BYG·DTU

NORDTEST

Workshop on Moisture Buffer Capacity

- Summary Report

DANMARKS
TEKNISKE
UNIVERSITET

DTU

August 21 – 22, 2003

Department of Civil Engineering
Technical University of Denmark

Edited 05.09.2003 by:
Carsten Rode, Technical University of Denmark (DTU), with contributions from:
Kurt K. Hansen (DTU), Tim Padfield (Conservation Scientist), Berit Time (Norwegian Building Research Institute), Tuomo Ojanen (VTT) and Jesper Arfvidsson (Lund Institute of Technology).

Department of Civil Engineering,
Technical University of Denmark

www.byg.dtu.dk
NORDTEST project nr.: 02x820

Summary

This report gives an account of a workshop on Moisture Buffering Capacity of Building Materials held August 21 – 22, 2003, at the Technical University of Denmark.

Moisture Buffering Capacity and related terms are often heard as an appraisal of building materials and other materials used in indoor furnishing to express the ability of the materials to moderate the daily or seasonal variations of humidity. This moderation may have a positive effect on occupants' perception of the indoor air quality, and it may have an effect on mechanisms that degrade the materials or cause indoor air problems, e.g. mould growth. However, there is currently a lack of a stringent definition of the term, and therefore the building industry and building owners do not have the right means to judge appraisals of moisture buffer capacity.

The report documents the activities during the workshop: Invited lectures on the first day, and work group and plenary discussions the second day. There were five themes for the work group discussions, see the *Introduction* for an overview of these. The intent of the workshop was mainly to determine whether there was background for continuing work on definition of a stringent term for moisture buffer capacity and to elaborate on related test methods, and the relevance for industry. The conclusion was *yes*, and follow-up activities should be prepared. The workshop also found the relevance in starting some dissemination activities about the subject targeted both for the academic world and for practitioners and industry.

The summary report focuses on the main results of the work group discussions. The summaries of work group discussions have been written by the different work group conveners, and may therefore differ somewhat in form. It should be noted also that not all views and input discussed in the work groups have found way to the short summaries. It would require too detailed elaborations to explain all supplementary views and input in this Summary Report, and in many cases, the groups were not conclusive in these discussions. It is our anticipation that a follow-up project could enlighten all relevant input.

The input given in invited presentations on the first day of the workshop, as well as other input supplied by all workshop attendants, was assembled in an abstract collection that has been distributed to the participants before coming to the workshop. An index of this input can be seen in Appendix D. The preprints are available as .pdf by request to Carsten Rode, car@byg.dtu.dk.

Contents

Introduction

There exists an increasing interest among building practitioners in the building industry to employ moisture buffering materials to moderate the indoor humidity and, allegedly, create healthier indoor climates which should also be better for the protection of objects kept in the indoor environment. However, there exists no clear and unique definition of this term. *Effective* (or *active*) *moisture penetration depth*, *moisture capacity*, *available water*, or *moisture effusivity* are examples of terms that are used in literature to represent various forms of the moisture buffering capacity of materials, but it is evident that clarification and stringency should be defined better for these terms. And it must be defined how the terms relate to each other.

In addition, it may be suspected that this lack of stringency also in some cases leads to misunderstandings where moisture buffering materials are used in the wrong way such that desired moisture storage effect cannot be deployed to the desired extent, or at worst such that degradation of materials due to moisture accumulation occurs.

It is anticipated that the increased awareness of moisture buffering that arises from having a well-defined unit for its measure will lead to better choices for materials that are used in contact with indoor air.

Purpose and aim of the Workshop

There is no generally accepted definition of moisture buffering capacity even though it is becoming a commonly used phrase in building design. The purpose of this workshop has been to gather a group of experts to discuss suitable definitions and to write a joint paper, which lays the theoretical foundation for continuing practical work on developing a usable standard for measuring moisture buffer capacity of building materials and constructions.

The analogy between heat and moisture movement has dominated discussion and computer modelling of moisture movement, yet the analogy with thermal properties such as heat capacity and diffusivity, while close is not sufficient, because of the slowness of moisture movement and its complicated penetration pattern. It could be suggested that a different approach to defining buffer performance is needed, or will at least be useful, as an aid to architects and building engineers.

The aim of the NORDTEST workshop has been to discuss possible definitions of Moisture Buffer Capacity and to discuss its feasibility as a term to be used in building design and analysis. The workshop was held at the Technical University of Denmark, August 21-22, 2003. Altogether 31 people participated in the workshop – mainly from academia but also from the building materials industry and consultants. 21 of the participants were from the Nordic countries, while the workshop also attracted 10 experts from other countries. The program and the participant list are attached as Appendix C of this report.

Participation in the workshop was by invitation to some 55 experts from academia who have in recent years shown interest or research activity in the area of moisture buffering of building materials. The invitation was also extended to representatives of different building material manufacturers, or their organizations. With the invitation was sent a small background document, which can be found as Appendix A of this report.

While signing up for the workshop, the participants also submitted an abstract or paper explaining their experience, skill or interest in the subject. These written contributions were collected and sent as a working document to the participants before the workshop. The content list of the Collection of Abstracts is attached as Appendix D of this report.

The workshop started the first day with presentations by invited speakers. On the second day five working groups were formed to discuss the following issues:

1. Which quantity to standardize?
2. Experimental techniques - what should one measure?
3. Reference material/start of Round Robin
4. Commercial application and exploitation
5. Modelling - can we extrapolate?

