RESEARCH REPORT | No. VTT-S-08448-11 | November 25, 2011

A survey of the breathable building structure concept – Effect of insulation material

Requested by: PU Europe

VTT EXPERT SERVICES LTD

Requested by	PU Europe Oliver Loebel Av. E. van Nieuwenhuyse 5 B-1160 Brussels
Order	26.4.2011
Contact person	**VTT Expert Services Ltd** Tuomo Ojanen P.O. BOX 1001, FI - 02044 VTT Finland Tel.+358207224743 Email: tuomo.ojanen@vtt.fi

Assignment **A survey of the breathable building structure concept – Effect of insulation material**

Introduction

Indoor air humidity conditions may have large daily variations depending on the thermal and moisture loads caused by occupation of the spaces. Temperature and humidity of the indoor air are some of the most important factors having effect on the indoor comfort, both thermal comfort and perceived air quality. Especially high humidity conditions may affect the indoor comfort.

Good indoor air quality requires humidity conditions that are in the range of suitable relative humidity area. Typically stabile conditions are more desirable than large fluctuations. The moisture buffering effect /1 - 3/ of building materials can be an important factor that helps to stabilize the daily fluctuations of the indoor air humidity conditions.

Under certain conditions the moisture capacity of building structures can be used to smooth down the daily humidity variations. Along with ventilation these passive structural methods may contribute to the controlling of indoor humidity conditions. Under cyclic moisture load periods, like night time occupation of a room, part of the indoor moisture loads can be absorbed in hygroscopic structures. Under unoccupied period the absorbed moisture may flow back to indoor air and ventilated out from the room. This moisture buffering effect leads to lower indoor humidity variations, which typically improves the indoor air quality and comfort.

Because this effect has not been widely studied there exist lots of beliefs and expectations for it.

Some of the main questions are: To what extent the passive structural methods can absorb the additional indoor moisture loads and what are the requirements for the properties of material layers in such structures.

Breathable structure is a term that has been commonly used to represent the interaction of the building envelope and the indoor air, especially in terms of indoor humidity control.

This *breathable* or *breathing* structure concept is not always well defined in common language and not even in all technical papers. One simplified viewpoint is the existence of the vapour barrier: No vapour barrier or vapour open air barrier (paper foil etc.) means breathing structure and a plastic vapour barrier means non-breathing. In this case the breathing structure has typically thermal insulation with some moisture capacity. This division is made without considering the dimensions or the moisture transfer and capacity properties of the structure layers at the inner side of the air/vapour barrier layer. Sometimes the air leakage properties of the building envelope are mixed with the breathing concept, which may cause even more confusion.

Objectives

The objective of this survey was to clarify the *breathing structure* or *breathable structure* concept, to study the role of thermal insulation material in the indoor air moisture buffering effect and the effect of other material layers or coatings on it.

This survey is mainly based on the published scientific papers that present research findings from this area. The main referred paper /1/ presents the results of a wide numerical study of this subject. Additional numerical simulations were carried out to complete some information.

Effect of humidity conditions on indoor air comfort

This chapter includes the summary of the possible effects of the indoor humidity on the thermal comfort and perceived air quality /1/.

Thermal comfort

The PD -values (Percent Dissatisfied) reflect the dissatisfaction with local thermal comfort (Figure 1). It is often recommended to keep PD with local thermal comfort below 15 % /5, 6/. When the temperature is 22°C, humidity level exceeding 55 % RH will cause PD to exceed 15 %. If the humidity was decreased to 45 % RH, the PD would be about 10 %.

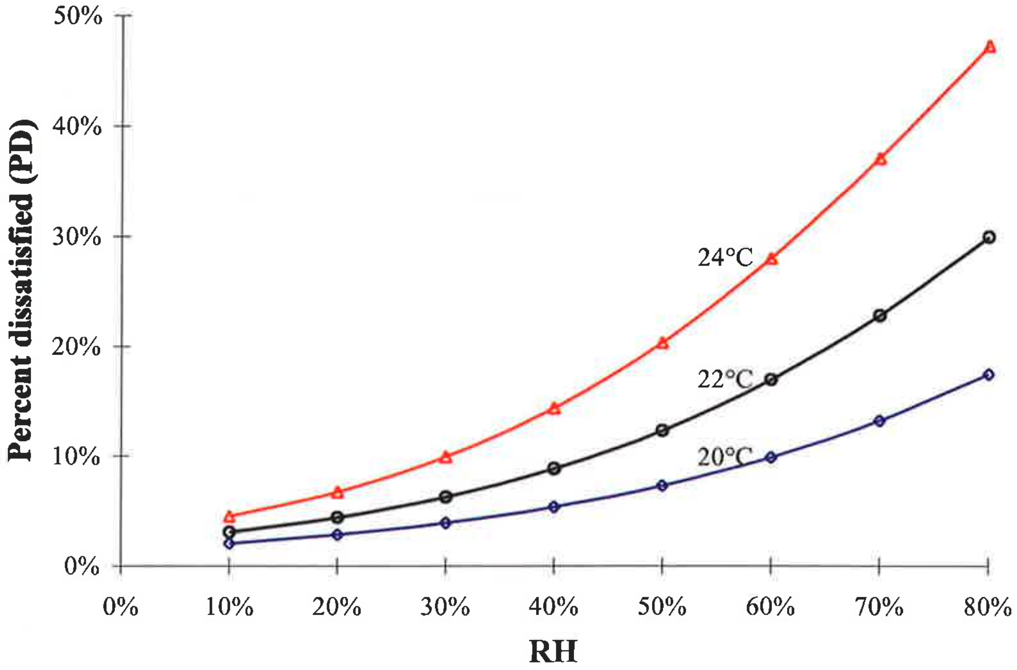


Figure 1. Percent dissatisfied with warm respiratory comfort as function of relative humidity at different temperatures.

Perceived Indoor Air Quality

Perceived indoor air quality (PAQ) is closely related to local thermal comfort. Research has shown that the perceived indoor air quality PAQ is strongly affected by temperature and humidity /7 - 9/. PAQ and acceptability (Figure 2) have linear correlation to the enthalpy of air. When the indoor air enthalpy increases, the acceptability decreases.

For example, clean air at 20°C and 60 % RH is slightly more acceptable than clean air at 24°C and 40 % RH. Roughly the 4°C temperature change corresponds to about 20 % RH change when considering clean air acceptability. This means that if the temperature increases by 1°C, the humidity must be decreased by 5% RH to keep the same acceptability. On the other hand, if the temperature decreases by 1°C, the humidity of the air is allowed to increase by 5% RH and the acceptability will still be similar. /1/

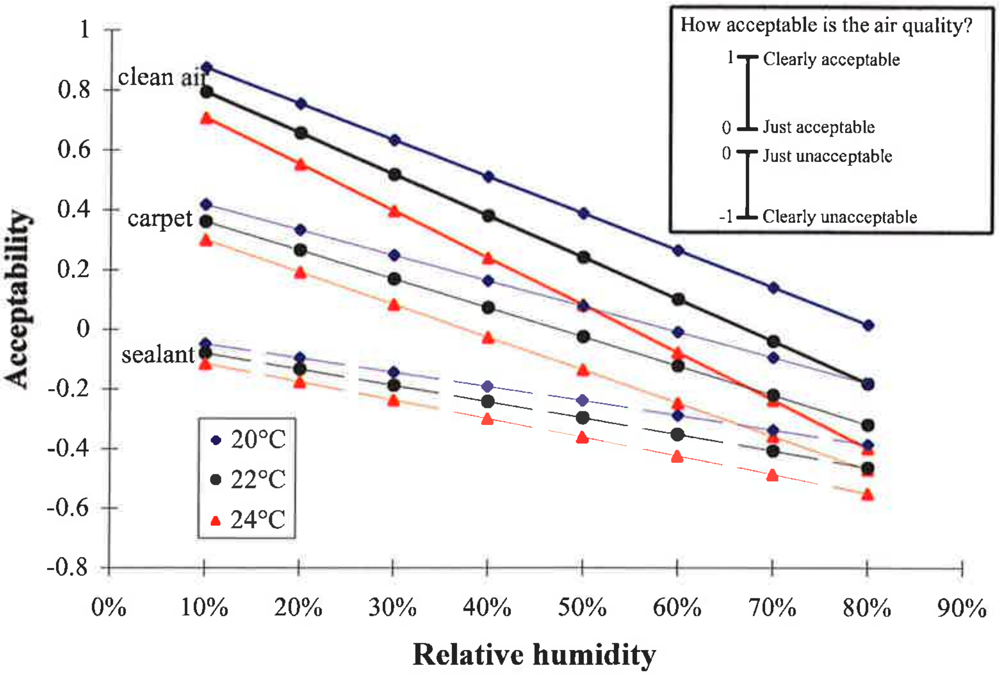


Figure 2. **The acceptability of indoor air as a function of relative humidity for different temperatures and pollution sources.**

Figure 3 represents a summary of several health and IAQ parameters. It shows that a favorable range of indoor humidity is between 30 % RH and 55 % RH /10/.

