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Full scale tests of moisture buffer capacity of wall materials

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KEYWORDS*: moisture buffer capacity, full scale testing, finish materials.*

SUMMARY*:*
Moisture buffer capacity of hygroscopic materials can be used to moderate peaks in the relative humidity (RH) of indoor air as well as moisture content variations in building materials and furnishing. This can help to ensure healthier indoor environments by preventing many processes that are harmful such as growth of house dust mites, surface condensation and mould growth.

Therefore a series of experiments has been carried out in a full scale test facility to determine the moisture buffer effect of interior walls of cellular concrete and plaster board constructions. For the cellular concrete, the buffer performance is investigated first for the untreated material, then after adding rendering on the surfaces, and finally with latex paint. Similarly for the walls of plasterboard construction, the buffer effects are investigated first for the insulation (cellulose or mineral wool), then after adding untreated plasterboards as cladding, and finally with additional latex paint. The walls were exposed to cyclic humidity variations like in an inhabited indoor environment, and the response of the indoor humidity was followed over time. The investigations also comprised simultaneous determination of the changes of moisture content in specimens of the wall composites exposed to the same environment.

It was found that the finishes had a big impact on the buffer performance of the underlying materials. Even though the untreated cellular concrete had a very high buffer capacity, the effect was strongly reduced even with the supposedly highly vapour permeable rendering finish, not to mention the case when the latex paint was used. In the same way, the experiments for the plaster board construction demonstrated how cellulose insulation, as a very hygroscopic material, is a good buffer compared to the almost non-hygroscopic mineral wool. For example, it was found that if half of the surface area of the walls in a test room consists of cellulose insulation, the variation in RH can be reduced to nearly half of the variation seen for a similar room using non-absorbing materials and the same moisture load. However, subsequent tests demonstrate that for daily humidity variations it is not possible to take advantage of the moisture buffer capacity of the interior layers of a composite wall if the absorbing layers are covered with plasterboard, painted or not.

1. Introduction

Surface materials exposed to variations in the surrounding climate will absorb moisture when the relative humidity (RH) increases, and desorb moisture when the RH decreases. This process is referred to as moisture buffering and is to a large extent due to the material composition and structure, and to the surface treatment of the material. The moisture buffer capacity of the surface materials in the indoor environment will help to minimize the daily variations of RH in the air, which results from the activities of the occupants and the operation of HVAC-systems. The surfaces of the inside of the building envelope such as ceilings, floors and walls, as well as the furniture and other furnishing have an impact on the moisture conditions in the room. For example Plathner and Woloszyn (2002) have shown that the correlation between simulated and measured moisture conditions of the indoor air is much better if the sorption of interior surface materials is taken into account.

The benefit of reduced humidity variations is that growth of allergenic or pathologic organisms can be minimized if the RH variations are held within 30% to 60%RH (ASHRAE 2001). Furthermore, reduction in peak values for RH can prevent condensation on cold surfaces and thereby reduce the number of spores from mould growth. Mould spores and dust mites are unwanted in the indoor environment because they can lead to Sick Building Syndrome, which comprises symptoms such as irritation of the mucous membranes, skin rashes, headaches etc. Hence, a lower maximum RH will benefit the many humans that are allergic to these allergens. Earlier research has supported that moist buildings should be avoided (Bornehag *et al.*, 2001). Another advantage is that lower RH will increase the well being of inhabitants in the indoor environment because a lower humidity will increase the cooling of the mucous membrane when breathing and thereby the air will be perceived as being fresher (Toftum *et al.*, 1999) and the air quality will be increased (Fang *et al.*, 1998). Air humidity also influences both chemical and sensory emission rate of waterborne floor varnish and acrylic wall paint (Fang *et al.,* 1999). These emissions should be avoided in order to keep a good air quality since work efficiency decreases with the rise in air pollution.

Moisture buffering capacity is not a standard unit but the topic is highly interesting and relevant for both researchers and material manufactures. So in 2003 a NORDTEST project to deal with *Moisture Buffer Performance* was initiated (Rode, 2003). The project continues the work of defining moisture buffer performance and to develop standardized measuring methods.