The program for the Workshop is attached as Appendix B of this report. The structure of this report follows the work group subjects.

Plenary sessions pulled together the results of the group deliberations. Finally, the whole group of participants discussed possibilities for continuation of the work of defining a measurable standard for moisture buffer performance. Also discussed were initiatives for academic and general dissemination of the information of the workshop.

As a technical tour the participants of the workshop visited the Museum repository of the National Museum of Denmark in Brede. The principle for conditioning of the repository is one of *Passive Climate Control*, where the buffer capacity of the stored objects plays a significant role in maintaining the constant humidity which is so important for them. The visit was kindly guided by one of the workshop participants, Dr. Lars Christoffersen, Birch & Krogboe A/S, and made possible by the kind co-operation of the National Museum of Denmark.

1. Which quantity to standardize?

WG 1 members:
Univ.-Prof. Max Setzer
Morten Hjorslev Hansen
Prof. Hugo Hens
Nuno Ramos
Prof. Carl-Eric Hagentoft, convener
Carsten Rode, convener

The purpose of the discussion was to outline some candidate quantities for declaration of the Moisture Buffer Capacity (MBC) of materials. The quantities should be scientifically rigorous in their definition, yet also comprehensible to the users.

Declaration of scope

The discussion started around the declaration of the scope for the new quantities. This was agreed as:

- The quantity should deal with material/air interactions. Thus, the utilization of moisture buffer effect *within* constructions to alleviate critical moisture uptake associated with internal moisture uptake and redistribution was considered as being out of the scope.
- Only periodic variations are of interest after quasi equilibrium has been attained. Thus, for instance drying out of built-in or “construction” moisture, or adaptation to a new use of the building, should be seen as out of the scope.
- The Moisture Buffer Capacity (MBC) should be established for “normal” indoor climates (no extremes). It must be realized that since the moisture transport vary non-linearly with the humidity level, it is important to know at which level it is determined. This caused some discussion about what “normal” would mean, since the normal would probably have to reflect regional and seasonal variation. An upper limit could be seen as the one where degradation mechanisms, such as mould growth or corrosion, become critical. Also extreme low humidity was seen as irrelevant. Reasonable choices could be to indicate MBC at 50% and at 75% RH. It would make sense to declare climate zones of validity for the chosen levels at which MBC is reported.
- For MBC numbers where the cycle duration is important (e.g. for the *penetration depth*) it would be most relevant in most buildings to observe daily variations. However, it should be acknowledged that also other periods may be relevant in some applications, e.g. weekly or annual.
- For analytical derivations of the terms that may be used, it is assumed that the conditions are quasi-linear. This is a reasonable assumption for moderate humidity variations in moderate humidity regimes – e.g. around 50% RH. However, it will be necessary to declare the RH level at which properties are taken - they will to some extent be different at other RH levels.

Essential Subjects

- An easy number to associate with Moisture Buffer Capacity is *moisture uptake* and release [kg/m^2] at a given cyclic change in boundary condition RH and period – or after a certain step change in humidity condition. This number can be determined experimentally by weighing specimens that are subjected to periodic (or step) humidity variations.
- Another intuitive number is the *Penetration depth*, i.e. the depth into a material at which a

certain periodic variation at the surface can be registered. This definition can also be calculated analytically. For instance, the depth at which the amplitude of variation at the surface is reduced to 37% can be calculated as: $d_p = \sqrt{D_w t_p / \pi}$, where D_w is the moisture diffusivity and t_p is the period.

- *Moisture effusivity*. The moisture effusivity is defined from the equivalent thermal term. The moisture effusivity is a material property that signifies the rate and amount of moisture intrusion after a given change in the boundary condition. It can be calculated as a number which is proportional to the square root of the product of the vapour permeability and the slope of the sorption isotherm (or “moisture capacity”): $\sqrt{\delta \cdot \xi}$. It can also be shown to be proportional to the product of the penetration depth and the moisture capacity: $d_p \cdot \xi$. The latter term is also referred to as *available water* which can also be seen as a rather intuitive definition. So the two terms *moisture effusivity* and *available water* should be regarded as synonymous.

Relationships to elementary material properties. From the analytical definitions above follow that penetration depth, moisture effusivity and available water can be calculated from elementary material properties: Water vapour permeability and the sorption curve. The sorption curve can be either based on moisture uptake pr. volume of the material or pr. mass of the material. In the latter case, it is also necessary to know the density of the material, which of course is also an elementary material property.

The properties for Moisture Buffer Capacity introduced above can be defined so they also allow consideration of a film coefficient and possibly a paint/rendering layer at the surface of the material.

With these definitions it could be realised that the MBC can be on either of two levels:

1. Either it can be seen as a new property of a *material* - basically an extension of existing and well known material properties for moisture transport.
2. On the other hand MBC definitions can also be used to analyse and declare properties of building *systems* (e.g. wall and paint) for the way in which they interact with the adjacent climates.

Advanced Analysis

Theory for more advanced analysis exist for studying moisture buffer properties of materials and systems. However, this involves more advanced mathematical optimisation methods that are seen as beyond the scope of the actual project, where we look for easy identifiable numbers about the moisture buffer properties of materials.

To analyse the utilisation of moisture buffer capacity in a real room means that one has to consider also the ventilation conditions, other moisture sources/sinks in the room, and it may be relevant to observe thermal bridges etc. for the building envelope. All these factors are relevant and should be regarded in for instance computer models for whole rooms. However, it is seen as beyond the scope for the actual project.