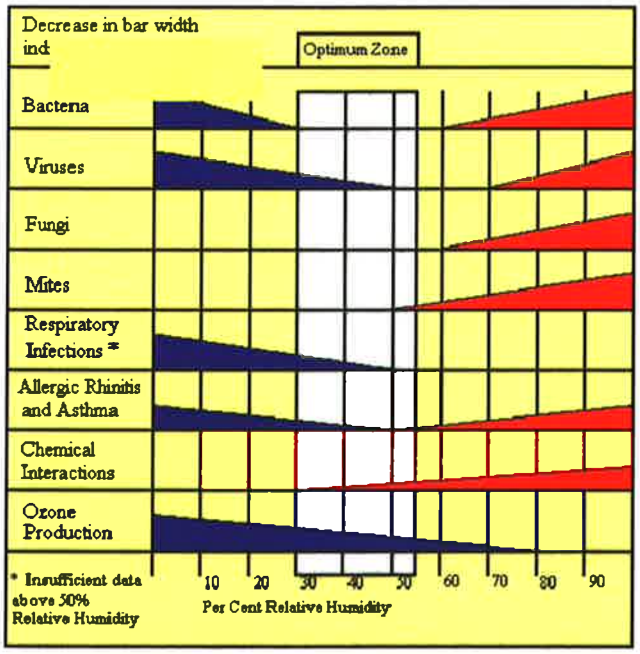


Figure 3. **The effect of humidity on several health and IAQ parameters showing that a favourable range of indoor humidity is between 30 % RH and 55 % RH /10/.**

This chapter shows that indoor humidity may have a significant effect on the thermal comfort and perceived air quality. Methods that can be used to lower the humidity peaks during occupation would improve the thermal comfort and acceptability of the indoor conditions. How this would be possible by utilizing the moisture capacity of building structures will be studied and discussed in the following chapters.

Breathable building structures – main parameters

General

The indoor humidity level depends on different factors like climate conditions, moisture sources, ventilation rate, volume of the space, and the possible moisture capacities of the building materials and their contact to indoor air.

The breathable building structure concept means that there can be hygrothermal interactions between the building structures and indoor air. These interactions may contribute to the indoor air comfort. The main issue is the buffering of indoor air humidity variations and especially the possibility to reduce the temporary peak humidity values that could affect the thermal comfort and perceived indoor air quality.

The building envelope can reduce the temporary high humidity peaks by allowing some of the additional moisture to be transported from indoor air into the structure. From the occupant comfort aspect there is not much difference between the cases where moisture is transported outdoors through the structure or if the additional moisture is stored in the material layers and then returned back to indoor air when the indoor humidity decreases. The latter case, where moisture buffering capacity is utilized, offers some possibilities to temporary increase the humidity level during lower humidity conditions, which may improve the comfort during cold and dry season.

Diffusion moisture flow through the building envelope

Moisture can be transported outdoors through the structures when the building envelope is open for water vapour diffusion. In climates having relatively long heating period, these kind of structures set requirements for the ratio of the diffusion resistance of the inner and outer layers. To achieve safe moisture performance, the diffusion resistance of the outer layers of the structure (wind barrier, exterior sheathing open to ventilation cavity, exterior finishing) should be more vapour open than the inner layers. Cold climates emphasize this requirement.

There is no practical use to lead additional moisture into the structures by using highly vapour permeable internal layers. During cold and dry climate conditions the highly vapour open structures may contribute to very low indoor humidity levels. When using vapour tight structures, additional indoor humidity can be stored into material layers close to indoor air, but it will not be transported outdoors. This helps in maintaining some indoor humidity levels during cold periods.

One benefit caused by the totally vapour open structure is that it may possibly reduce the risk for occasional summer time condensation. This risk can be possible for structures having vapour open thermal insulation and a vapour barrier. When the thermal insulation has relatively high diffusion resistance, like PUR, these temporary inverse thermal gradients do not cause such diffusion flow into the insulation that there could be significant moisture accumulation.

Air leaking structures are not breathable

Sometimes the breathable structure concept is mixed up with air leaking structures. Air convection may have a strong effect on moisture transfer, but the occasional air leakages can not contribute to safe moisture storage into the structure or restoring the moisture back to the indoor air. Air leaking building envelope typically affects the energy efficiency and also the moisture buffering effect due to its uncontrollable nature. Also, air tight building envelope is the basic requirement for controllable ventilation rates and pressure conditions in buildings.

Breathable structure having vapour barrier

A vapour tight layer in the structure does not exclude the utilization of the moisture buffering effect of structures. Vapour and air tight structures can have inside material layers that allow full use of this effect without compromising other performance aspects, like air tightness or controlled moisture flow through the building envelope.

Thermal capacity

The effect of thermal capacity is indirectly included in this concept, because temperature differences have an effect on moisture transfer. During occupation the temperature of indoor air typically increases while the temperature levels of massive structures remain lower for some time. This enhances the indoor moisture transfer into the structure. After the occupation period, the moisture flow from structures back to the indoor air can be enhanced due to the reversed temperature gradient. Temperature buffering alone can not be considered to make a breathable structure and the effect of temperature gradients on this effect will not be studied more in this survey.

Effect of wall structure on indoor air relative humidity /1 /

The hygrothermal performance of a bedroom was analysed using numerical simulation combining the room air space, ventilation and the wall, floor and ceiling structures.

Case definitions

The main features of the bedroom as well as the heating, cooling and ventilation of the bedroom are listed below.

- The bedroom was assumed to be in an apartment building where the surrounding rooms have the same temperature and vapour pressure as the investigated room.
- The room was 4 m x 3 m x 2.7 m and the west-facing external wall was 3 m long.
- The external and internal walls have the same construction.
- In most cases, the ceiling is active in moisture transfer with the indoor air, but the floor is not active because it is coated with a non-permeable coating.
- The external wall has a 1.2 m x 1.5 m triple-pane window with a closed venetian blind, which transmits 25 % of the solar radiation striking the window. For simplicity, it is assumed that the solar radiation is evenly distributed over all the internal surfaces.
- The building is located in an open terrain and the solar radiation absorption coefficient for the external wall is 0.8.
- The ventilation rate was normally 0.5 ach, which corresponds to 4.5 L/s, but it was varied in a few cases to determine the sensitivity of the results to the ventilation rate.
- There was no mechanical cooling in the room.
- The indoor temperature is at least 20°C during the heating season, where the heating season is chosen to be from October 1st to April 30th in Central Europe. Belgium climate was used in the simulations.
- The indoor loads are 2 adults for 9 h per day and lighting of 100 W for 1 the first hour of occupation (Figure 4).

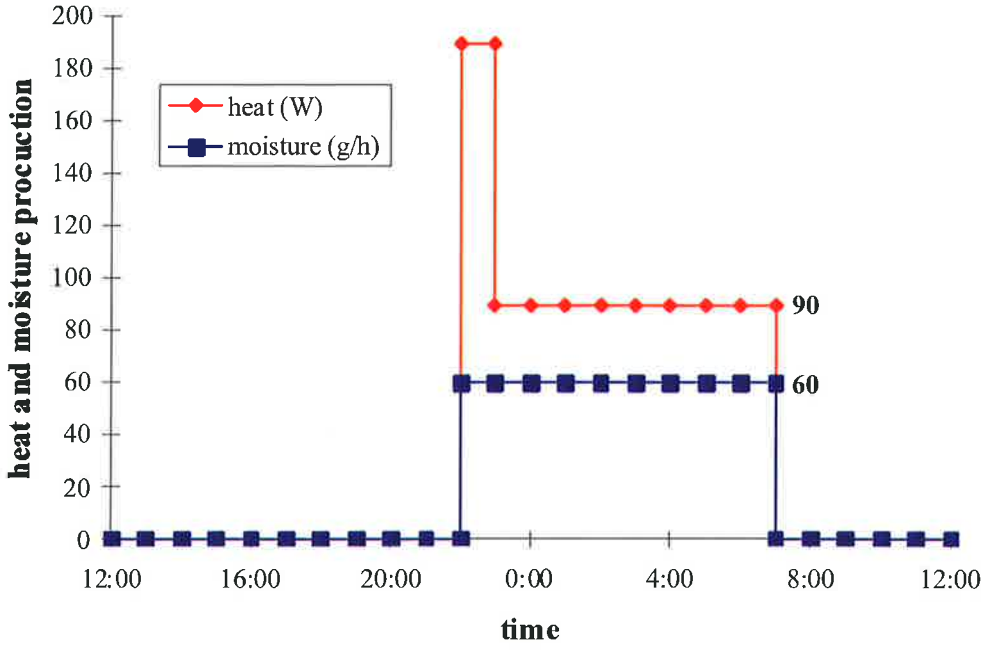


Figure 4. Heat and moisture production in the bedroom for two persons /1/.

Some relevant cases from /1/ studied in this summary report are presented in Table 1.

Table 1. Test cases /1/ studied in this work.

Case	Internal coating	Interior wallboard (11 mm)		Air/vapour barrier (0.3 mm)	Insulation (150 mm)
	permeance	hygroscopicity	permeability	permeability	hygroscopicity
1	high (v. perm. paint)	high (porous wood fibre board)	high	high (paper)	high (cellulose)
2	low (v. tight paint)	high (porous wood fibre board)	high	high (paper)	high (cellulose)
3	high (v. perm. paint)	high (porous wood fibre board)	high	high (paper)	low (mineral fibre)
4	high (v. perm. paint)	high (porous wood fibre board)	high	low (plastic)	high (cellulose)
5	high (v. perm. paint)	low (wood fibre board with	high mineral fibre sorption)	high (paper)	high (cellulose)
6	high (v. perm. paint)	high (wooden	low panel)	high (paper)	high (cellulose)
7 -12	Not studied in this summary report				
13	Same as case1, except the interior wallboard is gypsum				
In all cases the floor is impermeable and in cases 1 – 6 the wind barrier in the exterior wall is 11 mm of porous wood fibre board.					

