Moisture Buffer Value of Building Materials

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Moisture Buffer Value of Materials in Buildings

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KEYWORDS*: Moisture, materials, transport properties, indoor air, buffer capacity, Round Robin Test.*

SUMMARY*:*
Building materials and furnishing used in contact with indoor air may have a positive effect to moderate the variations of indoor humidity seen in occupied buildings. Thus, very low humidity can be alleviated in winter, as well as can high indoor humidity in summer and during high occupancy loads. This way, materials can be used as a passive means of establishing indoor climatic conditions, which are comfortable for human occupancy, or for safe storing of artefacts which are sensible to humidity variation.

But so far there has been a lack of a standardized figure to characterize the moisture buffering ability of materials. It has been the objective of a recent (ongoing until mid-2005) Nordic project to come up with such a definition, and to declare it in the form of a NORDTEST method. Apart from the definition of the term Moisture Buffer Value, there will also be a declaration of a test protocol which expresses how materials should be tested. Finally as a part of the project, some Round Robin Tests will be carried out on various typical building materials.

The paper gives an account on the definition of the Moisture Buffer Value, it will outline the content of the test protocol, and it will give some examples of results from the Round Robin Tests.

1. Introduction

Materials that absorb moisture and release it in other periods can be used positively to reduce peaks of humidity levels in indoor climates. Indoor humidity is an important parameter to determine the occupants' perception of indoor air quality (Fang et al. 2000), and is also an important parameter as a cause of processes which are harmful to the health of occupants (Bornehag et al., 2003).

Some investigations indicate that the use of hygroscopic materials can improve the indoor climate and comfort of occupants because of the way the materials moderate the indoor humidity variations (Simonson et al., 2001).

For these reasons, and because of the role played by indoor moisture conditions on the durability of the envelope of buildings, there is significant interest in characterizing both the moisture transmitting and buffering properties of absorbent, porous building materials.

Therefore, there is a need for a robust definition of a term for the moisture buffer effect of materials, which is technically appropriate, yet comprehensible and indisputable for the industry and users that will apply it. At present there is no consensus on how to describe the moisture buffer properties of building materials.

Next to establishing the term, there will be a need to define and declare which test methods are necessary to measure the moisture buffer performance according to the definition. A Round Robin Test should also be executed in order to ensure that testing laboratories are able to handle the test methods, and to establish the first reference measurements on a limited number of representative materials.

The purpose of the NORDTEST project described in this paper is to fulfil these needs.

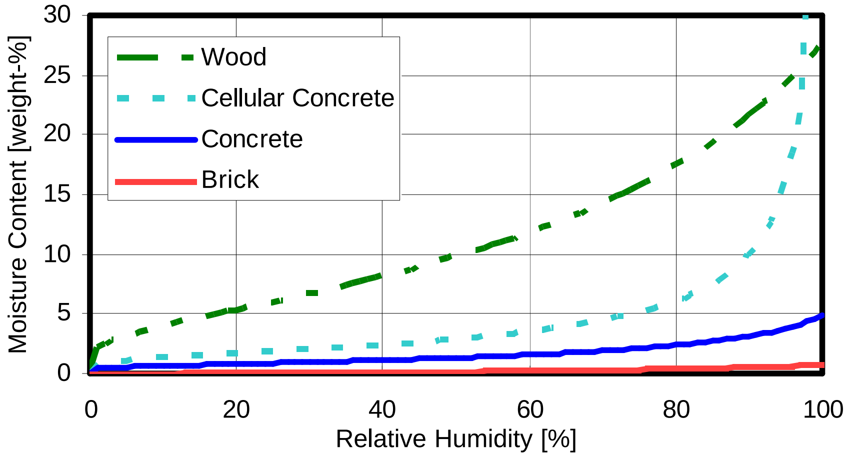

Figure 1 Sorption curves for different typical building materials. The slope of the curves indicates the specific moisture capacity.