Examples of application

It would be very useful to illustrate some examples of application of the knowledge about moisture capacity of building materials. The theme that would run through such examples will be "Reducing the peaks” (of room humidity variations). Examples could be:

- Will good moisture buffer capacity reduce the humidity in an office by the end of the day (thereby improving acceptability of the air, and increasing productivity of office workers)?
- Will good moisture buffer capacity help keeping the humidity levels down in bedrooms during night occupancy?
- For high RH-levels: Can good moisture buffer capacity help alleviate short, extreme loads, such as in bathrooms?

2. Experimental techniques - what should one measure?

WG 2 members:
Lars-Erik Harderup
Poul Klenz Larsen
Monika Woloszyn
Georg Christensen
Lone G. Hedegaard
Tim Padfield, convener
Kurt K. Hansen, convener

We propose applying to the specimen surface a square wave in RH, stepping at 12 hour intervals between 40% and 60% RH. The temperature is held constant, somewhere between 22C and 25C. The specimen is weighed continuously. The result is presented in two formats. The single number format is the peak to peak difference in specimen weight expressed as kg of water per second per square metre of exposed surface area (that is the SI formalism, in practice probably quoted as g/m2/12 hours). The second format is a continuous curve of the weight per square metre for a typical cycle, with the average weight subtracted.

Initial specimen conditions are not specified but there must be a reasonable (as yet undefined) repeatability in the cycles used for the final measurement. There is no requirement for effective infinite depth of the specimen, because the test is for both materials and for constructions. If more depth of penetration information is thought necessary, the test can be repeated with different thicknesses of the same material.

This test provides a simple figure of merit which can be used in rough order of magnitude calculations of expected RH variations dependent on water vapour production in the room, outside climate and air change rate. The continuous curve provides the experimental data for deriving the material properties required by the standard model of moisture diffusion - diffusivity, depth of penetration, water capacity and diffusion rate constant. The square wave provides, in principle, information at all time scales up to 24 hours.

Variations suggested on theoretical grounds

Use just one long cycle, which should encapsulate all the necessary information for modelling, but would not provide an instantly usable daily buffer figure of merit.

Use 8 hours high - 16 hours low, to give a better imitation of actual use of house or office.

Variations suggested on practical grounds

Use 8 hours high - 16 hours low, so the lab worker can throw the switch at start and end of the working day.

Use a sine wave RH variation, or a triangular waveform. Both require less capacity from the air conditioning equipment (note that the temperature must be held constant while the RH changes violently). This only matters for materials which buffer very strongly initially, such as an open paper structure.

The practical implementation of the principle

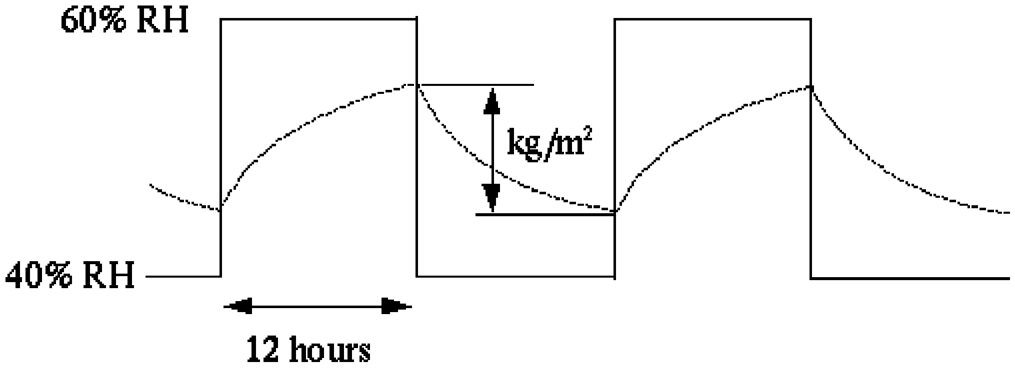
There shall be two scales of measurement

The lab bench scale can easiest be realised by weighing the entire specimen while it is suspended in a reaction chamber whose RH is controlled. The exact method of control must depend on further debate and experiment.

The large scale measurements can be on the whole room scale. It is then more practical to keep track of the exchanged water by measuring water loss and gain to the humidity controller, rather than weighing an office suite with chair, table and scattered documents. This can be done by evaporating water from a weighed container, and returning water from the dehumidifier to the same container. It is very difficult to generate a square wave in this system, so a triangular waveform or a sine variation would be much easier. This raises the problem of how to compare small scale material tests with room scale tests. It may be that we have to settle for a triangular or sine waveform in the small scale test, which is more difficult to do!
This seems to be a good subject for a Nordtest supported development project.

The test outlined above should give both intuitively interpretable data as well as allowing derivation of the parameters required by the theoreticians and modellers. However, we considered an additional test which could provide useful parallel information. This test is a modification of the cup test for water vapour permeability, adapted to the very permeable and thin materials which could be considered useful for moisture buffering in rooms. This test eliminates the uncertainty in transport through the stagnant air under the test specimen by inverting the cup so that the salt solution lies directly over the test specimen, with a semi-permeable membrane between. The resistance of the membrane is deduced by repeating the experiment with several different thicknesses of the test material.

We did not debate this proposal in detail for two reasons. One was time and the extra complication of presenting a second experiment to general debate. The other is that the static water vapour permeability is of doubtful use in modelling dynamic situations because it actually measures diffusion through the spaces within an already equilibrated material and is probably not specially a property of water vapour.