The internal coating used in cases having *high vapour permeable paint* had diffusion resistance $S_d = 0.04$ m. This level is about 5 times more permeable than very permeable paints typically /11/ and it represents a case with essentially no interior surface coating.

In Case 2 the bedroom walls were painted with a very vapour resistant paint that had 5 times higher vapour resistance than that given for a vapour retarder paint /11/.

Simulation results

Figure 5 presents the maximum and minimum relative humidity for each occupied hour during January and June in Belgium with different wall cases 1 – 5.

The desired effect of the hygroscopic materials would be reduced maximum humidity levels, especially during summer conditions. During winter conditions the relative humidity should not decrease to too low levels.

Differences between cases 1, 3 and 4 show the effect of hygroscopic thermal insulation material on indoor air relative humidity in cases having hygroscopic wall board. When the thermal insulation material is hygroscopic, the maximum relative humidity of the indoor air was about 1 % RH lower than in the case with low hygroscopic thermal insulation (mineral wool).

The results of the case 4 having hygroscopic wall board and a plastic vapour barrier are about the same as in case 3 having paper air barrier and mineral wool insulation.

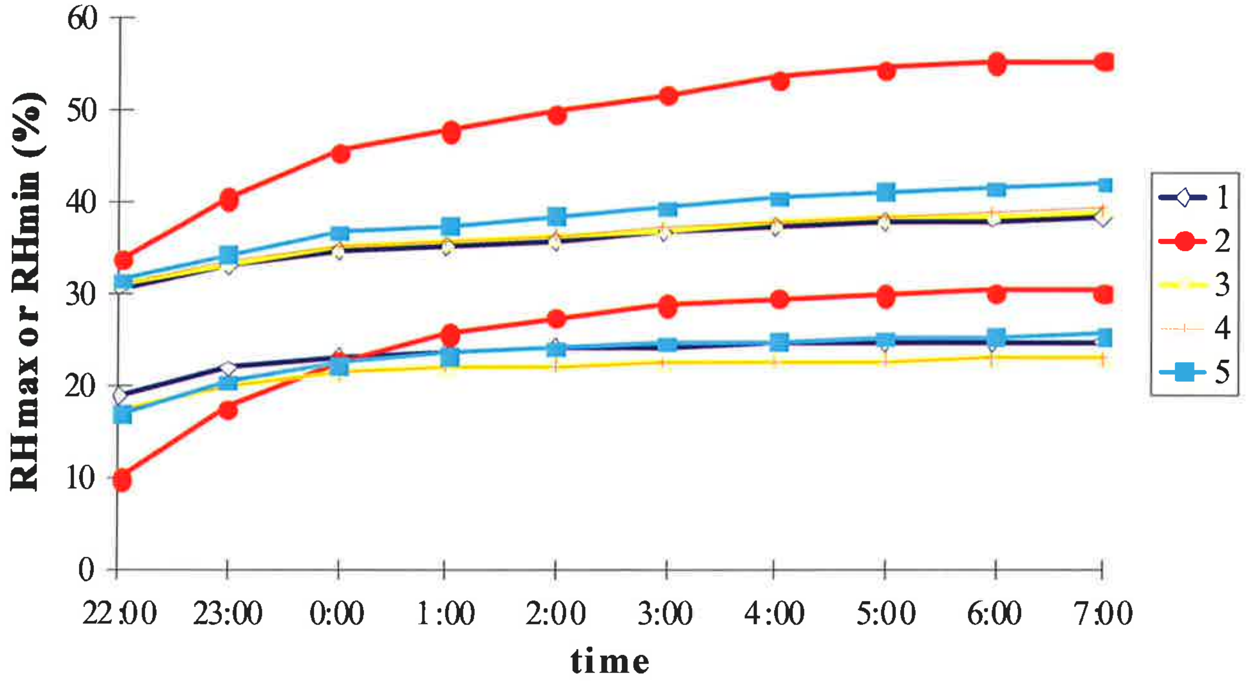
The results show that when insulation is situated behind a hygroscopic wallboard, the wallboard has the main effect on indoor humidity and the effect of the thermal insulation in these cases is almost negligible.

In case 5 the hygroscopic cellulose fibre insulation was behind a non-hygroscopic wallboard and hygroscopic building paper layer. This wallboard was a theoretical material having wood fibre board diffusion properties with mineral fibre sorption capacity. The aim was to study if the hygroscopic thermal insulation capacity could be utilized better when having a non-hygroscopic and highly vapour open wall board.

In this case with the artificial material properties set for the wall board, the maximum relative humidity during the analysed summer conditions was about 1 % RH higher than in cases 3 and 4. Thus hygroscopic insulation with non-hygroscopic wall board has lower effect on indoor air humidity conditions than in case hygroscopic wall board with plastic vapour retarder or in case with paper air barrier and mineral wool insulation.

The same effect can be seen in Figure 6 which presents the yearly average increase in absolute humidity during the nights (occupation periods) in cases 1 to

5 in Belgium /1/. Lower increase in humidity corresponds to lower moisture buffering effect of the wall structures.



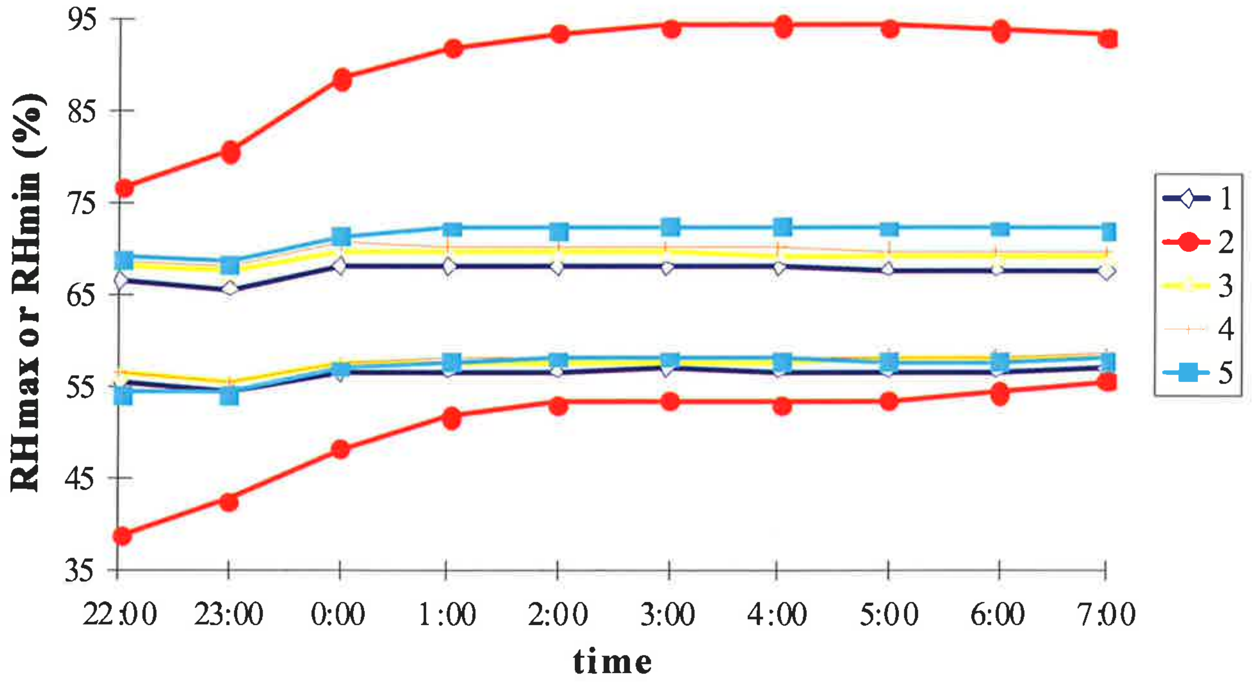


Figure 5. Maximum and minimum relative humidity for each occupied hour during January (above) and June (below) in Belgium with different wall cases.

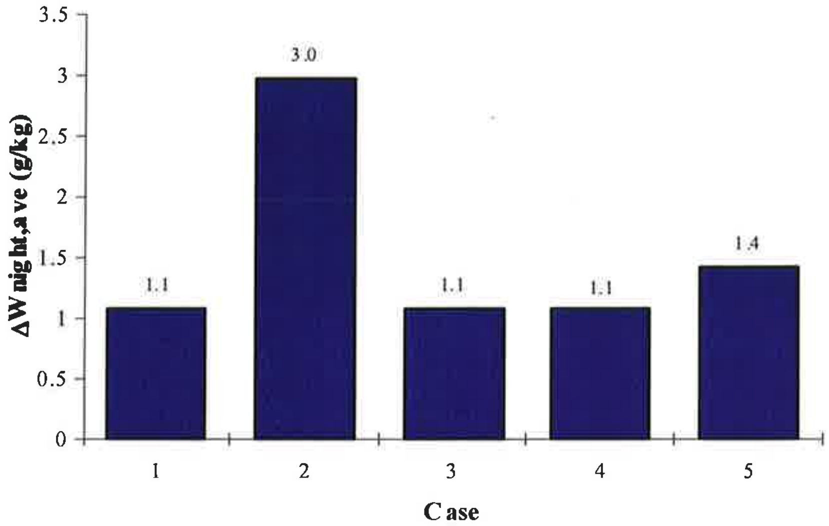


Figure 6. Yearly average increase in absolute indoor air humidity during the night in cases 1 to 5 in Belgium /1 /.