Many Nordic building products, such as wood based products, are expected to have an advantageous moisture buffer capacity, since they are often based on organic materials which have high hygroscopicity (see the sorption curves in Figure 1). The slope of the sorption curves indicates the moisture capacity, and a material, such as wood, appears to be very well performing in this respect. However, the definition of the sorption curve is for equilibrium conditions, found in a steady state situation, and in the version of the sorption curve shown in Figure 1, it refers to the weight ratio: water/dry material. But it is not always enough to use the hygroscopicity as the only indicator of the moisture buffering ability in a situation, where transient phenomena also play a role. The property should also take the material density into account, and it should consider whether a material has sufficient vapour permeability to facilitate high transport in and out.

For instance, some silicate materials have both high density and a pore structure that is very conducive for moisture exchange, and it may compensate for a lower hygroscopicity. Thus, other materials, which are less hygroscopic than wood may perform just as well as moisture buffers. There is a need for a new parameter which combines all relevant features of a material so it is able to indicate in one number the rate and amount of moisture flowing between a material and its surrounding climate in a dynamic situation. This was the conclusion at a workshop that was arranged prior to starting the NORDTEST project (Rode, 2003).

We propose to call this desired property the *Moisture Buffer Value*. Part of the NORDTEST project also comprises development of a NORDTEST method for determination of moisture buffer value. Thus the project provides manufacturers of building products and inventory for buildings with a unit to appraise the materials.

Partners in the NORDTEST project are the Technical University of Denmark (as project leader); VTT, Finland; Byggforsk, Norway; and Lund Institute of Technology, Sweden. In addition the project is followed by an international reference group with participants from Glasgow Caledonian University, UK; INSA-Lyon, France; KU Leuven, Belgium; Fraunhofer Institut für Bauphysik, Germany; Pontifical Catholic University of Paraná, Brazil; and Faculdade de Engenharia da Universidade do Porto, Portugal.

2. Definition of Moisture Buffer Value

The Moisture Buffer Value (MBV) indicates the amount of moisture uptake or release by a material when it is exposed to repeated daily variations in relative humidity between two given levels. When the moisture uptake from beginning to end of the exposure to high relative humidity is reported per open surface area and per % RH variation, the result is the MBV. The unit for MBV is kg/(m^2·% RH). The concept of moisture buffer value can easily be appreciated and understood from an experimental standpoint, and likewise, it is relatively straightforward to measure.

The value is a direct measure of the amount of moisture transported to and from a material when the exposure is given. The value is mainly, but not only a property of the material. Also the mass transfer coefficient at the boundary plays a role, and thus, the moisture buffer value becomes a true material property only in the limit of the convective mass transfer coefficient tending to infinity. For many materials the internal resistance to moisture transport is considerably large than the convective surface resistance.

MBV has a companion definition which is based on theoretical analysis and standard moisture transport and storage properties. This is the moisture effusivity, a property which could be seen as a companion to the well-known thermal effusivity. Thermal effusivity, *b* [J/(m^2· K·$s^{½}$)], is defined (Hagentoft, 2001) as:

$$b = \sqrt{l \cdot r_0 \cdot c_p} = \frac{l}{\sqrt{a}} \qquad (1)$$

where λ is thermal conductivity [W/(m·K)],
r_0 dry density of the material [kg/m³],
c_p heat capacity [J/(kg·K)], and
a thermal diffusivity [m²/s].

The thermal effusivity can also be understood as the heat accumulation capacity of the material. It indicates the rate of heat transfer into or out of a material when its surface temperature is brought to another level. For step changes in surface temperature the rate of heat transfer into the material, *q* [W/m^2], is proportional to $\frac{b}{\sqrt{t}}$ and to the temperature increment.

The moisture effusivity is equivalent in that it indicates a material's ability to loose or gain moisture over its surfaces, when it is brought in contact an environment at another condition. Moisture effusivity, b_m [kg/(m²·Pa· $s^{0.5}$)], is given by Equation 2.

$$b_m = \sqrt{\frac{d_p \cdot r_0 \cdot \frac{\partial u}{\partial j}}{p_{sat}}} \qquad (2)$$

where d_p is the water vapour permeability [kg/(m·s·Pa)],
u moisture content [kg/kg],
j relative humidity [-], and
p_{sat} saturation vapour pressure [Pa].