Principle Diagram

3. Reference material/start of Round Robin

WG 3 members:
Kaisa Svennberg
Prof. Graham Galbraith
Ruut H. Peuhkuri
Gorm Rasmussen
Prof. Anker Nielsen, convener
Berit Time, convener

Introduction

“What could be a reference material ?” was one of the issues discussed in the workshop. One could think of a reference material as a material or as e.g. indoor climate-data measurements from a building. Such climate-data measurements will typically contain hourly values of relative humidity and temperature. Climate-data measurements of this kind could be used in order to validate numerical models. Only reference material as a material has been considered.

In the discussion it was stressed that it would be an advantage that several institutes should perform a Round Robin test on the reference materials. This will give us an accuracy level of the measurements and it will be possible to evaluate the measurement methods.

Many researchers have done work on materials being exposed to step-functions. One task in a future work could be to collect what exist of such work.

Possible materials

There should preferably be more than one reference material. When considering materials suitable for moisture buffering one approach could be a classification system e.g. *low, medium and high moisture buffering capacity*. It would also be an advantage scaling *fast and slow* sorption materials. Considering all this it would be an advantage having a reference material in each category.

There was agreement about reference materials not being organic materials and being as homogeneous as possible. Materials having been used before in earlier project /experiments is to be preferred. For a start we think of materials representing those parts of a building envelope that directly interfere with the indoor air and also furniture etc. Materials within a construction are omitted.

The following materials are possible materials that were suggested

- plaster substrate (e.g. gypsum board)
- painted plaster substrate (e.g. gypsum board)
- aerated concrete
- textile materials (not building material)
- reference material for cotton textile (according to a British textile measurements standard ?)

- “Vycor glass” – a previously used reference material, a homogeneous material with a well defined pore structure

Plaster substrate with and without paint is proposed. By doing a Round Robin test on plaster substrate and painted plaster substrate we can also gain new information on measurement on painted materials.

The number of reference materials is also a matter of possible funding.

4. Commercial application and exploitation

WG 4 members:
Lars D. Christoffersen
Claus Rudbeck
Kurt Stokbaek
Poul Erik Hjort
Sergio Fox, convener
Tuomo Ojanen, convener

Background
As background discussion, some questions were aroused and preliminary answers were given basing on the existing information.
Does the moisture buffering effect exist? Yes, there is such an effect between material layers and adjacent air, like between structures and indoor air.
Does it have an effect (in buildings)? Yes, the effect has been shown both in numerical simulations and in some laboratory and field studies.
Is the effect positive? This effect is most probably positive for indoor air and structures.
Has it been studied enough? More tests and demonstrations need to be carried out to show the benefits in practice.

Promoting of the system
Moisture buffering effect needs promoting before commercial exploitation is possible. It is important that the concept of moisture buffering system will be generally known and accepted (also in public), which would then create demand for it. Also contacts with architects, health care people and those dealing with allergic problems are important.

Risks
Risk of loosing credibility if the phenomenon was sold /marketed using incorrect argumentation. It was noted that there exists this kind of, possibly misleading, interpretation of the performance of so called 'breathing structures'. Also false, malfunctioning applications may lead to moisture problems, for example, if the air change rate was lowered due to 'breathing' structures.

Demos and field trials
Solid scientific investigations are needed to demonstrate the performance and benefits for indoor air quality and structures of the system.

Database

There already exists a lot of information about the findings in this area. Unfortunately the information is not always easily accessible and therefore a common database or other kind of forum would be needed to collect and distribute information.

Test method

A new test method is needed to quantify the moisture buffering effect. This method should give one easily understandable and in reality applicable value. This is needed to be able to evaluate the moisture buffering performance of materials and multi-layer structure systems.

5. Modelling - can we extrapolate?

WG 5 members:
Heiko Fechner
Ian Ridley
Theodore W.C. Chen
Prof. Nathan Mendes
Dr. Andreas Holm, convener
Prof. Jesper Arfvidsson, convener

Defining the question.

Most people in the work group had a background in working with moisture calculations and numerical methods. We started with defining the meaning of the question: Can we extrapolate? After a short discussion we found two questions to answer:

- Is it possible to use the moisture buffering capacity from the single material to model the buffering behaviour in a construction, a rooms and even a whole house?
- How to do it?

Yes, it is possible to model the buffering behaviour.

The group didn't spend much time to find the positive answer to this question. The modelling abilities today are not the limitation in the process to find the buffering behaviour in a construction. If the material properties and the boundary conditions are known, the effects of the buffering capacity for a construction can be calculated.

How to do it

Moisture buffer catalogue

The first idea in the group was to make a "moisture buffer catalogue" for single materials and often used constructions. The calculation method could be standardised. The catalogue could be used as a design tool, putting materials and constructions together to a room or a whole house. A second model, using the results in the catalogue to determine the behaviour in a room or a house should be developed and standardised. After a while the group found that it would be very difficult to create such a catalogue. The number of parameters and variations are too many.

New models based on existing knowledge

Our second idea was to use the work already made in CEN.

- Hygrothermal performance of building components and building elements Assessment of moisture transfer by numerical simulation (CEN TC 89 WI 29.3)
- Thermal building simulation (CEN, VDI 6020)

Models that fulfil the criteria's stated in these standards should be combined to a new hygrothermal model.

