The Influence of Moisture Capacity of Building Materials on the Indoor Air Quality

Field Measurement

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***Abstract*- The aim of the study was to find out how hygroscopic material such as wood is influencing the comfort of indoor conditions (humidity). For the field measurement 14 single family houses were chosen, which represented massive hygroscopic, massive non-hygroscopic, light hygroscopic and light non-hygroscopic structures. According to the measurements there is no significant difference in behaviour when monthly values (temperature and relative humidity) were compared. However, when daily values were studied, differences can be found. The interior (furnishing, textiles, carpets etc.) has a high impact on hygroscopic behaviour of indoor climate. Thus, the non-hygroscopic structures were actually somewhat hygroscopic due to the interior.**

Keywords- Moisture Capacity; Air Change Rate; Wood Products Indoors

I. INTRODUCTION

Relative humidity indoors has a very important role in respect of indoor air quality, thermal comfort, occupant health, material emissions and energy consumption. A too low relative humidity indoors may cause respiratory illnesses and asthma. However, also too high relative humidity has negative effects such as mould and moisture problems, dust mites and it might also cause respiratory illnesses. In most of the previous studies the temperature and air pollutants are well analysed, but the indoor air humidity has far less been noticed although it can have important consequences.

Many previous studies have shown that the moisture storage of finishing materials has an effect on indoor air relative humidity [1]. In addition, the effect on moisture sorption capacity on indoor air relative humidity is shown in many studies [2, 3, 4, 5, 6, 7].

In a study by [8] it was found out that hygroscopic structures can improve indoor air quality and comfort. In that study as many as 10 more people of 100 are satisfied with the thermal comfort conditions (warm respiratory comfort) at the end of occupation if hygroscopic materials were used. They also found out that during certain times of the year (mainly summer), as many as 25 more people will be satisfied with the hygroscopic bedroom.

In a study by [4] they found that hygroscopic wall and ceiling give substantial stability to the indoor relative humidity in rooms which are ventilated at less than one air change at hour. In spite of these encouraging results [4] also emphasised that wood, as normally used, has rather small buffer capacity, because of the slow movement of water across the cell walls and into the interior. The indoor relative humidity is changed by natural ventilation faster than the wood can supply or absorb moisture to compensate for the change. The end grain wood is a very good humidity buffer but it is never used as an indoor finish.

Typically the humidity in indoor climate has rapidly changes due to behaviours of inhabitants such as cooking, showering etc. In northern climate the relative humidity is at lowest during winter months and at highest during summer period. In Finland the main concern has been too low relative humidity. Studies focusing on high humidity are far less common.

The aim of this study is to find out what is the influence of hygroscopic properties of wood based structures on indoor air humidity, temperature and comfort. This paper focuses on results based on field measurements.

II. MEASURED BUILDINGS

In this study four different kinds of buildings were selected to the measurements; 1) construction with high thermal but without moisture capacity, 2) construction with high thermal and moisture capacity, 3) construction with low thermal but high moisture capacity, 4) construction with low thermal and moisture capacity. 14 buildings were selected to the measurements. Six of the buildings had mechanical exhaust ventilation and the rest of them mechanically supply and exhaust ventilation, as shown in Table I.

TABLE I STUDIED BUILDINGS

Building no.	Location	Year of completion	Ventilation System	Building framework	Type of construction
1	Vantaa	1984	Mechanical exhaust	Aerated concrete	high thermal capacity, low moisture capacity
2	Helsinki	1990	Mechanical exhaust	Concrete	high thermal capacity, low moisture capacity
3	Tuusula	1999	Mechanical supply and exhaust	Timber log	high thermal capacity, high moisture capacity
4	Sipoo	2000	Mechanical exhaust	Timber log	high thermal capacity, high moisture capacity
5	Lappeenranta	1999	Mechanical exhaust	Timber	low thermal capacity, high moisture capacity
6	Lappeenranta	2001	Mechanical supply and exhaust	Timber	low thermal capacity, high moisture capacity
7	Lappeenranta	1999	Mechanical exhaust	Timber	low thermal capacity, high moisture capacity
8	Espoo	2000	Mechanical supply and exhaust	Timber	low thermal capacity, high moisture capacity
9	Espoo	2001	Mechanical supply and exhaust	Timber	low thermal capacity, high moisture capacity
10	Vantaa	2001	Mechanical supply and exhaust	Timber	low thermal capacity, low moisture capacity
11	Tuusula	2000	Mechanical exhaust	Timber	low thermal capacity, low moisture capacity
12	Tuusula	2000	Mechanical supply and exhaust	Timber	low thermal capacity, low moisture capacity
13	Tervakoski	2001	Mechanical supply and exhaust	Timber	low thermal capacity, low moisture capacity
14	Tuusula	2001	Mechanical supply and exhaust	Timber	low thermal capacity, low moisture capacity