The moisture buffer value, MBV, introduced in the beginning of this section can be anticipated to be proportional to the moisture effusivity times the square root of the time period, t_p, since the instantaneous moisture transfer rate, g_m [kg/m^2·s], is proportional to the moisture effusivity divided by the square root of the time, t-t_0, passed since the change of boundary condition:

$$g_m \approx \frac{b_m}{\sqrt{t-t_0}} \quad \Rightarrow \quad \mathrm{MBV} = \frac{\int_0^{t_p} g_m \cdot dt}{\Delta \mathrm{RH}} \approx b_m \sqrt{t_p} \tag{3}$$

The moisture effusivity is theoretically based on material properties which are determined under steady state and equilibrium conditions, and since the buffer property represents a dynamic characteristic, there may be some discrepancy between the appraisal of a material's moisture buffer effect whether it is based on one definition or the other. For instance, so-called non-Fickian behaviour (e.g. Håkansson, 1998) may show up in the dynamic situation, which may not be seen in the steady state. For practice oriented evaluations, one should prefer the value which is based on dynamic experiments, i.e. the MBV. However, the moisture effusivity has the elegant feature that it can be calculated based on standard moisture transport and storage properties of materials as shown by Equation 2.

3. Test Protocol

The NORDTEST project defines a test protocol for experimental determination of the moisture buffer value. The principle is based on climatic chamber tests, where a specimen is subjected to environmental changes that come like a square wave in diurnal cycles.

The test protocol proposes to use climatic exposures which vary in 8 h + 16 h cycles: 8 hours of high humidity followed intermittently by 16 hours of low humidity. The reason for the asymmetry in this time scheme is twofold: (1) It replicates the daily cycle seen in many rooms, e.g. offices or bedrooms, where the load comes in approximately 8 hours, and (2) for practical reasons during testing if the climatic chamber conditions are changed manually, it is a scheme which is easier to keep than a 12 h + 12 h shift.

The low humidity is proposed to be 33% RH, while the high should be 75% RH. However, the NORDTEST project also proposes the following alternatives: 33/54%, 54/75%, and 75/93%. Testing should always be carried out at 23°C. The humidity levels are chosen such that they can be maintained by use of salt solutions, but some other conditioning system may also be used.

Specimens will normally be sealed on all but one or two surfaces. The thickness of the specimen should be at least the moisture penetration depth for daily humidity variations, or 10 mm, whichever is larger. At least three specimens should be used for testing. Before testing, the test specimens shall be stored and initially be in equilibrium with 50% RH, or possibly with the mean RH of exposure during test.

Using an accurate scale, the specimens should be weighed continuously during the test, or if not, then at least at the beginning and end of each climatic exposure. At least five weight measurements should be carried out during the 8 hour high humidity part of the last cycle. A minimum of three cycles have to be carried out, or until the change in specimen weight over the cycle varies by less than 5% from day to day.

The results should be plotted and also be analyzed as mass change ($m_{8\ hours}$-m_0) per m^2 and per ΔRH. In addition, like in a liquid water uptake test the initial weight change after increasing RH should be plotted vs. $\sqrt{t}$ and the linear slope of the curve determined. Results should be shown for all days of investigations, but typically, only the results from the last day of testing will be reported finally.