New strong validation

The result from the new hygrothermal model should be validated, in a standardised way, against measurements at different levels:

- Isothermal behaviour with changes in ventilation or/and moisture production
- Nonisothermal with changes in ventilation or/and moisture production or/and heatproduction

Limitations

Identified problems areas are: Aging, hysteresis, initial conditions, built in moisture, user behaviour, timescales, changes in material, chemical processes.

Conclusion and follow-up

The meeting concluded with a consensus about the need for a formal declaration of a term for Moisture Buffer Capacity. It would be relevant to elaborate on the necessary testing methods to determine the moisture buffer capacity for building materials and systems as well as for material used in indoor furnishing. To exemplify the measurements, and to train laboratories and manufacturers in handling of the new test method, a round robin exercise should be carried out. The new term should be explained to the industry such that they could benefit from the rigorous definition in maturing this feature in their product development and marketing. As a supplement, using the definition of moisture buffer capacity, one should make analysis of the importance of moisture buffer materials in relation to other means to maintain moderate humidity levels in indoor environments, e.g. ventilation or reduction of moisture sources.

A working group consisting of Berit Time, Byggforsk; Tuomo Ojanen, VTT; Jesper Arfvidsson, LTH; and Kurt K. Hansen and Carsten Rode, DTU would prepare a proposal for a follow-up project where the above mentioned topics will be dealt with. The proposal will be sent to NORDTEST for the September 15, 2003 deadline. As international reference for the proposal, Graham Galbraith, Monika Woloszyn, Hugo Hens, Andreas Holm, Nathan Mendes, and Nuno Ramos indicated their willingness to support the proposal. In addition, as much as possible should be done to gather the interest and support of industry (building materials and indoor furnishing) for the further elaboration of the topic in a new NORDTEST project. Each of the core partners will be responsible for establishing contacts with industry.

It was found relevant already now after the workshop discussions to start some dissemination activities about the Moisture Buffer Capacity subject. Two directions were discussed for the dissemination:

1. Communication to the academic world about the workshop and its results. This should be done in a research journal, although for the moment there are no research results as such to present. It was decided to submit the communication in the form of a “technical paper” (as opposed to a “scientific paper”) for Journal of Thermal Envelope and Building Science. A group consisting of Andreas Holm, Nathan Mendes, Monika Woloszyn, Carl-Eric Hagentoft, Kaisa Svennberg, Heiko Fechner, and Carsten Rode would contribute to this paper.
2. In addition there would be a need for more popular dissemination about the topic aimed at people in the building industry. This dissemination would often take place on a local/national level. It was agreed to exchange as much as possible information of this kind among the workshop participants in the near future.

APPENDIX A – Introductory note: How do we define Moisture Buffer Capacity?

Introduction

There exists an increasing interest among building practitioners in the building industry to employ moisture buffering materials to moderate the indoor humidity and, allegedly, create healthier indoor climates which should also be better for the protection of objects kept in the indoor environment. However, there exists no clear and unique definition of this term. *Effective* (or *active*) *moisture penetration depth*, *moisture capacity*, *available water*, or *moisture effusivity* are examples of terms that are used in literature to represent various forms of the moisture buffering capacity of materials, but it is evident that clarification and stringency should be defined better for these terms. And it must be defined how the terms relate to each other.

In addition, it may be suspected that this lack of stringency also in some cases leads to misunderstandings where moisture buffering materials are used in the wrong way such that desired moisture storage effect cannot be deployed to the desired extent, or at worst such that degradation of materials due to moisture accumulation occurs.

It is anticipated that the increased awareness of moisture buffering that arise from having a well-defined unit for its measure will lead to better choices for materials that are used in contact with indoor air.

Purpose and aim of the Workshop

There is no generally accepted definition of moisture buffering capacity even though it is becoming a commonly used phrase in building design. The purpose of this workshop is to gather a group of experts to discuss suitable definitions and to write a joint paper, which lays the theoretical foundation for continuing practical work on developing a usable standard for measuring moisture buffer capacity of building materials and constructions.

The analogy between heat and moisture movement has dominated discussion, and computer modelling of moisture movement, yet the analogy with thermal properties such as heat capacity and diffusivity, while close is not sufficient, because of the slowness of moisture movement and its complicated penetration pattern. We suggest that a different approach to defining buffer performance is needed, or will at least be useful, as an aid to architects and building engineers.

Therefore the aim of the NORDTEST workshop is to find a definition of Moisture Buffer Capacity. The workshop will be held at the Technical University of Denmark, August 21-22, 2003. The preliminary program is enclosed in the end of this document.

The workshop will start with presentations by invited speakers, then assembled experts will split into working groups to discuss various aspects. A plenary session will pull together the results of the group deliberations. Finally the whole group will work on a paper giving recommendations for practical work towards establishing a measurable standard, or a set of standards, for moisture buffer performance.

Moisture Buffer Capacity

In a general way, moisture buffer capacity can be defined as a material's ability to reduce moisture variations within an enclosure. For example instead of RH variations oscillating between say 40 – 80 % RH due to indoor activities, proper use of moisture buffering material variations can be reduced to 55 – 65 % RH, or maybe even less.

Some of the properties that influence the buffer capacity are: Moisture capacity, water vapour permeability, density and cycle time.

- The *moisture capacity* is expressed by the gradient of the sorption isotherm. Since the sorption curve is not linear it is important to use the gradient for the actual variation of moisture.

- *Water vapour permeability* is a material parameter that describes the amount of water that can move through the material.

- *Density* is also a material parameter. The density is of importance since a material with a great moisture capacity and a low density has only a small ability to contain water as opposed to a material with a higher density.