Measurements of temperature and relative humidity (RH) in living room, parents' bedroom and shower room were done. The values were logged continuously in 15 min intervals from the beginning of July till the end of September. In some buildings also the concentration of carbon dioxide in the master bedroom was measured.

Before the continuous measurements of temperature and relative humidity a detailed study of the building was done. The air flow rates and pressure difference between indoor and outdoor air were measured at different stages of ventilation system. The air tightness of the building was also measured according to standards EN 13829:2000 and ASTM E779-87. In this test a 50 Pa under or over pressure is caused inside the building by using a fan. In our study we caused under pressure. The air flow through the fan is equal to the air flow through leakages in building envelope. The air flow measured and the n50-number (air change rate through leaks at 50 Pa) can be established. In three of the buildings the concentration of carbon oxide was measured continuously in the two-persons-bedroom.

The acceptability of the indoor climate was analyzed according to ISO 7730 standard by calculating predicted percentage of dissatisfied (PPD). The PPD values can be calculated from predicted mean values (PMV).

In this study the mean radiant temperature, surface temperature and air temperature were assumed to be equal. The air velocity was 0.1 m/s, metabolic rate in living room was 63.8 Wm^{-2} (1.1 met) and in bedroom was 46.4 Wm^{-2} (0.8 met). Thermal resistance of clothing was 0.08 $m^{2}°CW^{-1}$ (0.5 clo) in the living room and 0.2 $m^{2}°CW^{-1}$ (1.3 clo) in the bedroom. The higher thermal resistance of clothing in the bedroom also takes the thermal resistance of the blankets and coverages.

III. RESULTS

A. Air Tightness, Ventilation Rates and CO_2 Concentrations

The average of the air tightness, n_{50}, was 3.7 ach, which is typical for dwellings in Finland, Table II. The building 2 was extremely tight having a n_{50} of 0.3 ach. The pressure difference between indoor and outdoor air at the normal use of the ventilation system was small, in average -1.7 Pa, indicating a slight under pressure inside the building. Only one building had a slight over pressure, 1 Pa, Table II. Exhaust air flow was 0.31 L/s,m2 in average.

TABLE II N50, PRESSURE DIFFERENCE AND THE EXHAUST AIR FLOW OF THE STUDIED BUILDINGS. NEGATIVE PRESSURE DIFFERENCE INDICATES THAT THE PRESSURE IS LOWER INSIDE THE BUILDING.

Building no.	Volume (m^3)	Area (m^2)	n_{50} (ach)	Pressure difference at normal use (Pa)	Exhaust air flow at normal use (L/s,m^2)
1	800	150	1.7	-2	0.17
2	630	126	0.3	-8	0.15
3	560	167	4.7	-1	0.28
4	659	270	5.0	-2	0.22
5	502	152	3.2	-1	0.07
6	730	140	2.4	1	0.62
7	519	185	5.4	-4	0.31
8	610	195	3.4	-1	0.31
9	406	140	7.2	-1	0.46
10	520	168	4.5	0	0.33
11	399	120	3.1	-3	0.43
12	520	172	4.2	0	0.27
13	420	137	4.2	-1	0.28
14	540	167	2.3	-1	0.38
Average	**558**	**163**	**3.7**	**-1.7**	**0.31**

The pressure differences were low since most of the buildings had mechanical supply and exhaust ventilation, Fig. 1. Typically in buildings with mechanical exhaust ventilation the pressure difference rises when the ventilation is higher. In buildings 10 and 12 a pressure difference could not be found at any stage of the use of the ventilation system. In building 5 they did not have the ventilation at normal use, thus the ventilation at normal is lower than in minimum.