Moisture buffer performance is also part of an international research project of *Whole Building Heat, Air and Moisture Response*, which is Annex 41 of the International Energy Agency's (IEA) *Energy Conservation in Buildings and Community Systems Programme* (Hens 2003). As an IEA activity it is also the scope to illustrate how a better understanding of the overall hygrothermal behaviour of buildings can lead to better energy performance, e.g. by inventing optimized strategies for ventilating, heating and cooling that take the overall hygrothermal reality of buildings into account.

Previous studies also concerned moisture buffer performance. A full scale investigation in Finland in an ecological building without vapour retarder concerned the moisture buffer capacity of a bedroom in (Simonson 2000). It was found that daily variations of high peak humidities in the bedroom could be reduced by up to 20% RH. A similar investigation concerned simulation of the same room when exposed to weather data from four different cities and buffer materials was found to have most impact in a moderate climate like in Scandinavia, and the buffer effect of hygroscopic thermal insulation was strongly reduced when it was not directly exposed (Simonson *et al.*, 2001). In earlier studies the moisture buffer capacity of several materials has been investigated in small scale (Padfield 1998, Mitamura *et al.* 2001; Svennberg & Harderup 2002; Peuhkuri 2003, and Ojanen *et al.* 2003).

The background for accomplishing these experiments is that humans spend most of their lives indoors combined with the fact that there might be a number of health risks involved if the moisture conditions are not controlled. This is a main reason for further studies of moisture capacities of building materials. The focus of this investigation is on interior walls. The experimental investigation has been carried out stepwise so the layers in the wall have been added continuously.

2. Test cell and equipment

The experiments were performed in an air and moisture tight test room. The test facility consists of a highly insulated steel box standing on pillars with an indoor floor area of 13.8m^2, and room height 2.75m^2, giving a volume of 38.0m^3. The test cell consists of two rooms, a test room and a service room. The walls are insulated with 0.40 to 0.50m of polystyrene and mineral wool and are covered with steel sheets on both the inside and the outside. An exception from this is the south wall, which is exchangeable. During the later described experiments the south wall consisted from the outside of a wooden cladding, 0.30m of mineral wool, 0.11m of brick wall and a polyethylene foil on the inside to provide a vapour tight and non-absorbing interior surface. The air change rate (ACR) of the test cell has been measured with tracer gas using the decay method and found to be about 0.20h^{-1} at 50 Pa (0.015 in Hg) pressure difference. Without pressurization the ACR was about 0.007h^{-1} (Mitamura et al. 2001). A picture and a diagram of the test cells are shown in Fig. 1 and Fig. 2.

FIG. 1: Picture of the test cells at DTU. Only the test cell on the left is used for the experiments presented in the paper.

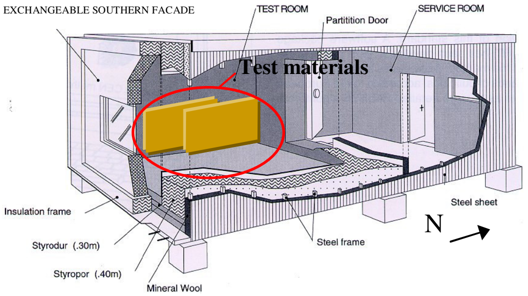

FIG. 2: Drawing of the test cell. The test room is covered with steel sheets on the inside on all sides except the exchangeable facade, which is covered with a polyethylene foil to be moisture tight. Adapted from the original Paslink homepage, www.paslink.org and then modified.

The test room has an air distribution system connected to heating and cooling coils. The service room is placed in the northern end of the test cell and contains the cooling and control systems. The cell is instrumented with sensors for measuring both outdoor climate and the indoor conditions (air temperatures, surface temperatures, heating, power used by the cooling system and fans, heat fluxes, air infiltration rate, RH and air velocity). The indoor RH is measured with capacitive moisture sensors with an accuracy of about ± 2% RH. The data acquisition system is located in an adjacent building, from which the test cell can be controlled and here registered average data is saved for ten-minute periods of measurements with sampling every thirty seconds.