Figure 7 presents the yearly average increase in absolute humidity during the nights (occupation periods) in cases 1, 2, 6 and 13 in Belgium. In case 6 the wall board is wooden panel and in case 13 it is gypsum board, both having the same high vapour permeable paint surface, paper air barrier and cellulose insulation. Both the cases 6 and 13 caused the same yearly average increase in indoor air humidity, 1.2 (g/ kg) (moisture /dry air), which is slightly higher than those in cases with porous wood fibre wall board (Cases 1, Case 3 with mineral wool and Case 4 with vapour barrier).

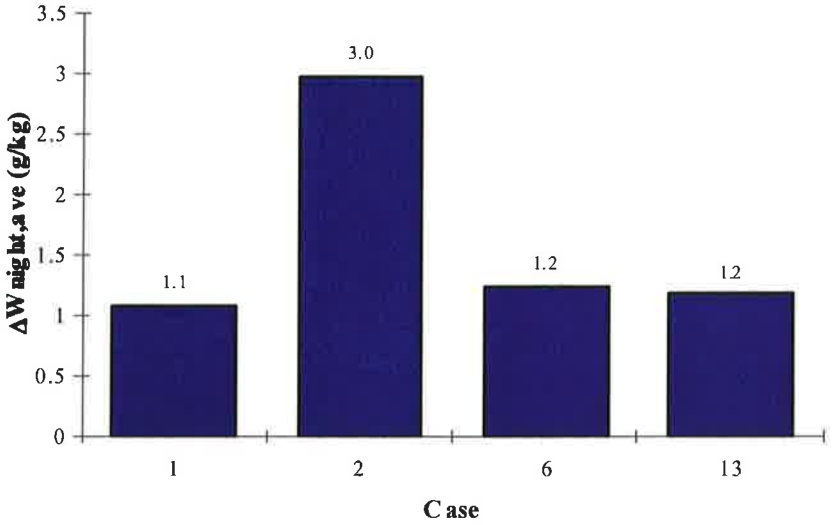


Figure 7. Yearly average increase in absolute indoor air humidity during the night in cases 1 2, 6 and 13 in Belgium.

Effect of ventilation on indoor air moisture flows

Figure 8 presents the yearly average moisture flows during the nights for the studied bed room case (occupation periods) in Belgium for case 1 with hygroscopic wall materials and case 2 having walls with vapour tight paint. The moisture flows were solved using different constant air change rates.

With air change rate 0.25 1/h and in the hygroscopic case 1, the wall structures could remove about 45 % of the moisture and ventilation about 42 %.The moisture surplus in the room air was less than 10 % of the production. In case 2 the share of ventilation was about 63 % and almost all the rest was accumulated in the air.

When the air change rate was 0.5 1/h (minimum required in living spaces in Finland), the part of moisture flow into the structure was about 40 % in case 1. In case 2, ventilation covers already about 80 % of the total moisture flow and with ach 1 1/h this share is about 86 %. Higher air change rate cause lower need and potential for the utilization of the hygroscopic structures in controlling of the additional humidity. The best benefit of the hygroscopic materials for the indoor air humidity conditions can be achieved with low air change rates.

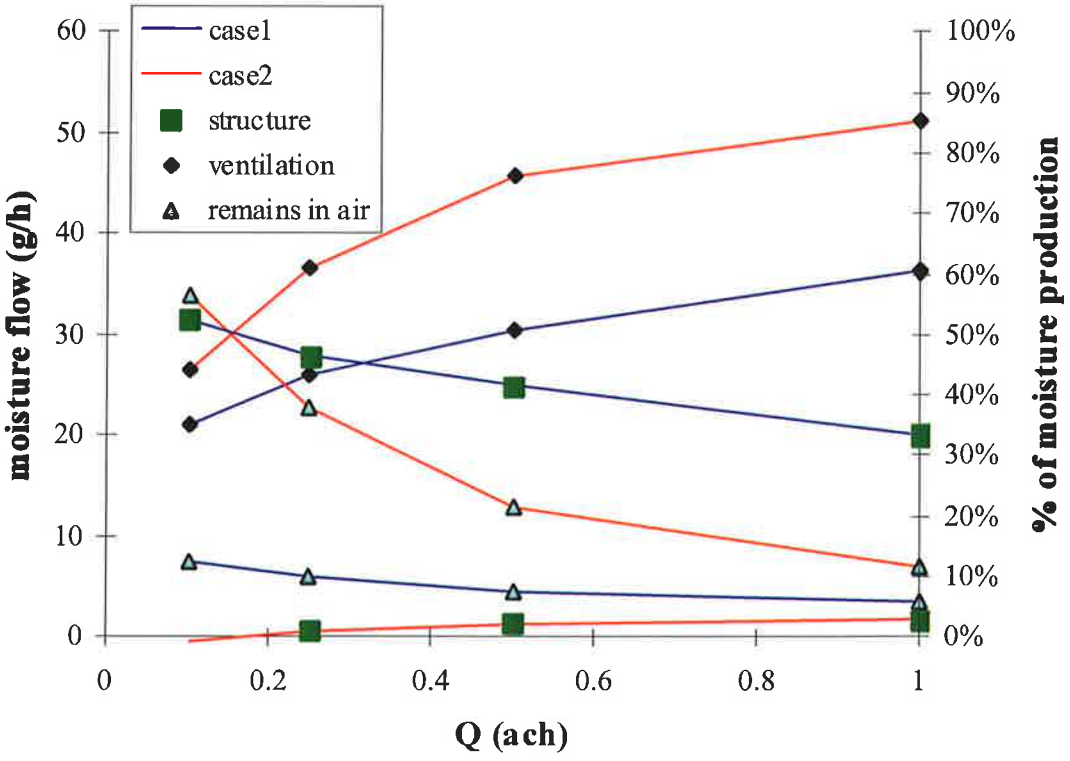


Figure 8. Yearly average moisture flows during the night in Belgium. Case 1 with hygroscopic materials (blue curves) and case 2 with vapour tight paint (red curves) on the wall board. /1/

Effect of interior coating resistance on moisture buffering

The effect of the vapour resistance of the interior coating is very critical for the moisture buffering effect. Figure 9 presents the yearly average value of the daily maximum increase in room air absolute humidity during the nights (Belgium climate) for various ventilation rates and surface coating resistances in Case 1. When the surface coating corresponds better to a normal paint layer (R* = 5, Sd = 0.20 m), the yearly average of the daily maximum increase in room air absolute humidity is about 1.7 g/kg, and in case with R* =10, it is about 2 g/kg . In case 2 (vapour tight surface) this value was 3 g/kg. When the diffusion resistance of the surfaces increases, also the potential to utilize the moisture buffering capacity decreases strongly.

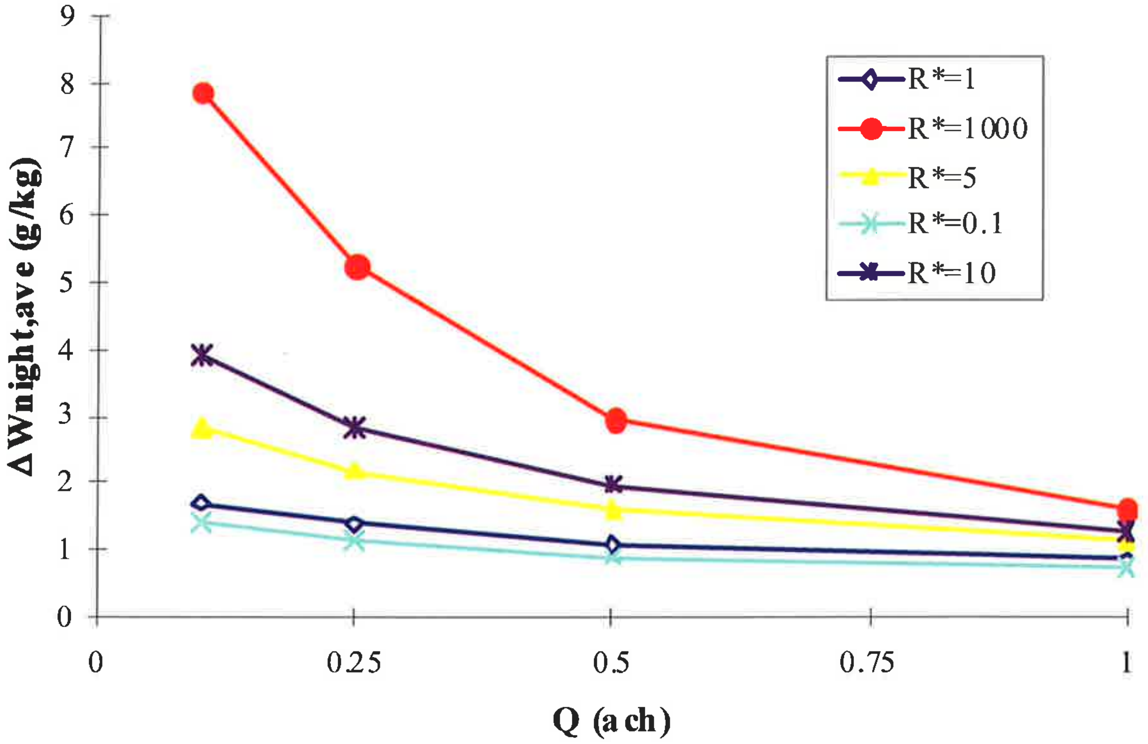


Figure 9. Yearly average value of the daily maximum increase in room air absolute humidity during the nights for various ventilation rates and surface coating resistances in Case 1. R* is the ratio of the vapour resistance of the interior coating in a given test case to the vapour resistance in test case 1 (Sd = 0.04 m).