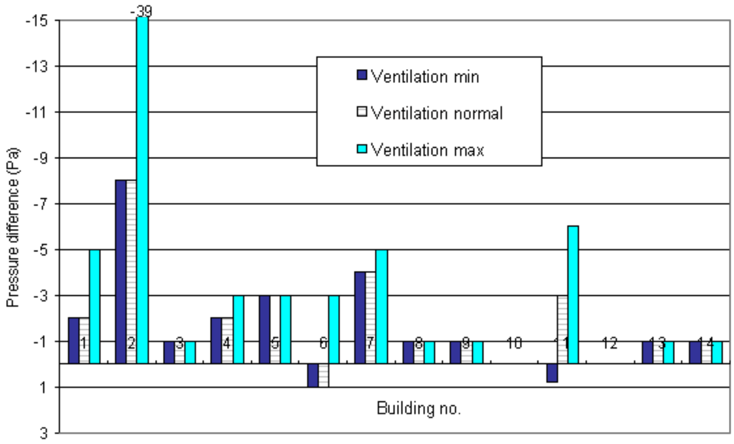


Fig. 1 Pressure difference at different positions of ventilation. Negative pressure difference indicates lower pressure inside the building.

In four of the buildings the normal use of the ventilation was the same as minimum or even lower, Fig. 2. However, in majority of the buildings the normal use of the ventilation was higher than minimum. In average the exhaust air at minimum was 0.25 L/s,m^2 and at maximum 0.51 L/s,m^2.

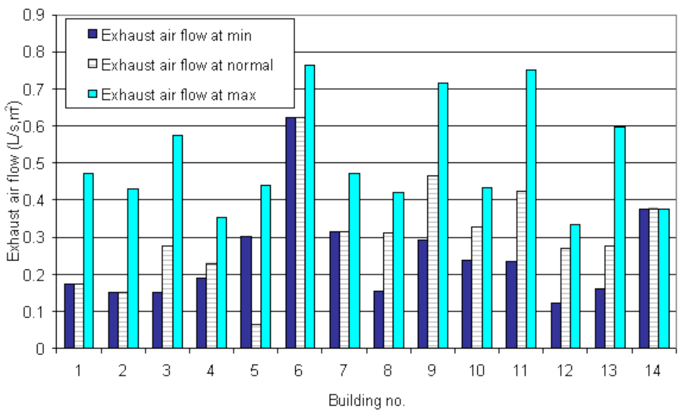


Fig. 2 Exhaust air flow at different ventilation stages

Supply air flow in two-persons-bedroom was measured from buildings with mechanical supply and exhaust ventilation. Although building 6 had mechanical supply and exhaust ventilation, there were no supply air valves in the bedroom.

According to Finnish Classification of Indoor Climate 2000 the air flow should be 6 L/s,person for Class S3, 8 L/s,person for Class S2, and 12 L/s,person for the highest Class S1. At normal use the buildings 8, 9 and 14 were qualified for class S3, in the buildings 3, 10 and 12 even the highest air change rate was not enough to meet the criteria of class S3, Table III.

TABLE III SUPPLY AIR FLOW RATES IN TWO-PERSON-BEDROOMS

Building no.	Air flow at min (L/s)	Air flow at normal (L/s)	Air flow at max (L/s)
3	3	5	10
8	9	11.5	14
9	9	12	22
10	7	7.5	10.5
12	2	5	6
13	4	5	16
14	12	12	12
Average	**6.6**	**9**	**13**

In average the measured sound level in bedroom was low, 22 dB(A) at normal use, Table IV. In Finnish Classification of Indoor Climate 2000 a sound level lower than 30 dB(A) is classified as the highest Class S1. Although all measured buildings met this criterion the inhabitants often complained that the ventilation created noise in bedrooms.

TABLE IV THE SOUND LEVELS IN TWO-PERSON-BEDROOM

Building no.	Sound level at min (dB(A))	Sound level at normal (dB(A))	Sound level at max (dB(A))
1	23	23	26
2	20	20	21
3		23	
4	21		28
5			28
6	30	30	30
7	21	21	21
8	19	19	23
9	18	20	28
10	19	20	22
11	25	25	26
12	19	21	25
13	18	20	27
14	20	20	20
Average	**21**	**22**	**25**

In three of the buildings the concentration of carbon dioxide was measured. During day time when inhabitants are at work the concentration of the carbon dioxide is as low as in outdoor air, 400 ppm, Fig. 3. In the bedroom of building 11 only one person was sleeping, thus it had the lowest CO_2 concentration. The CO_2 concentration in the building 3 is close to the limit value of the last Class of indoor air S3. Probably the inhabitants had the bedroom door open since the supply air flow was not high enough to qualify the Class S3. The concentration of CO_2 was highest in the building 9 and it seemed that the inhabitants were using the ventilation system at a lower rate than they reported at the beginning of the study.