To measure the moisture buffering effect of the materials in this experiment, the room was subjected to controlled moisture variations. The idea was to mimic the exposure of moisture variations to interior surface materials in a common indoor climate, but in a controlled way. The moisture production was controlled, and the resulting RH variation within the test cell was registered. Two small fans were placed on the floor in both ends of the test cell to ensure well-mixed air. The indoor humidification, that represents the moisture production of an inhabited room, was provided by evaporation of moisture from a reservoir of water heated by an electric coil. Humidity was withdrawn from the air by a dehumidifier draining into the same reservoir. The drying represents the removal of humidity from the room that would normally take place by ventilation.

The water reservoir was suspended in a load cell, and the rates of humidification and drying were controlled according to a predefined schedule. Padfield (1998) has used the principle in a small ($0.5m^3$) test chamber in the laboratory. A schematic diagram of the apparatus is shown in Fig. 3.

Another similar load cell, as for the water reservoir, was suspended in a rack from which a material specimen could be weighed continuously during the tests. The range and accuracy of both load cells was 10kg ±3g.

3. Measurements

The measurements were performed in the test cell described in the previous section. The purpose of the measurements was to gain information about the moisture buffer capacity of two types of interior walls in both untreated form and with finish. The two types of interior walls were of plasterboard construction (case 1) and cellular concrete (case 2). For both experiments the aim was to perform the experiments with standard materials that are common in the building industry. The material properties for the used materials are given in Table 1.

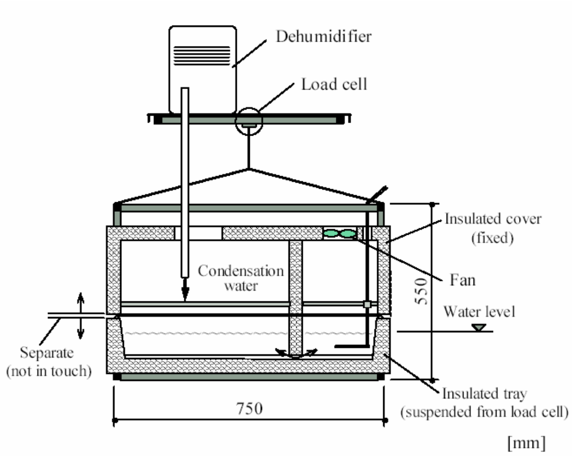

FIG. 3: Principle for the weight change of the water reservoir (Mitamura et al. 2001)

TABLE 1: Material properties

Materials	Density ρ_0	Vapour permeability, δ	Diffusion resistance, Z
	$[\frac{kg}{m^3}]$	$[\frac{kg}{Pa \cdot m \cdot s}]$	$[\frac{Pa \cdot m^2 \cdot s}{kg}]$
Mineral wool (case 1B)	32	$157 \cdot 10^{-12}$	$2.23 \cdot 10^{08}$
Cellulose insulation (case 1C)	65	$130 \cdot 10^{-12}$	$2.15 \cdot 10^{08}$
Plasterboard, untreated (case 1D)	700	$23.6 \cdot 10^{-12}$	$2.97 \cdot 10^{08}$
Paint (case 1D, 1E)			$2.90 \cdot 10^{09}$
Cellular concrete, untreated (case 2B)	535	$23.6 \cdot 10^{-12}$	
Rendering (case 2C)			$1.08 \cdot 10^{09}$
Paint (case 2D)			$1.50 \cdot 10^{09}$

3.1 Plasterboard construction walls

In the first experiment (Hedegaard 2002) studied the moisture buffer capacity of an interior wall of a plasterboard construction. The experiment consisted of 6 cases, where the first case (case1A) was the empty test cell, as a reference. In the other 5 cases the walls consisted of steel frames with insulation where moisture transport though the edges of the test walls was prevented by use of moisture proof tape. During the tests there were some variations in the exposed surface areas. The thickness of steel frames was 70mm. In case 1B and 1C the exposed surface area was 15.38 m^2 and the measurements were made with mineral wool as insulation, or alternatively with loose fill cellulose insulation (65 kg/m^3). A metal wire netting was added in order to keep the cellulose insulation in place. The following cases were made only with cellulose insulation. In case 1D untreated plasterboards were added on each side of the construction and here the exposed surface area was 20.15 m^2. The thickness of the plasterboard was 13 mm. In case 1E painted plasterboards replaced the untreated plasterboards. The painting consisted of two coats of latex wall paint. Finally in case 1F, a vapour retarder was added between the insulation and the painted plasterboards although that is non standard in interior walls. For the cases 1E and 1F the exposed surface area was 20.24m^2. During the experiments the daily variation in the test cell was humidification and dehumidification moisture load of 25 g water/hour and an isothermal temperature of 20.0 ± 0.5°C.