Effect of climate

The climate typically affects the level of indoor temperature and humidity, but not the changes during occupation. The increase in absolute humidity and temperature during the occupation period is quite independent of the climate. The studies show that passive methods of controlling the indoor climate are more successful in moderate climates than in hot and humid climates due to the effect on daily extreme humidity levels /1/. In moderate climates the moisture buffering can reduce the daily time for unacceptable conditions more effectively than under conditions where the humidity level is constantly high due to the climate.

Other simulation findings

Carsten & al. /2/ have carried out numerical simulations of one room. These simulations were done using model called building simulation tool BSim2002 /12/, which can take into account the structures, ventilation and varying thermal and moisture loads. First the model was verified in actual field tests and then it was applied to study the effect of structures and materials.

The calculation model was used in full year simulations to investigate the possible differences in indoor air conditions for three different choices of insulation material and vapour retarder solutions. All the walls and roof were clad with 13 mm of gypsum that was plastered and then primed with a single coat of diffusion open paint. In practice this surface diffusion resistant is typically higher due to several paint layers and higher resistance of the coatings. The other layers were:

1. Wood fibre insulation and building paper, but no vapour retarders.
2 Same structure as number 1, but all internal surfaces were covered with a plastic vapour barrier. The barrier represents a non-hygroscopic structure or a vapour tight paint.
3 Mineral wool insulation and polyethylene vapour retarders between the gypsum board and insulation in the exterior constructions.

Case 3) corresponds to a typical wall structure with vapour barrier and Case 1) that of a *breathable structure*. Case 2) corresponds to any structure with highly vapour tight inside surface coating.

The calculations were carried out for a test room (10.5 m^2 and 29 m^3) and building located in Helsinki. The air change rate was set to be constant 0.5 changes per hour. A sufficient heating system was prescribed with a set-point of 21°C. All other internal rooms adjacent to the test room were set to follow the same conditions as the test room had. The room was assumed to be occupied for 9 hours every night by two adults that released 66 W of heat and 30 g/h of humidity each.

The numerically analyzed hourly indoor air relative humidity conditions are presented in Figure 10 for the first two weeks of June.

The monthly average indoor relative humidity levels were practically the same for the three different cases of construction, i.e. no long term moisture buffering effect could be detected. The differences could be seen only in daily humidity variations /2/.

In Case 2 (vapour tight indoor surface) the humidity has both higher peaks and lower valleys than in the two other cases. The highest relative humidity occurs in the early morning (by the end of occupation for the night), and has its minimum in the middle of the afternoon.

There were only a negligible difference in indoor relative humidity variations between the Case 1 when wood fibre insulation was used without a vapour retarder, and Case 3 with mineral wool and polyethylene vapour retarder. This means that almost all the moisture buffering happens in the gypsum board and the effect of thermal insulation on the indoor humidity almost negligible.

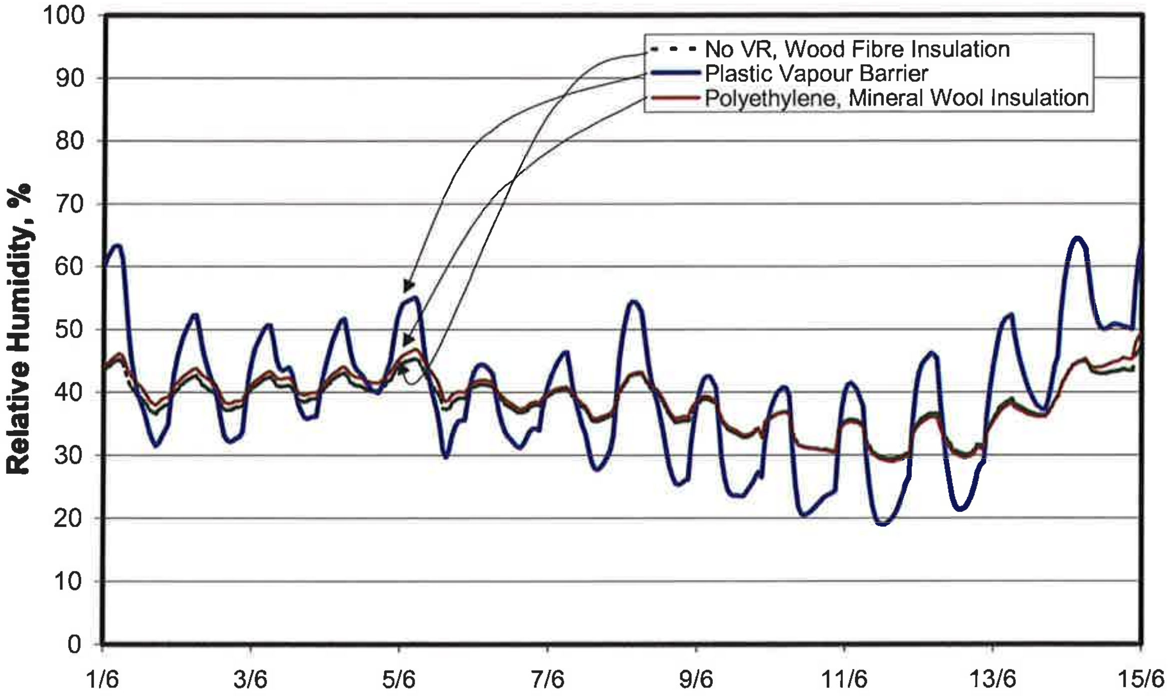


Figure 10. Hourly development of the indoor relative humidity during the first two weeks of June for each of the three different construction types /2/. In case *Plastic Vapour Barrier* (Case 2) the wall was covered with almost vapour tight coating and in case *Polyethylene, Mineral wool insulation* (Case 3) there was PE vapour barrier between the gypsum board and thermal insulation.

Moisture buffering effect

Due to the potentials to improve the thermal comfort and perceived air quality of the indoor air by passive structural methods, a Nordtest -method was created to define the moisture buffering value of building material layers and to create a protocol to measure this value /3, 4/.

The test protocol is based on daily cycles consisting of 8 h long higher humidity condition period (corresponding to the room occupation period) and a 16 hours long period having lower humidity (non-occupied period). The test are carried out under constant temperature conditions, +23°C. Typically the initial moisture content of the tested material or product is 50 % RH, and the exposure humidity conditions are 75 % RH and 33 % RH. The test sample is weighed continuously. From the open surface area, measured mass change and the varying conditions a moisture buffer value (MBV, [g/(m^2 %RH)] can be solved. This MBV value can be used to compare the moisture buffer properties of different products and to predict the effect on indoor air conditions.

Comparison of the MBV of eight building materials is presented in Figure 11. The highest value was detected with spruce boards about 1.2 g/(m^2 %RH)], while gypsum board had about half of this value, brick and concrete only about 1/3 of that of spruce.

The MBV of laminated wood with varnish finishing was about 0.42 g/(m^2 %RH)], mostly due to the additional diffusion resistance caused by the surface finishing. Gypsum boards had paper sheathing on both surfaces. All the other materials had untreated surfaces.

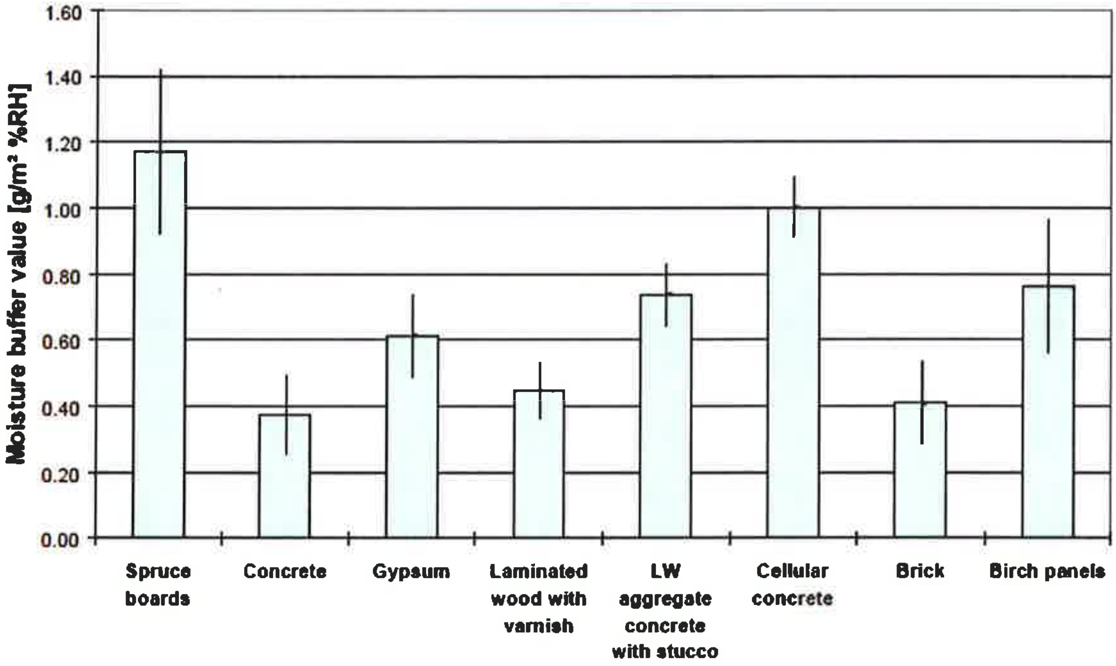


Figure 11. Moisture buffer value for some typical building materials, each measured in three different laboratories using three samples /4/.