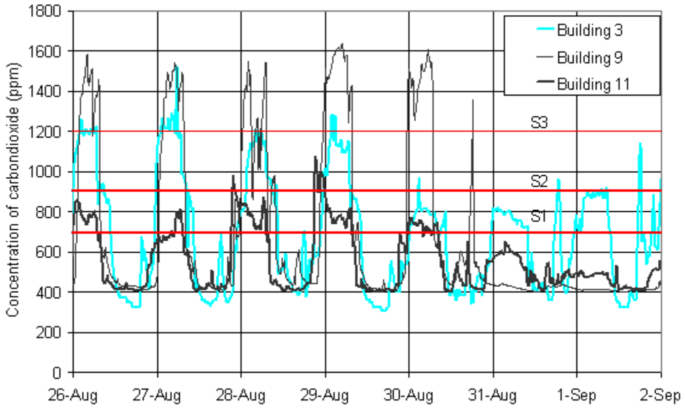


Fig. 3 Concentrations of carbon dioxide in buildings 3, 9 and 11 during one week

B. Absolute and Relative Humidity in Bedrooms

August was chosen for a detailed study since the temperature is still high and the inhabitants are already back at home for summer holydays. The buildings with a high thermal and moisture capacity had clearly lower relative humidity in August than the buildings with high thermal but low moisture capacity, Fig. 4 (left). Relative humidity and temperature are strongly linked together and when the absolute humidity of the buildings is compared, the difference is nearly negligible, Fig. 4 (right).

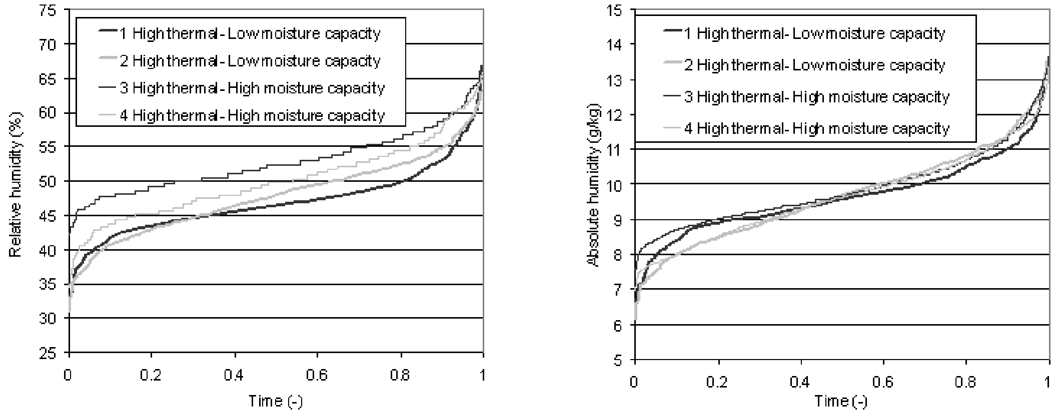


Fig. 4 Duration curves of relative humidity (left) and absolute humidity (right) in bedrooms in buildings with a high thermal and high or low moisture capacity

Buildings with low thermal capacity and low moisture capacity had fairly similar duration curves of relative humidity in August, Fig. 5 (left). Only the relative humidity of building 12 is clearly lower. However, when the absolute humidity is compared, the differences are once again small, Fig. 5 (right). The duration curve of relative humidity in buildings with low thermal but high moisture capacity had a wide range of variation, Fig. 6 (left). Absolute humidity in buildings is quite the same but building 9 has a higher absolute humidity, Fig. 6 (right).