3.2 Cellular concrete walls

In the second experiment (Bisgaard, 2004) studied the moisture buffer effects of cellular concrete. Here 4 different cases were tested all with an exposed surface area of 16.8m^2 and moisture transport through the edges of the walls was again prevented.The reference test was again the empty test cell, case 2A. The remaining 3 cases were all carried out with a cellular concrete core of 50mm thickness. Case 2B was the untreated concrete and for case 2C the walls were added rendering finish and in the last case, 2D cellular concrete with one layer primer and one layer of latex wall paint as finish (without rendering). During the experiments the daily variation in the test cell was humidification and dehumidification moisture load of 33 g water/hour and an isothermal temperature of 20.1 ± 0.3°C.

4. Results

For all the tested cases the measurements were continued until equilibrium was reached with the changing test cell climate. The measuring period was typically around 5 days but in some cases much longer because of different problems with the control system for the climate in the test cells. The results shown in this paper are based on representative one-day periods. The representative day was chosen when both temperature and moisture load in the test room were stable and after equilibrium was reached.

4.1 Plasterboard construction walls

The results of indoor RH-variation with interior walls of plasterboard construction as moisture buffers are shown for one-day periods in Fig. 4 where the data points represent an average hourly value. During the experiments the variations in RH were in the range 38-80% RH. When comparing the results it should be kept in mind that the experiments have been accomplished with different surface areas.

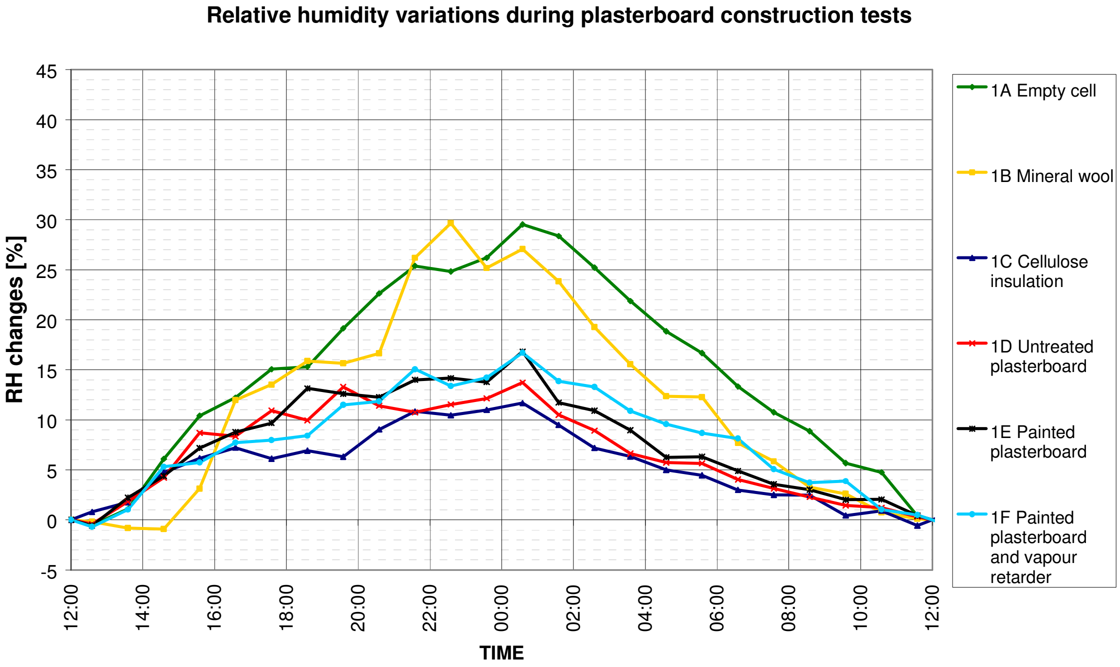

FIG. 4. Curves showing the variations in RH during a period of one day for plasterboard constructions.