4. Round Robin Test and Initial Results

A Round Robin Test will be carried out within the NORDTEST project to try the testing paradigm and to obtain some initial results for some typical building materials. In addition, and to guide the formulation of the test protocol, a preliminary test was carried out on some spruce plywood boards that were distributed to all project partners. For the main Round Robin, the following materials will be tested:

- Spruce panels delivered by *Wood Focus*, Finland
- Concrete from *Betonelementforeningen* and *Leo Nielsen Elementfabrik A/S*, Denmark
- Gypsum from *Gyproc AB*, Sweden
- Laminated wood from *Anneberg Limtræ A/S*, Denmark - with acrylic knot sealing varnish
- Light weight aggregate concrete from *maxit a.s*, Denmark - with a 3-layered rendering system

- Cellular concrete from *H+H Celcon A/S*, Denmark
- Brick delivered by *Kalk- og Teglværksforeningen* and *Gandrup Teglværk*, Denmark
- Birch panels delivered by *Tresenteret*, Norway

Each material is tested by three partners in the project, e.g. by the country which is responsible for delivery of the material, and two other. By the time of writing this paper, the tests are ongoing, and are planned to be completed by the summer 2005. Results are available however, for the first material, spruce panels, and will be illustrated in the following. Testing of this material was carried out by VTT, Byggforsk (NBI) and the Technical University of Denmark (DTU).

The three institutions do not have quite the same experimental equipment available and some of the operational routines were also dissimilar, although in accordance with the common test protocol. E.g., some institutes made manual weighing of the specimen, while it for others took place by automated logging. Thus, it has been part of the Round Robin Test to see if it were possible to obtain similar and agreeable results by all institutes.

Figure 2 shows a drawing and photograph of one of the climatic chambers used at the Technical University of Denmark. The humidity control of the chamber works by supplying it with either humid or dry air in an intermittent mode, such that the desired humidity in the chamber is achieved.

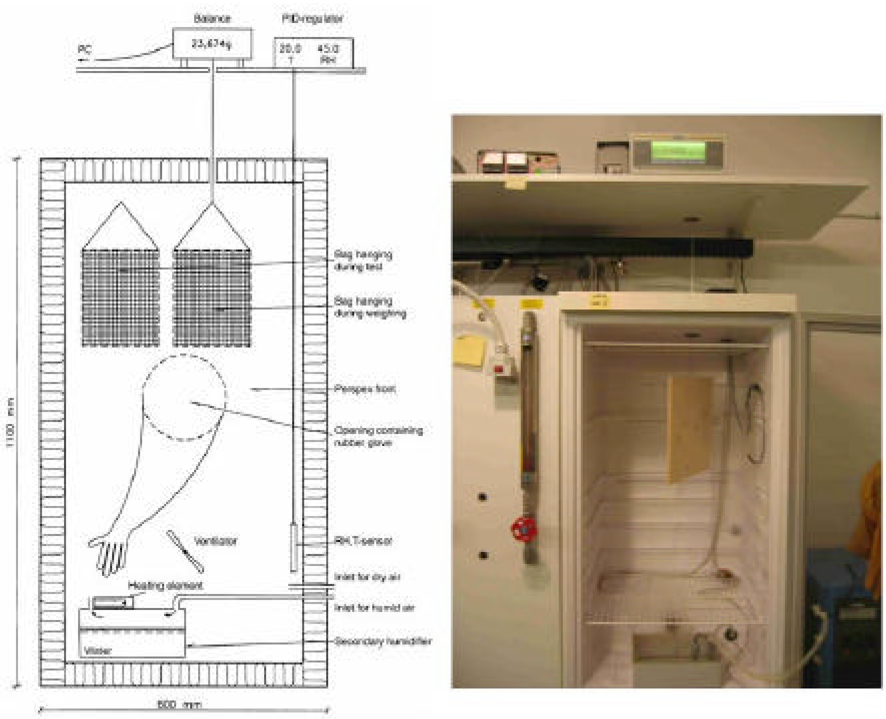

Figure 2 Drawing and picture of one of the climatic chamber used at DTU.

Figure 3 shows the spruce specimens after sealing with aluminium tape on the edges and the back side, such that the specimens are ready for test. Figure 4 shows for all specimens and all institutes who have tested this material, the results of the weighing on the last day of the cycles – typically after some 3-5 days. The results have been plotted per unit area of open surfaces, and they have been shifted to a common starting point, which is the weight at the beginning of exposure to the high humidity on the last day. The MBV is then found by dividing the weight change per area with the RH-change, which was 33 - 75% RH. The results for all specimens and institutes is shown in Table 1.