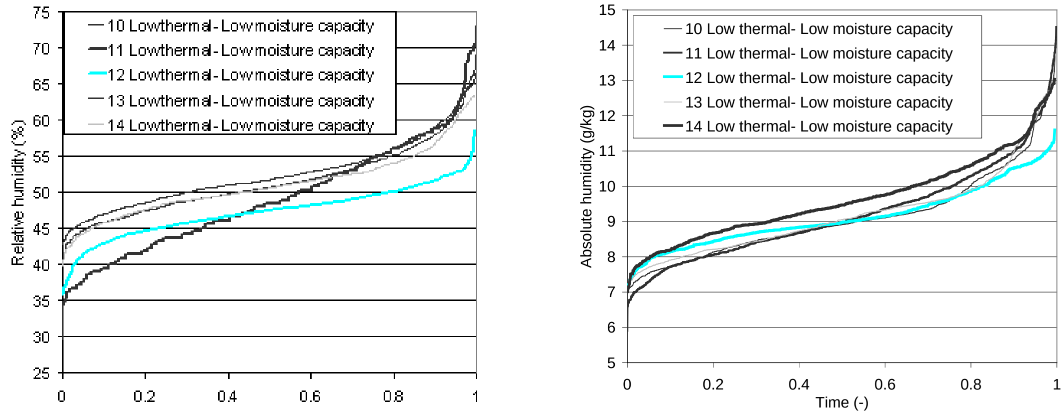


Fig. 5 Duration curves of relative humidity (left) and absolute humidity (right) in bedrooms in buildings with a low thermal and low moisture capacity

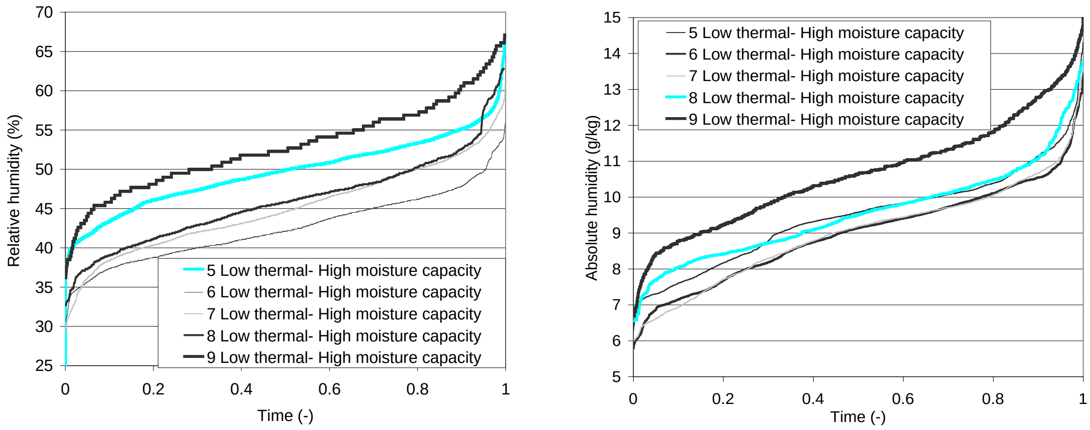


Fig. 6 Duration curves of relative humidity (left) and absolute humidity (right) in bedrooms in buildings with a low thermal and high moisture capacity

The difference between minimum and maximum absolute humidity was highest in building 11 and lowest in building 12; both buildings had a low thermal and moisture capacity, Table V. It seemed that the temperature had a stronger effect on humidity in the buildings than the moisture capacity of the construction.

TABLE V MINIMUM AND MAXIMUM AND THE DIFFERENCE BETWEEN MINIMUM AND MAXIMUM ABSOLUTE HUMIDITY, AND THE DIFFERENCE BETWEEN MAXIMUM AND MINIMUM RELATIVE HUMIDITY IN AUGUST

Construction type	Building no	Min. of absolute humidity (g/kg)	Max. of absolute humidity (g/kg)	Diff. in absolute humidity (g/kg)	Diff. in relative humidity (%)
High thermal and low moisture capacity	1	6.2	13.4	7.2	35.7
	2	6.2	13.5	7.4	32.1
High thermal and high moisture capacity	3	7.6	13.7	6.1	23.8
	4	7.0	13.4	6.4	31.8
Low thermal and high moisture capacity	5	6.3	14.3	8.0	30.9
	6	5.8	13.4	7.7	32.2
	7	6.0	13.7	7.7	31.5
	8	6.5	13.7	7.2	30.1
	9	6.7	15.3	8.6	30.9
Low thermal and low moisture capacity	10	7.1	13.7	6.6	29.2
	11	5.9	14.5	8.6	43.4
	12	7.1	11.6	4.5	22.8
	13	7.1	13.2	6.1	23.9
	14	7.0	13.1	6.0	23.7

C. Temperature in the Bedrooms

Temperature was clearly lower in the buildings 3 and 4 than in buildings 1 and 2. According to Finnish Classification of Indoor Climate 2000, temperature shall not exceed 26°C in the summertime for Class S2 and only building 3 satisfies this criterion. Building 1 exceeds S2 criterion in 50% of the time in August, Fig. 7.