Table 2 presents the classification of the moisture buffering values /4/. This classification show that the limit for good practical MBV level is 1 g/(m^2 %RH) during the 8 hour high humidity and 16 h low humidity periods.

Table 2. Ranges for practical Moisture Buffer Value classes /4/.

$MBV_{practical}$ class	Minimum MBV level	Maximum MBV level
	[g/(m^2 % RH) @ 8/16h]	
Negligible	0	0.2
Limited	0.2	0.5
Moderate	0.5	1.0
Good	1.0	2.0
Excellent	2.0	...

Example given in /4/: The moisture production of two sleeping persons is about 60 g/h corresponding to 480 g during 8 hour period. A practical assumption of the increase of relative humidity of a bedroom during the occupation period was 20.5

% RH, and the area having moisture buffering capacity was 12 m^2 (only ceiling). The MBV –level of the ceiling should be about 2 g/(m^2 %RH) so that it would correspond to the additional moisture load. This simplified study gives an idea of the level of moisture buffering effect under practical conditions.

Moisture absorption in thermal insulation layer through the inside sheathing – supplementary numerical study

The objective of this study was to show the potential of the thermal insulation to store moisture after the change of indoor air humidity conditions. This study was done by numerical simulations of the moisture buffering tests. The objective was to show how much moisture can be stored in the thermal insulation layer behind a wall board.

This study was carried out using numerical simulation with WUFI® 5.0 model /13/. The modelled case corresponds closely to the *moisture buffering value tests* /3/. The initial moisture content of the material layers of the wall structure correspond to the equilibrium moisture content under 50 % relative humidity. In these tests cycles consisting of eight hour indoor air moisture load period and 16 hour period with low indoor humidity are repeated. The indoor air relative humidity is 75 % RH during the 8 h moisture load period and 33 % RH in the 16 hour long period without moisture loads. Indoor temperature is constant, +23 °C.

Instead of repeating these cycles, only the moisture load period where the indoor air relative humidity changes from initial 50 % RH to 75 % RH was studied. The aim was to analyze the amount of moisture that can be accumulated in the thermal insulation layer behind the inside sheathing board.

Different thermal insulation and sheathing layer materials were used in the numerical analysis. The thickness of the sheathing board layer was 12.5 mm and that of the thermal insulation 300 mm. Four different interior sheathing board options were studied:

- Typical gypsum board having relative low moisture capacity and high vapour permeability,
- Artificial layer that had almost no moisture capacity and the same vapour resistance as gypsum board,
- Porous wood fibre board layer with relatively high moisture capacity and low vapour resistance, and
- Wooden panelling layer.

The indoor sheathing had surface coating (paint) only in those cases where the effect of this resistance was studied. The structure in this study was simplified: There were no air- or vapour barriers in the structure, except in one case there was a building paper layer between the thermal insulation and interior finishing board. In practice, the vapour barrier can be placed inside the thermal insulation so that the inner layer of the insulation could contribute to the moisture buffering.

The thermal insulation (300 mm thick) was either cellulose fibre insulation (70 kg/m^3) that has relatively high moisture capacity and low diffusion resistance, mineral wool having low capacity and resistance, and polyurethane (PU) insulation with low capacity and high resistance. Table 3 presents the numerically analysed cases. The studied period was 8 hours long and the timestep in simulations was 0.1 h.

The material properties correspond to those presented in WUFI model /13/.

The main interest was in how much moisture can be accumulated into different structures and especially into the thermal insulation layers under such conditions. Table 3 represents the different cases used in the study.

Table 3. Numerically solved cases.

Case code	Interior layer	Performance properties	Thermal insulation	Performance properties	Other layers
Non-cap. + CFI	Non-capacitive layer	Very low capacity, low diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	
G + CFI	Gypsum board	Low capacity, low diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	
Pwfb + CFI	Porous wood fibre board	high capacity, low diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	
Pwfb + PU	Porous wood fibre board	high capacity, low diffusion resistance	Polyurethane	Low capacity, high diffusion resistance	
Wooden panel + CFI	Wooden panel	high capacity, high diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	
G + MW	Gypsum board	Low capacity, low diffusion resistance	Mineral wool	Low capacity, low diffusion resistance	
G + PU	Gypsum board	Low capacity, low diffusion resistance	Polyurethane	Low capacity, high diffusion resistance	
Paint + G + CFI	Gypsum board	Low capacity, low diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	Interior paint, $S_d = 0.2$ m
Paint + G + PU	Gypsum board	Low capacity, low diffusion resistance	Polyurethane	Low capacity, high diffusion resistance	Interior paint, $S_d = 0.2$ m
G + pap+ CFI	Gypsum board	Low capacity, low diffusion resistance	Cellulose fibre insulation	High capacity, low diffusion resistance	Building paper 1 mm, $S_d = 0.8$ m
G + pap+ PU	Gypsum board	Low capacity, low diffusion resistance	Polyurethane	Low capacity, high diffusion resistance	Building paper 1 mm, $S_d = 0.8$ m

The paint layer used in two cases was chosen so that it produced relatively low surface resistance, the S_d –value was set to be 0.20 m. These cases correspond better to practical cases than those without any internal coating. The surface resistance used in reference /1/ study ($S_d = 0.04$ m) is relatively low compared to the resistance of typical paint coatings, and the $S_d = 0.20$ m corresponds better to practical values.

Cellulose fibre insulation has relatively high moisture capacity when compared to the density of the material. This material was used as a reference material to represent moisture buffering of thermal insulation.

Figure 12 presents the moisture mass flow rates into the wall structure from indoor air and from interior board to the thermal insulation in two cases: Gypsum + CFI and painted Gypsum + CFI.

Figure 13 presents the solved moisture flow rates through the interior surface board to the CFI thermal insulation in four different cases having different interior layers. The moisture flow rate histories give an idea about the moisture transfer process.

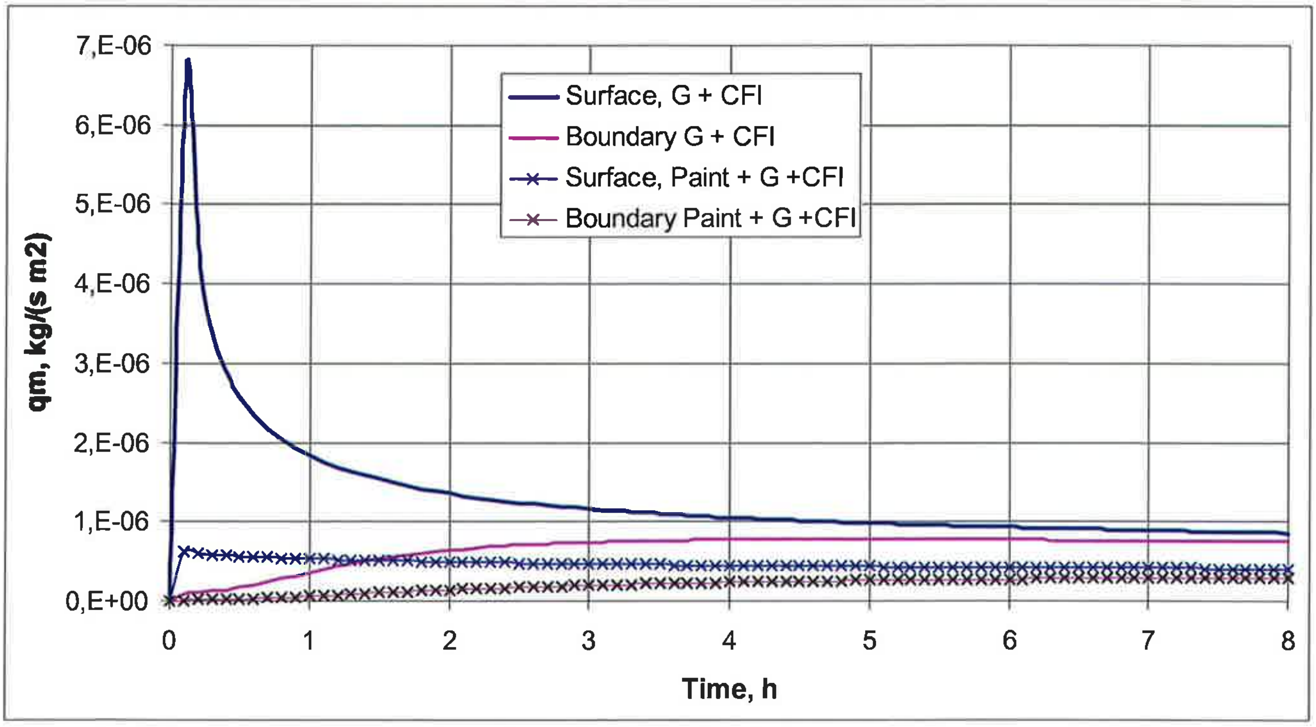


Figure 12. Moisture mass flow rates into the wall (Surface) and between indoor board layer (12.5 mm gypsum) and cellulose fibre insulation (Boundary) after the change of indoor relative humidity from 50 % (initial equilibrium moisture content of all material layers in the structure) to 75 % RH. Positive values correspond to moisture flow into the structure.