For the three cases with plasterboards it is hard to differentiate between the moisture buffer capacities. The curves for the two painted plasterboards are very similar. The plasterboards have a moisture buffer effect somewhere between that of mineral wool and that of cellulose insulation.

It is also clear that the mineral wool has the smallest moisture buffering effect because the curve lies very near that of the empty room. It should be noted that for the test with mineral wool (case 1B) the RH in the test cell is not increasing from 12-14:30. This was due to an error in the control system, where it was impossible to dehumidify to less than 40%RH and the solution for the other tests were to assure that 40%RH was the daily minimum value. The cellulose insulation and the untreated plasterboard have the best buffer capacity and the two painted plasterboard coverings lies in between. Compared to the empty room the cellulose insulation and the untreated plasterboard reduce the range of the RH variations to half the variation for the reference test (the empty room).

4.2 Cellular concrete walls

The result of the experiments with cellular concrete is shown in Fig. 5. The figure shows the resulting indoor RH for one-day periods and as for the plasterboard constructions hourly average values are used. For the reference case 2A the variation of the relative humidity in the room is 42%RH, for case 2B 21%RH, case 2C 37%RH, case 2D 32%RH.

The untreated cellular concrete has a good buffering effect since the RH variations in the test room decreased to 21%RH, which is exactly half the variation for the empty reference room. It is also clear that the rendering is quite vapour tight since the range of RH variations has increased 16%RH from case 2B to 2C. This could also be expressed by a reduced RH variation compared to the empty case of 5%RH. For the test with the painted cellular concrete the results show that the RH variation in the room is 5%RH less than case 2C with rendering.

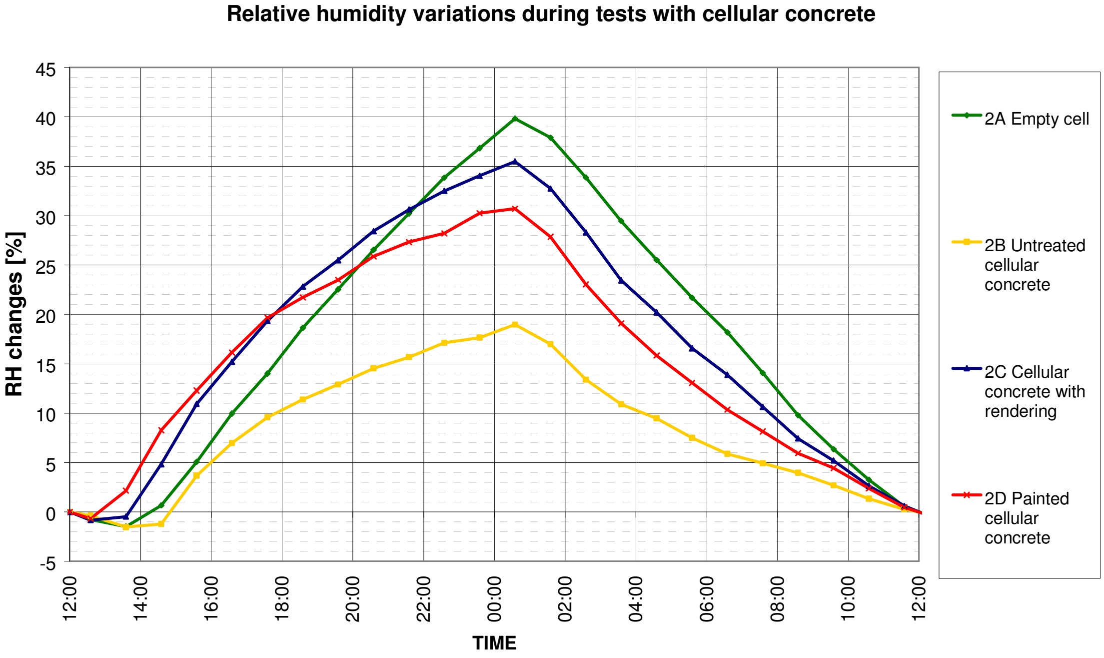

FIG. 5. Curves showing RH variations during a period of one day for cellular concrete constructions.