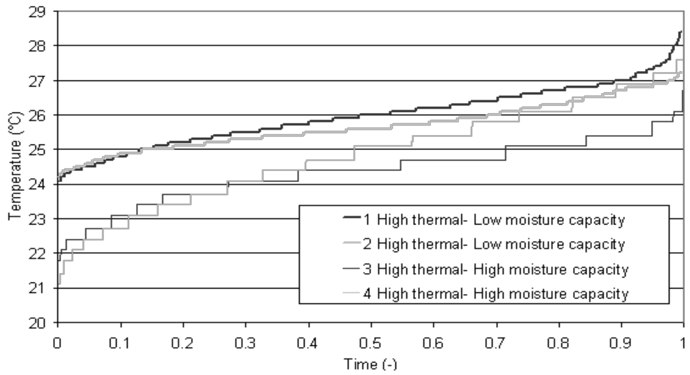


Fig. 7 Temperature in the buildings with high thermal capacity

Buildings with low thermal and moisture capacity in this study had lower temperature than buildings with low thermal and high moisture capacity. The different temperature behaviors can be explained in different locations and sun shadow. Buildings 10 and 13 meet the criterion of Class S2 nearly all the time. Fig. 8. Buildings 6 and 8 exceed 26°C in 60% of the time in August, Fig. 8.

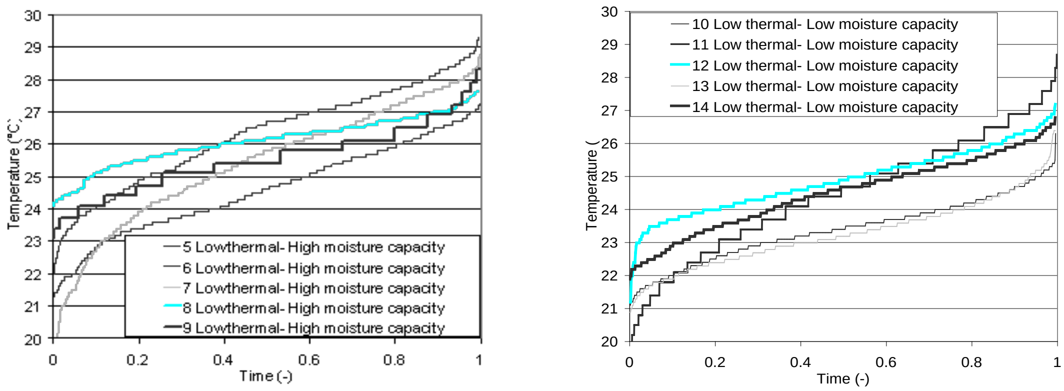


Fig. 8 Temperatures in buildings with low thermal and high moisture capacity (left) and in the buildings with low thermal and moisture capacity (right)

D. Predicted Percentage of Dissatisfied

The predicted percentage of dissatisfaction was shown in Figs. 9-10. In building 3 only in 2% of the time the recommended value of dissatisfaction of 20% was exceeded. The construction with high thermal and low moisture capacity exceeded the value of dissatisfied in 20% of the time.

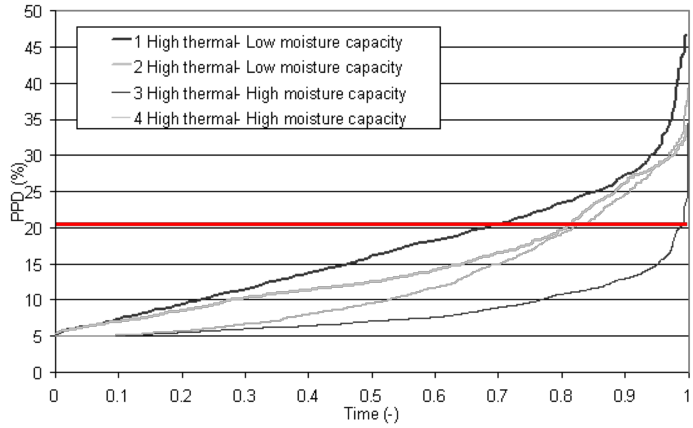


Fig. 9 Duration curve of predicted percentage of dissatisfied for constructions with high thermal capacity in August

Building 11 had the highest value of dissatisfaction of buildings with low thermal and low moisture capacity, PPD 48%, Fig. 10. In that construction 17% of the time the limit value PPD 20% was exceeded. Buildings 10 and 13, which had the lowest temperatures, had also very low PPD values; their PPD values exceeded 20% limit value only in a few percentages of the time in August. Building 6 with low thermal but high moisture capacity exceeds the limit value in 53% of the time in August; this building also had the highest temperatures, and it has the highest peak value of PPD 66%.