Several different ways of defining moisture buffer capacity have been suggested. In the following some of them will be presented as inspiration for the upcoming discussion. It is not an intention to show all different ways of defining moisture buffer capacity.

Derived from the thermal effusivity a buffer effect can be described as a *moisture accumulation ability* (or *moisture effusivity*?), which derives from density (ρ), vapour permeability (δ_p), moisture capacity (ξ), and the saturation pressure (p_s).

Moisture accumulation ability: $\sqrt{\dfrac{\rho \cdot \delta_p \cdot \xi}{p_s}}$

The unit for the moisture accumulation ability becomes [$\mathrm{kg/(m^2 \cdot Pa \cdot s^{1/2})}$].

This expression does not take the cycle time into consideration. In the following figure is shown calculated moisture accumulation abilities for various materials.

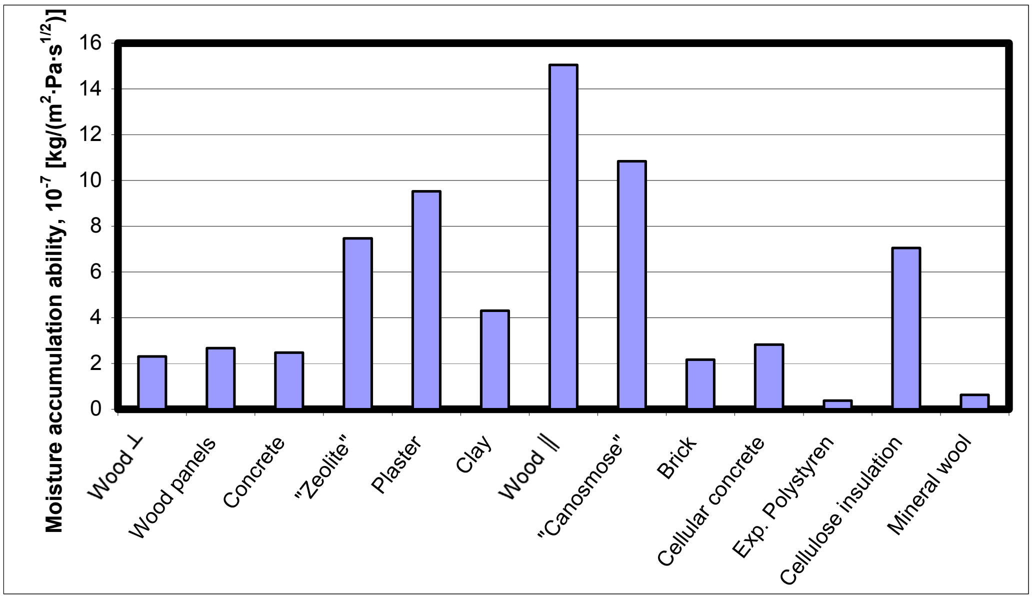


Figure showing moisture accumulation ability for several building materials.

Penetration depth is also a combined parameter. It comprises cycle time, water vapour permeability, saturation moisture content in the air (highly temperature dependant) and the moisture capacity. The penetration depth gives the active layer of a construction.

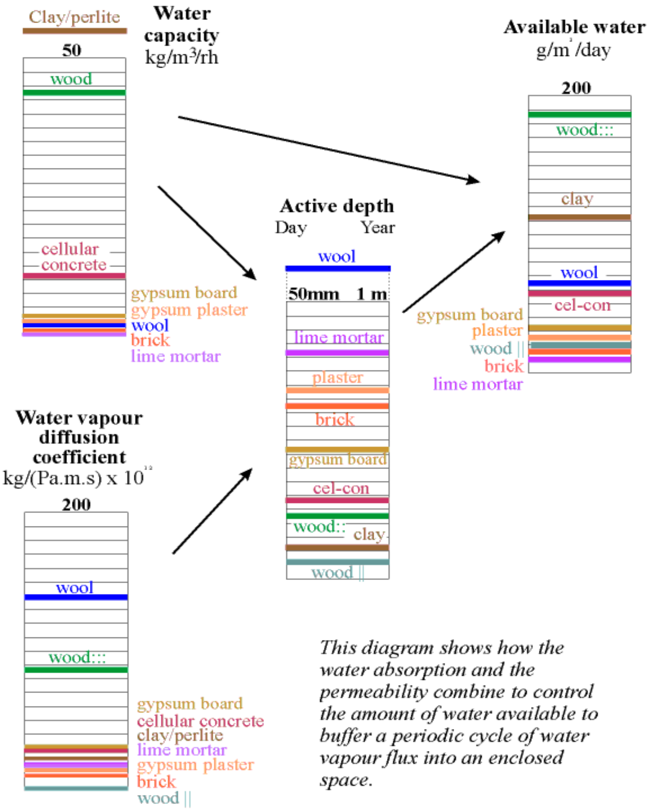
Here is an example where the buffer effect depends of the penetration depth.

Tim Padfield (Padfield, 1999) uses the term, *available water* during a given period, to compare moisture buffer capacities for different materials.