5. Discussion

The experimental results shown in the previous chapter indicate that the moisture buffer capacity of materials can be used to reduce the humidity variations in the indoor environment. The peaks in both high and low values of RH are reduced. Especially the reduction of high peak is beneficial for the indoor environment since less humid air is perceived fresher and both chemical and sensory emissions from material surfaces may be reduced.

The exposed material surfaces in rooms are very important since they will interact with the room air. Thereby the surface structure of the materials is essential because open porous materials are permeable and hygroscopic like e.g. concrete, tile, wood and other organic materials. Compared to porous materials the finish materials such as paint or varnish are quite moisture tight. In inhabited rooms it is common to have painted walls and varnished furnishing. On the other hand, it is also common to have curtains and upholstered furniture and books and paper in the indoor environment. These are open hygroscopic materials. However, vapour open finish materials on building constructions would be beneficial because this could ensure that also these surfaces could be used to moderate RH variations. In relation to the surface materials there is a lack of information about the microclimatic transfers. Of special importance is the microclimate in critical regions like e.g. near thermal bridges, corners and places with limited airflow such as behind furniture. These areas have risk of condensation due to cold surfaces in periods of high peak RH values e.g. when cooking or showering. The results of these full scale investigations showed that there is a need for further investigation of surface finishes.

The mineral wool does not have the ability to absorb much moisture from the surroundings. Opposite to this the cellulose insulation has a good moisture buffering capacity as the results showed that the RH variations could be reduced from a 31% change in RH to 18% RH-change during a day (a relative reduction of 42%). The two cases with painted plasterboards (1D and 1E) are very similar. This seems reasonable since the penetration depth for the diurnal variations for the untreated plasterboard is less than the board thickness of 13mm's so the test results were expected to be identical. In the tests there was a resulting error of 10 % based on temperature variations, actual moisture load, exposed surface area and RH sensor. If the error is taken into account it is impossible to differ between the test with the untreated plasterboard and the tests with the painted plasterboards. So from this investigation alone it is impossible to draw clear conclusion of the effect of finish materials. The discussion of the plasterboard coverings can lead to a speculation about usefulness of moisture buffer capacity in the inner layers of an interior wall. The results show that there is only a small difference between the two tests with the painted plasterboards. This can lead to a result stating that the insulation in an interior wall is unable to function as moisture buffer when the coverings are plasterboards.

The investigation of untreated cellular concrete as interior walls showed a good moisture buffering effect. The RH variations in the test room decreased to 21% RH, which is exactly half the variation for the empty reference room. However the buffer effect of the cellular concrete was reduced when it was treated with finish material. The used rendering was quite vapour tight since the range of RH variations increased much compared to the untreated case and the variations was even bigger than those found for the painted cellular concrete. This was unexpected since the paint was supposed to be more moisture tight. A closer investigation of the painted walls showed that there were cracks in the paint and it is assumed to be the explanation for the decreased variation since within the cracks the untreated cellular concrete is directly exposed.

The ventilation rate governs the mean level of RH in the indoor air, and the moisture buffer performance will affect only the amplitude of the RH variations. In this investigation the ACR of $0.007h^{-1}$ is extremely low and a low ventilation rate increases the impact of the moisture buffering effect of the surface materials. However, moisture buffering can never replace ventilation in occupied buildings because ventilation also removes heat, sensory and chemical pollution and provides clean air.

During the measurements there were some deficits in the experimental configuration. The dehumidifier used to withdraw humidity from the air had some difficulty to desiccate the air significantly below 40% RH, so not all the planned humidity variation could be realized as is seen for case 1B in Fig. 4. This problem mainly influenced the experiments with the plasterboard constructions as interior walls. For both investigations another potential source of error was some hygroscopic absorption of moisture in the paint, polyethylene sheets, dust and electrical wires in the otherwise empty room.

Despite of the deficits the usefulness of this type of controlled full-scale measurements should still be considered to be very high, since it provides an important step between calculations and laboratory measurements on one hand, and field measurements in real environments on the other hand. Especially this type of test cell with an exchangeable wall (see Fig. 2) provides an advantage when future experiments can be done more realistically, by conducting non-isothermal test with a naturally varying indoor climate due to solar gain.

In the current IEA Annex 41 project there will be activities that seek to gather as much field and test case information as possible from the different participating countries so that a broad knowledge base will be obtained. It appears obvious that the effect of surface materials to moderate the indoor humidity will be a part of the study in this international work.