Figure 3 Picture of spruce panels after preparation so they are ready for test.

Table 1 Moisture Buffer Value [g/(m²x%RH)] of all together nine different specimens of spruce panel tested in the NORDTEST Round Robin.

	Specimen		
Institute	#1	#2	#3
VTT	1.19	1.23	1.19
Byggforsk	1.09	1.16	1.10
DTU	1.20	1.17	1.18

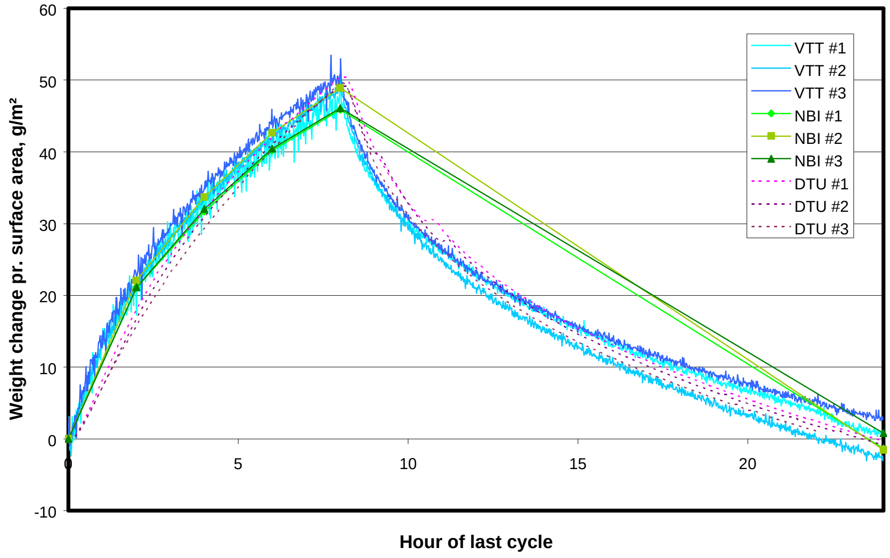

Figure 4 Spruce panels: Normalized weight change for the last day of the cycles for three specimens at each of three institutes.

Figure 5 shows the moisture uptake curves plotted vs. square root of time as measured by Byggforsk. Similar curves exist for the other two institutes (measured with more data points). The moisture uptake coefficients determined for all three institutes are listed in Table 2. There is a fair amount of agreement between the institutes' results, but most notable are somewhat higher values found from the results of DTU, and partly by VTT. This is because of a time lag in the initiation of the moisture uptake. The linear portion of the moisture-$\sqrt{t}$ relation does not occur until after half to one hour, but since the total weight increase is about the same found by all institutes, the linear part of moisture uptake becomes more steep. This problem is due to the experimental equipment not always being able to make the sudden RH changes (particular it has been a problem for DTU's testing of these specimens).