The available water is given by the moisture capacity (ξ) and the penetration depth (d_p):

$$\xi \cdot d_p$$

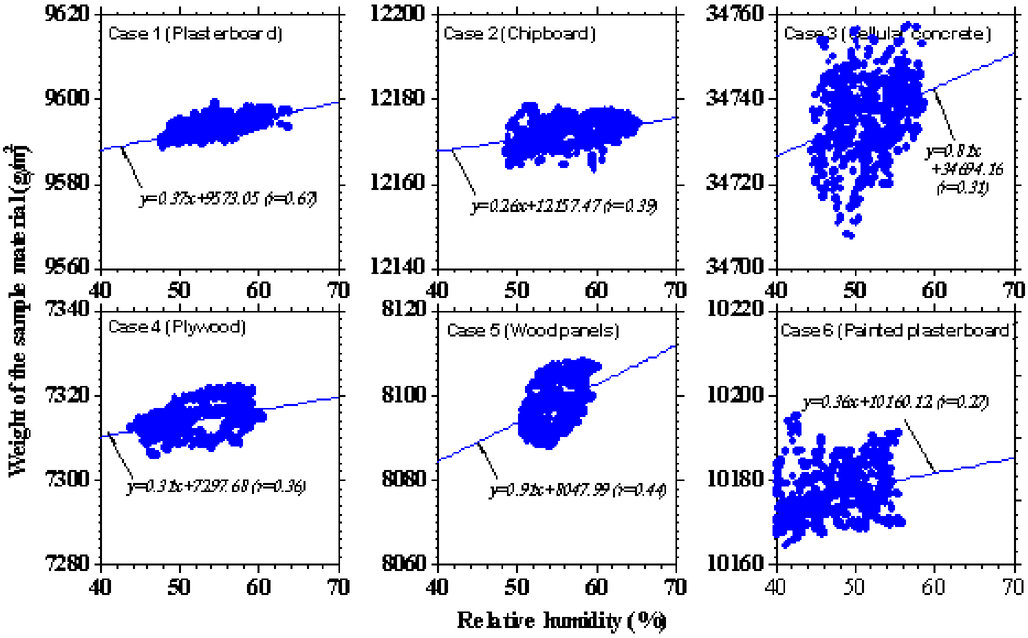
The unit for the available water becomes [g/m^2/day].



This diagram shows how the water absorption and the permeability combine to control the amount of water available to buffer a periodic cycle of water vapour flux into an enclosed space.

A so-called *Feuchtepufferefunktion* was introduced by researchers from University of Essen and an overview of its declaration can be seen on the web-page http://www.feuchtepufferfunktion.de/

(Mitamura et al., 2001) introduced yet another way to express the buffer capacity. The weight of a tested sample as a function of variation in ambient RH was used. The drawback of this method is that it requires all materials to be tested experimentally.



This way of expressing the moisture buffer capacity has the unit [g/($m^2 \cdot$ %RH)].

The lack of an agreed definition of moisture buffer capacity makes it difficult to make comparisons. Firstly because of the different units and secondly because it is unclear which parameters are the most important.

Additional issues to discuss

Some of the other factors that have an effect on the moisture buffer capacity are:

- ventilation
- surface texture
- furniture
- absorption of other substances than H_2O
- less ventilation in buildings than usual
- surface treatment

An example is: there is no point in calculating a possible moisture buffer effect if the ventilation rate is too high, because the materials need time to react.

Other questions for discussion could be:

- What is the use of an interest in the building materials' moisture buffer capacity if the materials are surface treated with somewhat vapour tight coatings, and:
- Is the indoor furnishing much more important than the materials of the building structure/surface?

Experimental setups

During experimental testing there are some other issues that need to be addressed:

- How shall a typical daily variation be expressed?
- Should there be introduced standardized surrounding conditions?
- What kind of wave type should be used?
- What is the ability of experimental equipment?

An example could be a sine curve or a triangular curve. It must be kept in mind that the chosen wave is supposed to be a model of every day life. Another issue could be to consider the influence of the surface airflow-

References

Harderup, L.-E. (1998), ‘Luftfuktighet inomhus med hänsyn till icke-stationära fenomen - Sammanställning av publiceringar under perioden 1979 - 1998’, Rapport TVBH-3033

Mitamura, T., Rode, C. and Schultz, J., Full scale testing of indoor humidity and moisture buffering in building materials, ASHRAE Conference Indoor Air 2001

Padfield, T., Humidity buffering by absorbent materials in walls, 1999, http://www.natmus.dk/cons/tp/wallbuff/wallbuff.htm

Dipl. Ing. M. Reick and Univ.Prof. Dr. rer.nat. Dr.-ing. habil. M.J. Setzer, Various articles dated 1994-2000, http://www.feuchtepufferfunktion.de/

APPENDIX B – Agenda for Workshop

Agenda for NORDTEST Workshop on Moisture Buffer Capacity, Technical University of Denmark, August 21-22, 2003. (As realized with slight changes on the second day compared to the original plan).

Thursday, August 21

09:00 – 12:00 M.Sc. Ruut Peuhkuri defends her Ph.D. thesis on:
“Moisture Dynamics in Building Envelopes”
Supervisors: Carsten Rode and Kurt Kielsgaard Hansen.
Everyone is invited to attend!

12:00 – 14:00 Reception

14:00 – 15:00 Introduction to NORDTEST
Introduction to the concept:
Overview on existing definitions for "Moisture Buffer Capacity"
Short introductory contributions from the NORDTEST partners:
- Norwegian Building Research Institute (Dr.Ing. Berit Time),
- VTT (Senior Research Scientist Tuomo Ojanen),
- Lund University (Prof. Jesper Arfvidsson),
- National Museum of Denmark (Dr. Tim Padfield),
- Technical University of Denmark (Dr. Carsten Rode).