Altogether, this kind of investigations should lead to better understanding of hygroscopic behaviour of materials and their ability to function as moisture buffers. This can hopefully form basis for better empirical and analytical understanding of how real rooms buffer the indoor humidity.

6. Conclusion

The main conclusion of this study is that the finishes have a big impact on the buffer performance of the underlying materials. Even though the untreated cellular concrete had a very high buffer capacity, the effect was strongly reduced even with the supposedly highly vapour permeable rendering finish, not to mention the case when the very vapour tight latex paint was used. In the same way, the experiments for the plaster board construction demonstrated how freely exposed cellulose insulation, as a very hygroscopic material, is a good buffer compared to the almost non-hygroscopic mineral wool. For example, it was found that if half of the surface area of the walls in a test room consists of cellulose insulation, the variation in RH can be reduced to nearly half of the variation seen for a similar room using non-absorbing materials and the same moisture load. However, subsequent tests demonstrated that for daily humidity variations it is not possible to take advantage of the moisture buffer capacity of the interior layers of a composite wall if the absorbing layers are covered with plasterboard, painted or not.

7. Acknowledgements

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8. References

ASHRAE (2001). *ANSI/ASHRAE Standard 62-2001, Ventilation for acceptable indoor air quality*, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bisgaard, A. (2004). Moisture Buffer Capacity of Buildings. M.Sc. thesis (in Danish). Department of Civil Engineering, Technical University of Denmark.

Bornehag, C.-G., Blomquist, G., Gyntelberg, F., Järvholm, B., Malmberg, P., Nordvall, L., Nielsen, A., Pershagen, G. and Sundell, J. (2001). Dampness in building and health, review article, Indoor Air, **11** 72-86.

Fang, L., Clausen, G. and Fanger, P.O. (1998). Impact of temperature and humidity on the perception of indoor air quality. *Indoor Air* **8**, 80-90.

Fang, L., Clausen, G. and Fanger, P.O. (1999). Impact of temperature and humidity on chemical and sensory emissions from building materials. *Indoor Air* **9**, 193-201.

Hedegaard, L. (2002). Moisture Buffer Capacity of Building Materials. M.Sc. thesis (in Danish). Department of Civil Engineering, Technical University of Denmark.

Hens, H. (2003). Whole building heat, air and moisture response (MOIST-ENG). Proposal for a new annex; International Energy Agency, EXCO Energy Conservation in Buildings and Community Systems. Department of Civil Engineering, KU-Leuven, Belgium.

Mitamura, T., Rode, C. and Schultz, J. (2001). Full scale testing of indoor humidity and moisture buffering in building materials, ASHRAE Conference, IAQ'01.

Ojanen, T. and Salonvaara, M. (2003). A method to determine the moisture buffering effect of structures during diurnal cycles of indoor air moisture loads. *Research in Building Physics,*eds. Carmeliet, Hens & Vermeir, Lisse: Swets & Zeitlinger, ISBN 90 5809 565 7, 353-361.

Padfield, T. (1998). The role of absorbent materials in moderating changes of relative humidity, Department of Structural Engineering and Materials, Technical University of Denmark, Report R-054.

Peuhkuri, R. (2003). Moisture dynamics in building envelopes, Department of Civil Engineering, Technical University of Denmark, Report R-071.

Plathner P. and Woloszyn, M. (2002). Interzonal air and moisture transport in a test house. Experiment and modelling. Buildings and Environment*,* **37**, 189-199.

Rode, C. (2003). Nordtest Workshop on Moisture Buffer Capacity – Summary Report. DTU, Lyngby, Denmark. August 21-22, 2003.

Simonson, C.J. (2000). Tapanila ecological house, VTT Building Technology, Technical Research Centre of Finland.

Simonson, C.J., Salonvaara, M. and Ojanen, T. (2001). Improving indoor climate and comfort with wooden structures, VTT Building and transport, Technical research centre of Finland.

Svennberg, K. and Harderup, L-E. (2002). Time-dependent moisture properties for plasterboard with surface coating. Indoor air 2002.

Toftum, J. and Fanger, P.O. (1999). Air humidity requirements for human comfort, ASHRAE Trans., **105**(2) 641-647.