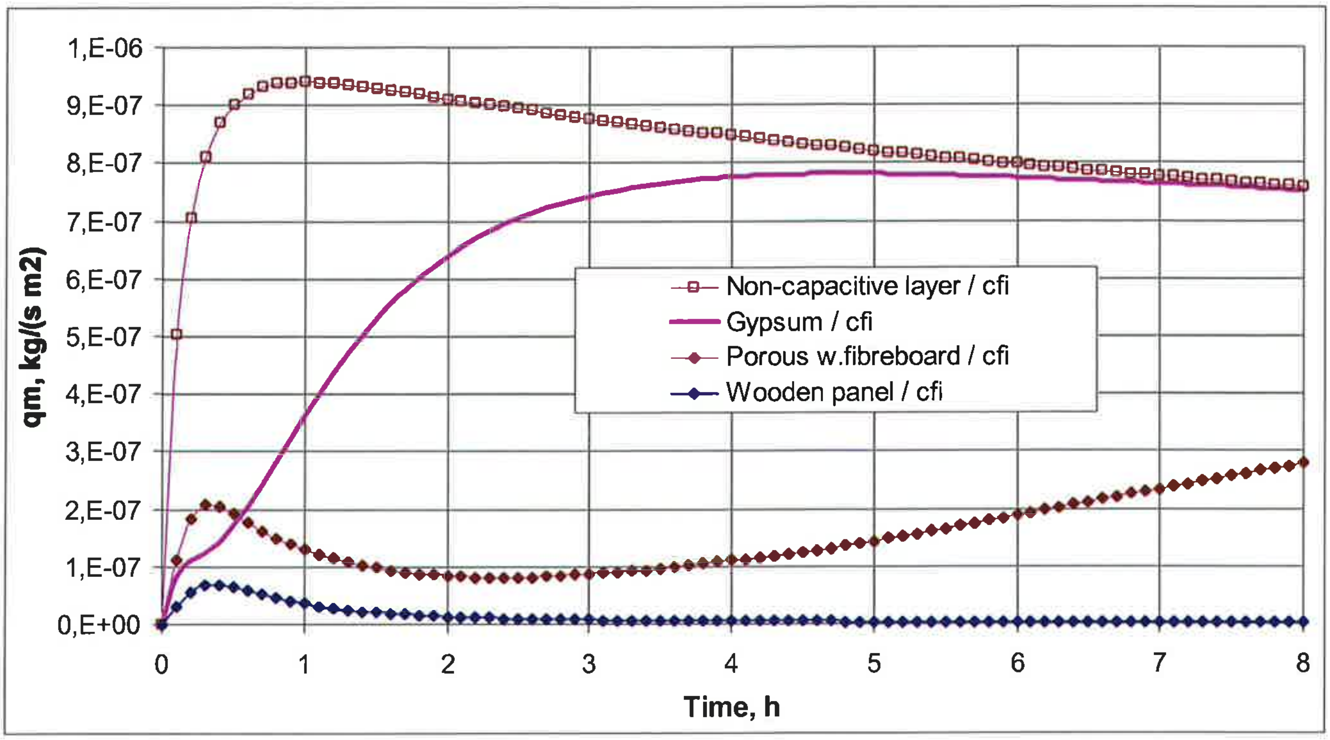


Figure 13. Moisture mass flow rates between indoor board layer (12.5 mm) and cellulose fibre insulation after the change of indoor air relative humidity from 50 % (initial equilibrium moisture content of all material layers in structure) to 75 % RH. Positive values correspond to moisture flow into the thermal insulation.

The figures show that when the interior surface board has high moisture capacity, the moisture flow into the thermal insulation remains lower than in other cases. Gypsum board that represents relatively low moisture capacity and low vapour diffusion resistance, results into significantly higher moisture flow through the board into the thermal insulation. If the interior finishing board had no moisture capacity, the moisture flow rate had the highest values during the first 3 – 4 hours after the change of boundary conditions. In eight hours the cases with non-capacitive and gypsum boards resulted in similar moisture flow rates into the insulation, which is due to the saturation of the gypsum board moisture capacity.

The curve shape during the first half hour is due to the effect of the low temperature increase of the structure surface caused by the latent heat released in moisture absorption. Small and temporary temperature gradient slightly increased the potential for diffusive moisture transfer. This effect during the beginning of the absorption process caused merely moisture redistribution, i.e. moisture from surface board into the insulation. For example with wooden panelling there was no moisture flow through this boundary after the initial temperature gradient had fainted.

Figure 14 presents the moisture accumulation into the wall board and thermal insulation during the first hour and during eight first hours of exposure to high humidity conditions. During the first hour there were practically no moisture accumulation into the thermal insulation layer, not even in the case with non-capacitive wall board.

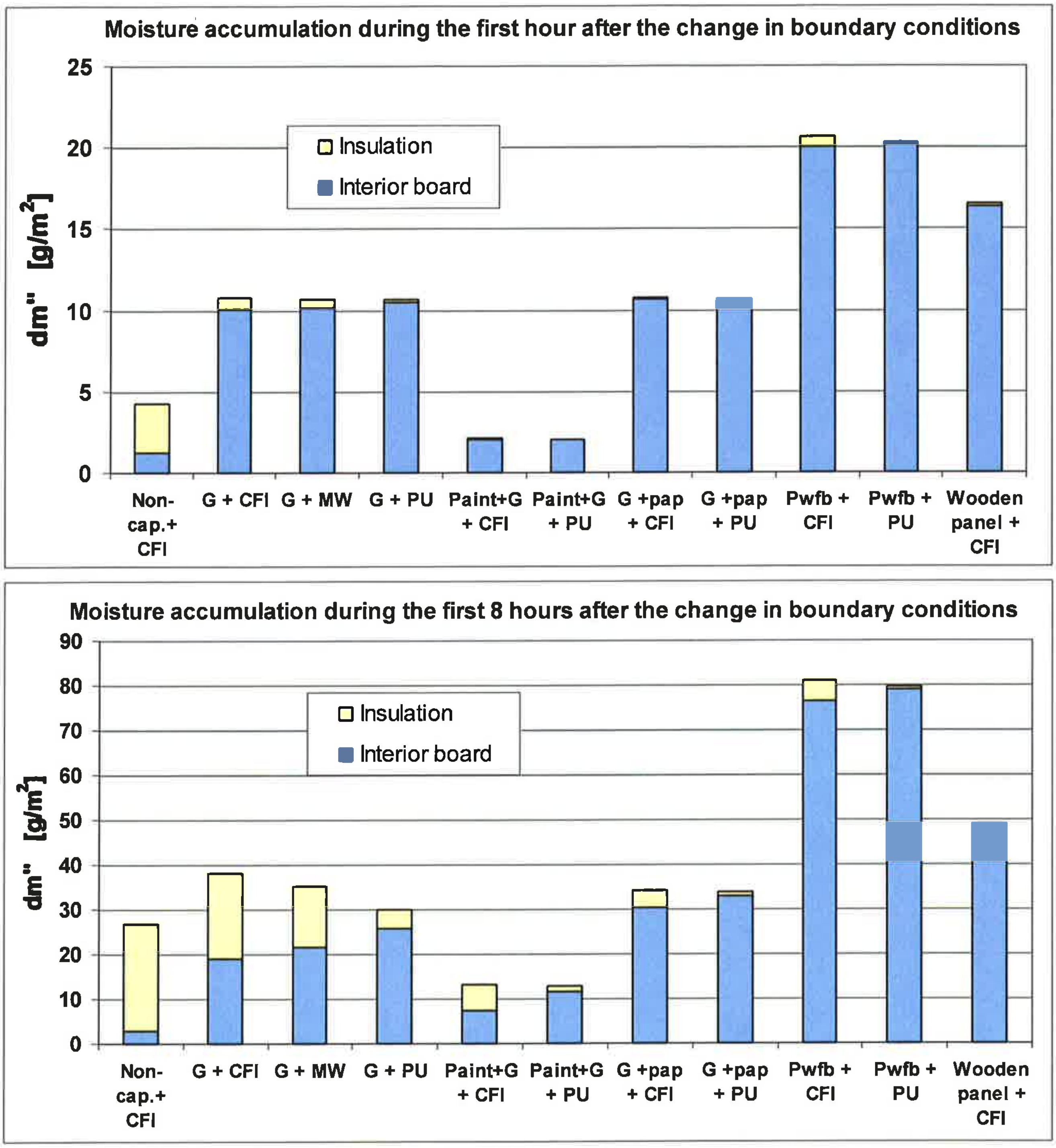


Figure 14. Moisture absorption in inside surface layer (12.5 mm thick) and in the thermal insulation layer of a wall after a step change in relative humidity boundary conditions (from 50 % RH to 75 % RH) and under constant temperature conditions. Absorbed mass of moisture per surface area during the first hour (above) and during the first eight hours (below) after the change.

During the first eight hours the moisture capacity of the thermal insulation could be utilized only in cases having low moisture capacity (gypsum) or non-capacitive wall boards. The highest moisture buffering levels could be reached with porous wood fibre wall boards (about 80 g/m^2 moisture absorption) in cases with CF or

PU insulations. With wooden panelling the figure was about 50 g/m^2. In these cases the absorption in the thermal insulation was practically negligible.