15:00 – 15:30 Discussion of plan for Friday’s work:
- Proposals for WG-subjects and WG-chairmen

15:30 – 16:00 *Coffee break*
16:00 – 18:00 Key note presentations
- Prof. Carl-Eric Hagentoft: “Analytical solutions for moisture buffer phenomenon”
- Prof. Max Setzer: “The humidity response function. Experimental evaluation and improved Modelling using sorption and diffusion data”
- Prof. Nathan Mendes: “A modified moisture diffusion Biot number for evaluating moisture buffer capacity of building materials”
- Prof. Hugo Hens: “Moisture buffer capacity from the Whole Building Moisture Performance view”

18:00 – 18:30 Relevant Activities at Other Institutions
- Prof. V. Freitas and Nuno Ramos: “Moisture Buffer Capacity – how to define the concept. FEUP contribution”
- Dr. Monika Woloszyn: “Moisture modelling integration into heat-airflow simulation tools: Cethil experience”

19:00 – 19:45 Visit to museum repository at the National Museum of Denmark, Brede
20:00 – Dinner at *Brede Spisehus*

Friday, August 22

09:00 – 09:15	Summary of day one
09:15 – 10:15	Work groups (suggested topics): - Which quantity to standardize? - Experimental techniques - what should one measure? - Reference material/start of Round Robin - Commercial application and exploitation - Modelling - can we extrapolate?
10:15 – 11:00	*Coffee break*, preparation of work group summaries
11:00 – 11:45	Plenary presentation of work groups' discussions and results (each of 10 min., one by one)
11:45 – 12:00	Plenary discussion: "Is the concept real?"
12:00 – 13:00	*Lunch*
13:00 – 13:15	Information about the new IEA ECBCS Annex 41 by Prof. Hugo Hens
13:15 – 14:30	Continuation of plenary discussion
14:30 – 15:00	*Coffee break*, WG-chairmen prepare summary
15:00 – 16.30	Presentation of summary and input for synthesis report Discussion of follow-up work: - Proposal for NORDTEST project - Journal Paper and other dissemination activities
16:30	Closure

APPENDIX C - List of participants

List of participants

NORDTEST Workshop on "Moisture Buffer Capacity". Technical University of Denmark. August 21-22, 2003.

Name	**Institution/Company**	**e-mail**
Academic		
Univ.-Prof. Max Setzer	Universität Essen	mj.setzer@uni-essen.de
Lars D. Christoffersen	Birch & Krogboe	ldc@birch-krogboe.dk
Sergio Fox	Danish Energy Agency	sgf@ens.dk
Prof. Carl-Eric Hagentoft	Chalmers University of Technology	hagentoft@buildphys.chalmers.se
Morten Hjorslev Hansen	Danish Building and Urban Research	mhh@by-og-byg.dk
Lars-Erik Harderup	Lund Institute of Technology	lars-erik.harderup@byggtek.lth.se
Prof. Hugo Hens	Katholieke Universiteit Leuven	Hugo.Hens@bwk.kuleuven.ac.be
Heiko Fechner	Technische Universität Dresden	Fechner@abkfs2.arch.tu-dresden.de
Poul Klenz Larsen	The National Museum of Denmark	poul.klenz.larsen@natmus.dk
Ian Ridley	UCL, The Bartlett Faculty of the Built Environment	i.ridley@ucl.ac.uk
Theodore W.C. Chen	UCL, The Bartlett Faculty of the Built Environment	t.chen@ucl.ac.uk
Prof. Anker Nielsen	Swedish National Testing and Research Institute	anker.nielsen@sp.se
Kaisa Svennberg	Lund Institute of Technology	kaisa.svennberg@byggtek.lth.se
Monika Woloszyn	INSA-Lyon	woloszyn@insa-cethil-etb.insa-lyon.fr
Georg Christensen	Bygge- og Miljøteknik A/S	gc@bmd.dk
Prof. Graham Galbraith	Glasgow Caledonian University	G.H.Galbraith@gcal.ac.uk
Dr. Andreas Holm	Fraunhofer Institut für Bauphysik	holm@hoki.ibp.fhg.de
Nuno Ramos	Faculdade de Engenharia da Universidade do Porto	nmmr@fe.up.pt
Prof. Nathan Mendes	Pontifical Catholic University of Paraná	NMendes@ccet.pucpr.br
Berit Time	Norwegian Building Research Institute	Berit.Time@byggforsk.no
Tuomo Ojanen	VTT	Tuomo.Ojanen@vtt.fi
Prof. Jesper Arfvidsson	Lund Institute of Technology	jesper.arfvidsson@byggtek.lth.se
Tim Padfield	Conservation Scientist	tim@padfield.dk
Kurt K. Hansen	Technical University of Denmark	kkh@byg.dtu.dk
Ruut H. Peuhkuri	Technical University of Denmark	rhp@byg.dtu.dk
Lone G. Hedegaard	Technical University of Denmark	loh@byg.dtu.dk
Carsten Rode	Technical University of Denmark	car@byg.dtu.dk
Industry		
Claus Rudbeck	Rockwool International A/S	claus.rudbeck@rockwool.com
Kurt Stokbæk	KS Byggeteknisk Service	Fax: +45 43 73 28 61
Poul Erik Hjorth	Betonelement-Foreningen	poh@danskbyggeri.dk
Gorm Rasmussen	H+H Celcon A/S	gr@hhcelcon.dk

APPENDIX D – Contents of Collection of Abstracts

Invited lectures

Other contributions (sorted alphabetically by author name)