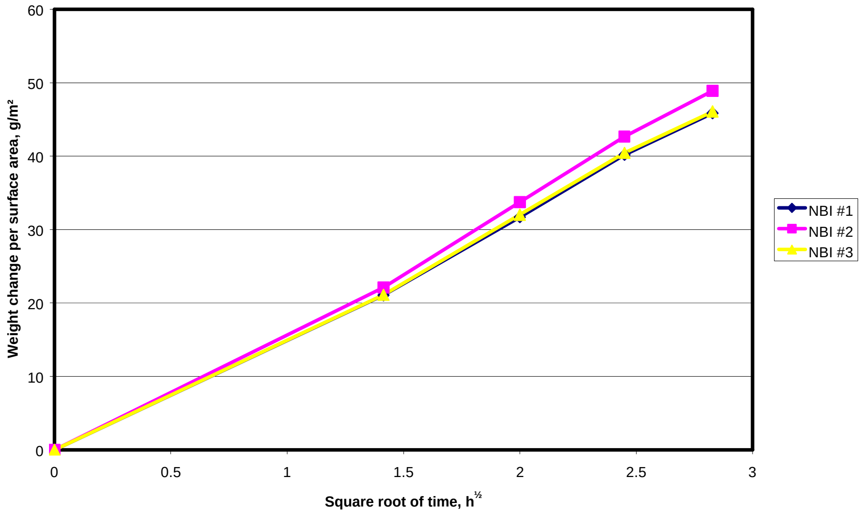

Figure 5 Moisture uptake vs. square root of time for the three spruce specimens tested at Byggforsk.

Table 2 Slope of the moisture uptake vs. square root of time curve for altogether nine different spruce panels as determined by the institutes [g/(m^{2}xh^{½})].

	Specimen		
Institute	#1	#2	#3
VTT	18.9	19.8	20.3
Byggforsk	16.4	17.4	16.5
DTU	23.1	23.1	23.6

5. Practical application of the Moisture Buffer Value

The Moisture Buffer Value is primarily meant as a number that can be used to appraise a material's ability to absorb and release moisture from an adjacent space. For practical application it can also be useful as a number for estimation of the moisture balance of rooms, as indicated by the following example.

5.1 Example

A room has dimensions 4 x 5 x 2.5 m, and thus a volume of $V = 50$ m^3. The occupancy and activity in the room releases $G = 100$ g of moisture per hour. The room is clad with $A = 45$ m^2 wall panels of spruce board with MBV = 1.2 g/(m^2·ΔRH). Initially the room is assumed unventilated, and the storage capacity of the room air is neglected. By how much will the indoor humidity increase during a working day (8 hours)?

All the released moisture is absorbed by the spruce board, and thus, the increase in indoor relative humidity can be calculated from the amount of absorbed moisture, and the moisture buffer value of the wood:

$$\Delta RH = \frac{G \cdot \Delta t}{\mathrm{MBV} \cdot A} = \frac{100\,\mathrm{g/h} \cdot 8\,\mathrm{h}}{1.2\,\mathrm{g/(m^2 \cdot \%RH)} \cdot 45\,\mathrm{m^2}} = 15\,\%\mathrm{RH}$$

In comparison the RH would increase in principle by about 90 % RH (or condensation would occur before then) if there were no ventilation or absorbing materials – this is evaluated at 20°C.

Finally, if the room were ventilated at an air change rate of $n = 0.5\ \mathrm{h}^{-1}$, the indoor humidity would in an equilibrium situation have an indoor vapour concentration, *n*, which is higher than the outdoors by:

$$\Delta n = \frac{G}{n \cdot V} = \frac{100\,\mathrm{g/h}}{0.5\,\mathrm{h}^{-1} \cdot 50\,\mathrm{m}^3} = 4\,\mathrm{g/m}^3$$

At 20°C this would correspond to 23% RH higher indoor relative humidity compared to the same room without moisture release.

These calculations are too simplistic to fully represent the real dynamic conditions of a room which is influenced by both ventilation, and buffering of room air and materials. However, it indicates some orders of magnitude and renders some possibility to reflect over which parameters are important to govern indoor humidity variation in an indoor space with occupancy and cladding with various materials.

6. Conclusion

The described work will declare a uniform definition of a term such as *Moisture Buffer Value* as well as an experimental protocol for its determination. *Moisture Buffer Value* can be used to appraise the ability of materials used in buildings to moderate indoor humidity variations. The term should replace an inconsistent variety of other numbers used till now to appraise this quality of building materials. The definition and test protocol will be tried out by the execution of a Round Robin Test, in which the first results for some examples of common building materials will be determined. The results of the described project will be published in the form of a NORDTEST method.

7. Acknowledgement

The companies or trade organizations mentioned in the list of materials used in the Round Robin Test (Section 4), have contributed financially to the project and by delivery of materials for testing. Their support is gratefully acknowledged.

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