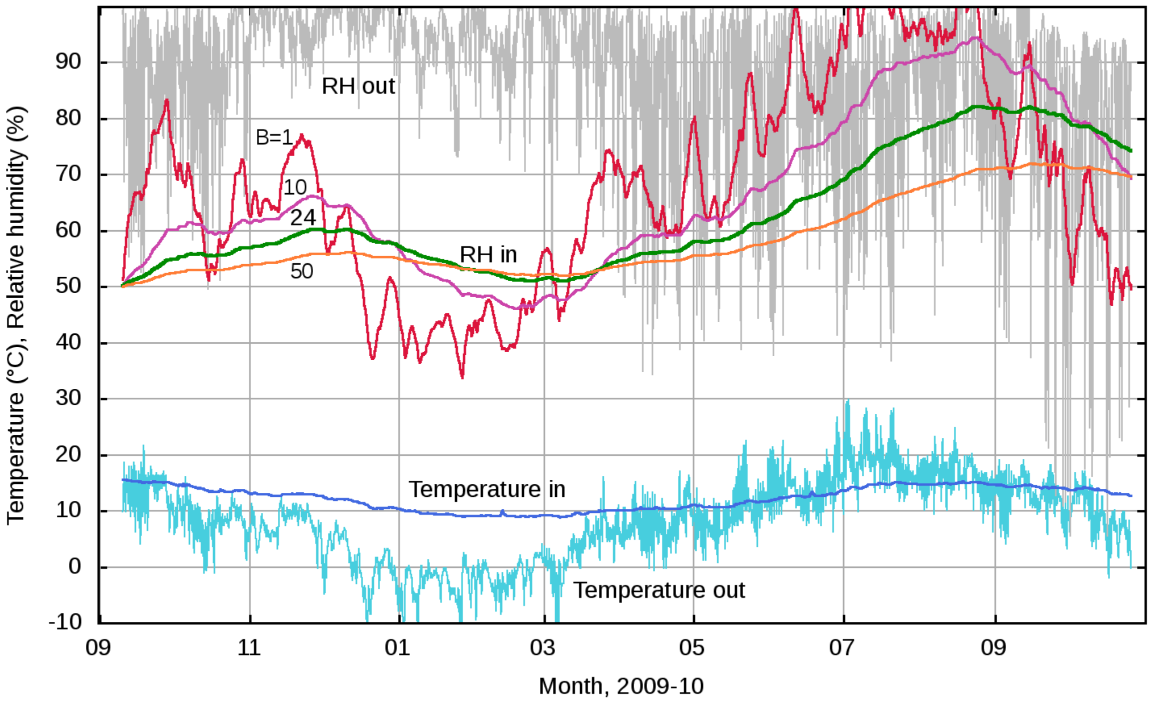

FIG 5. Simulated buffering of the RH in a museum store by lining the walls with unfired brick (trace 24). The interior RH starts arbitrarily at 50%. The trace marked B=1 shows the course of the RH in a completely water-inert building with an air change rate of 0.03 h^{-1}.

6. The B-value compared with other descriptions of buffer capacity

The buffer capacity test described here is similar to the method defined in the Japanese standard (JIS 2002) and the proposed Nordtest standard (Rode 2005). These methods, which are summarised by Roels and Jannsen (2006), use a set series of step RH changes and express the result as the weight of water exchanged through one square metre per percent RH change. Both these measuring protocols give a single number for the buffer performance, which roughly corresponds with the B-value for a 24 hour cycle.

The B-value can be considered a lumped vapour capacity which is always in equilibrium with water vapour in the space within the room. The element of delay caused by slow diffusion within the material is approximately compensated by choosing a B-value matching the typical cycle of water vapour production.

The virtual volume concept can be invoked as a pre-processor for heat and moisture simulations of moisture movement through the outer walls of buildings. This is because the interior RH influences the vapour flux through the surface of the wall, but the reverse influence, of the moisture content of the wall on the interior RH, is normally very small, because of the impermeability of interior wall surfaces compared with the infiltration rate.

This approximation may be too naive for particular cases. Janssen and Roels (2008) propose a procedure for combining data from different cycle times into a capacity, an equivalent thickness and a diffusion rate which can be integrated into a finite element diffusion program. They demonstrate this by modifying the proposed Nordtest procedure, using the water transferred at an early state of the cycle to represent the performance on a shorter cycle.

7. Conclusion

The clear winner in buffer performance is unfired perforated brick. This is a material in large scale production as an intermediate stage in the making of fired perforated brick. The energy used to dry the unfired brick is derived from the waste heat from the firing process, but a small proportion of unfired brick can be removed from the production line before firing without disturbing the normal production process.

In a practical building the dusty brick will be covered. Even the permeable covering with Whatman no.1 filter paper restricted air flow into the perforations and reduced the 24 hour B-value by about three quarters. Even the long period performance was half that of the naked brick (figure 4). On the other hand, blowing air through the perforations gave nearly double the performance of the unventilated brick. These large changes in buffer performance emphasise the importance of access of circulating air to an intricately perforated or grooved surface. One must conclude that passive buffering by absorbent materials in the walls and furnishing of houses and public exhibition spaces is unable to compete with typical indoor vapour flux and air exchange rate.

For specialised use such as stores and archives, humidity buffering gives real benefit in stability and in reducing the peak load on dehumidifiers, allowing intermittent operation driven by solar energy.

8. Acknowledgements

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