In cases having gypsum wall board, some moisture could be accumulated in the thermal insulation layer during eight hours. Unpainted gypsum with cellulose fibre had only moisture accumulation about 38 g/m^2, while with mineral wool insulation this was 8 % lower and with PU insulation 21 % lower. When the gypsum was painted with relatively vapour open paint ($S_d = 0.20$ m), the moisture absorption in the PU insulated structure was only 4.6 % lower than into that with CF insulation. This paint layer reduced the moisture accumulation into the structures by 57 – 65 % from that of the unpainted case and the buffering effect was about the same walls having gypsum board and either cellulose fibre or polyurethane insulation.

When there was a building paper layer between the unpainted gypsum wall board and the thermal insulation, the wall with cellulose insulation had only 1 % higher moisture accumulation during the eight hours period than the structure with PU insulation.

Only in a case with non-capacitive wall board that have the same low diffusion resistance as gypsum board (artificial product) and when there was no coating (paint) on the wall board surface, the moisture absorption in the insulation exceeded that into the wall board during eight hours. In this case the total moisture absorption was lower than in the case having unpainted gypsum board and polyurethane insulation. Even if the hygroscopic capacity of the thermal insulation layer was tried to be utilized as efficiently as possible, the result showed lower moisture buffering capacity than a practical solutions with gypsum board and non-capacitive insulation layer.

These simulations show the marginal effect of the moisture capacity of the thermal insulation layer on the indoor air humidity conditions. Only when the surface is close to uncoated and the wall board has low moisture capacity, the thermal insulation can have some practical effect on the indoor humidity conditions. However, when the moisture buffering effect is to be efficiently utilized, the wall board should have the buffering capacity. In such case, the thermal insulation does not play any practical role in the indoor air moisture buffering phenomenon.

Discussion and conclusions

Terms *breathing* or *breathable structures* typically represent the ability of structures to damp down the daily indoor air humidity variations by utilizing the hygroscopic capacity of the material layers in structures.

Vapour open structures

The moisture damping ability does not mean that the structures should be totally vapour permeable from inside to outer surface. Totally vapour open structures increase moisture flow out from indoor air, which can reduce the indoor humidity level more than typical structures having vapour barrier. This may cause too low humidity levels during cold periods. A breathable structure having indoor air moisture buffering capacity can be implemented practically with any kind of structure by using inside sheathing materials that have high hygroscopic moisture capacity in the relative humidity range corresponding to practical indoor conditions. The inside surface of the structure should be as vapour open as possible to allow moisture flow between indoor air and the capacitive layer, but there can be a vapour barrier or other vapour tight layer inside the structure.

Air leaking structures

Air tight building envelope is part of good building practice. Airtightness allows controlled ventilation and pressure conditions for the building and enables proper performance of the ventilation heat recovery.

Air leaking building envelope may cause local discomfort in indoor conditions, increased energy consumption and even moisture risks for structures, and it do not contribute to moisture buffering of structures or the generation of good indoor conditions. Building structures, breathable or not, should not be air leaking.

Benefits of indoor humidity control

Indoor humidity has a significant effect on occupant comfort and perceived air quality. It may also have effect on building durability and material emissions, and indirectly also to energy consumption. The ability of hygroscopic materials to damp down diurnal changes of indoor humidity can contribute to good indoor comfort along with HVAC system. The main benefit of the moisture buffering capacity of structures is the reduction of indoor humidity peak values during occupation period, which improves the comfort and acceptability of the indoor conditions.

When hygroscopic structures having vapour open inside surface was compared with structures having vapour tight surface, the long term (weeks and longer) average humidity values were almost the same. The moisture capacity of structures could be seen mainly in the daily humidity variations that could be smoothed down by this effect.

Effect of Climate

The climate typically affects the level of indoor temperature and humidity, but not the changes during occupation. The increase in absolute humidity and temperature during the occupation period is quite independent of the climate. The studies show that passive methods of controlling the indoor climate are more successful in moderate climates than in hot and humid climates due to the effect on daily extreme humidity levels /1/.

Moisture buffering applications

The conditions to generate and utilize the moisture buffering effect are quite demanding.

The inside surface of the structure should be as vapour open as possible, which gives preconditions for the vapour resistance of the possible surface coating, like paint layers. When the surface resistance is in typically practical levels, the effect of the moisture buffering potential and also that of the thermal insulation layers is decreased from the maximum possible levels with uncoated surface. A relatively diffusion open paint layer (S_d = 0.20 m) on the wall surface could reduce the moisture buffering of a wall by about 55 – 65 % from that of an uncoated case.

The wall board that is in contact with indoor air has the main capacity to act as a moisture buffering material layer. Depending on the vapour permeability and especially on the moisture capacity properties of the wall board, thermal insulation may have some relatively low or practically no effect on the moisture buffering of indoor air under daily cycles.

Effect of thermal insulation

Carsten & al. /2/ studied a room where all walls and the ceiling structure had a 13 mm gypsum board that was plastered and then primed with a single coat of diffusion open paint. The results showed that the effect of structures on the indoor air humidity was practically the same in so called *breathable case* having wood fibre insulation and building paper and in a typical wall case having polyethylene vapour retarder between the gypsum board and mineral wool insulation. Only when the inside wall surface was covered with a plastic vapour barrier, the indoor humidity loads could cause more than 15 % RH higher indoor humidity peak values during occupation when compared to the breathable or typical vapour barrier cases.

The highest moisture buffering effect during 8 hours moisture load periods can be achieved in cases with uncoated wall board that has high hygrothermal capacity and high vapour permeability. In this case the thermal insulation material has a negligible effect on the indoor air humidity. Also, in such case where all the moisture accumulation takes place in the wall board, a vapour barrier between the inside wall board and the thermal insulation does not reduce the moisture buffering effect.

According to simulations, a structure having a wall board with high moisture capacity and low diffusion resistance (like porous wood fibre board) and a non-capacitive thermal insulation (polyurethane) or even a PE vapour barrier, could have significantly higher (about 100 %) moisture buffering capacity than a structure with gypsum board and high moisture capacity thermal insulation. The same result was detected also with a structure having high moisture capacity wall board with some relevant diffusion resistance, like wooden panels. Thermal insulation behind the panels did not take part in the moisture buffering, but the moisture buffering effect was close to 30 % higher than in case with gypsum board and cellulose fibre insulation.

Thermal insulation layer that is behind the internal sheathing layer has quite limited effect on the indoor humidity conditions during daily moisture load cycles. The effect depends strongly on the vapour permeability and moisture sorption properties of the wall board and the possible other material layers between insulation and indoor air. A well performing breathable structure can be achieved also using thermal insulation with low moisture capacity and low vapour permeability.

Espoo, 24.11.2011

Juhani Hyvärinen
Manager, Services

Tuomo Ojanen
Senior Scientist

References

1. Simonson, C., Salonvaara, M., Ojanen, T. Improving Indoor Climate and Comfort with Wooden Structures. VTT PUBLICATIONS 431. Technical Research Centre of Finland (VTT), Espoo 2001. 200 p. + App. 91 p.

2. Rode, C.; Salonvaara, Mikael; Ojanen, Tuomo; Simonson, Carey; Grau, K. Integrated hygrothermal analysis of ecological buildings. Proceedings of the 2nd international conference on building physics, IBPC 2003. Antwerpen , Belgium, 14-18. Sept. 2003, . K.U.Leuven, Laboratory of Building Physics. Antwerpen (2003), pp. 859 – 868

3. Rode, C., Peuhkuri, R., Hansen, K., Time, B., Svennberg, K., Arfvidsson, J. and Ojanen, T. NORDTEST project on moisture buffer value of materials. Proceedings of the AIVC Conference Energy Performance Regulations, Brussels, Sept. 21-23, 2005. 6 p.

4. Moisture buffering of building materials. BYG - DTU Report R-126. 2005. 78 p.

5. ISO 7730-1994, Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, International Organization for Standards, Geneva, Switzerland.

6. ANSI/ASHRAE Standard 55-1992, Thermal environmental conditions for human occupancy, ASHRAE, Atlanta.

7. Toftum J., Jorgensen, A.S. and Fanger, P.O., 1998a, Upper limits for indoor air humidity to avoid uncomfortably humid skin, Energy and Buildings, 28, 1-13.

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

9. Fang, L., Clausen, G. and Fanger, P.O., 1998b, Impact of temperature and humidity on the perception of indoor air quality during immediate and longer whole-body exposures, Indoor Air, 8, 276-284

10. ITS, 1999, Information Technology Specialists Inc., The Residential Energy Efficiency Database (designed and created by B. J. Mitchell, M. Ryder and M. Mitchell): Indoor Air Quality - moisture and humidity, http://www.its-canada.com/reed/iaq/chart1.htm.

11. ASHRAE, 1997, Fundamentals handbook, ASHRAE, Atlanta.

12. Grau, K. and Wittchen, K.B., 1999, Building design system and cad integration, Proceedings of IBPSA Building Simulations '99, Kyoto, Japan, http://www.sbi.dk/english/publishing/software/bsim2000/mainmenu.htm.

13. WUFI® (Wärme und Feuchte instationär - Transient Heat and Moisture) 5.02 Pro software, The Fraunhofer Institute for Building Physics IBP. 2009.

Distribution	Customer	Original
	Archive	Original