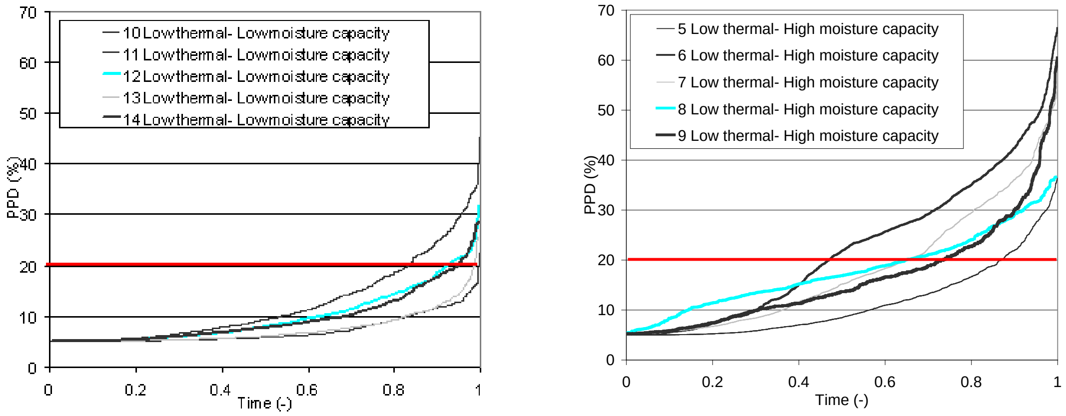


Fig. 10 PPD values for constructions with low thermal and moisture capacity (left) and with low thermal and high moisture capacity (right)

E. Difference of the Relative Humidity in Bedrooms and Living Rooms

Both buildings 1 and 13 did not have any moisture capacity in the structures. Building 1 had a high thermal capacity, and the thermal capacity of the building 13 was smaller. Relative humidity in both buildings at night time was higher in the bedroom, when people were there, Fig 11. During the day time relative humidity was quite similar in both living room and bedroom.

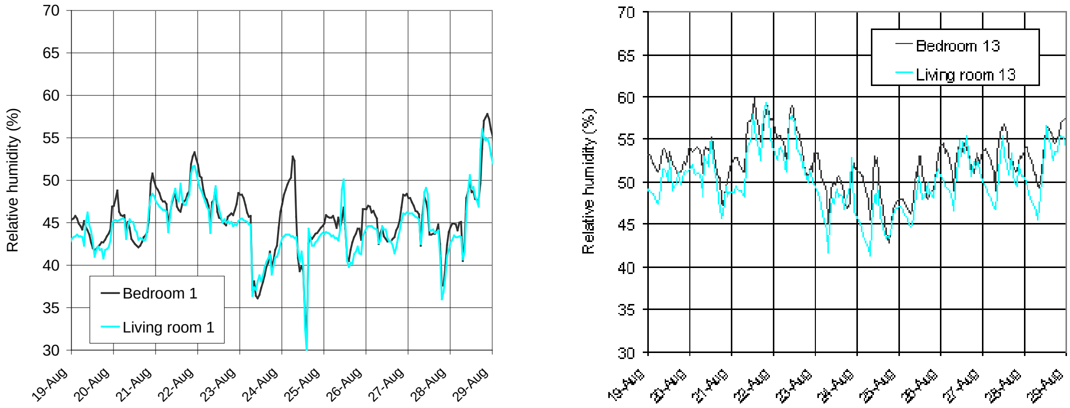


Fig. 11 Relative humidity in the bedroom and living room in building 1 (left) and in building 13 (right)

Although both buildings 11 and 12 had a low thermal and moisture capacity, the fluctuation of relative humidity was clearly higher in building 11 due to different living habits. However, in both buildings the relative humidity at the night time was mainly higher in the bedroom, Fig. 12.

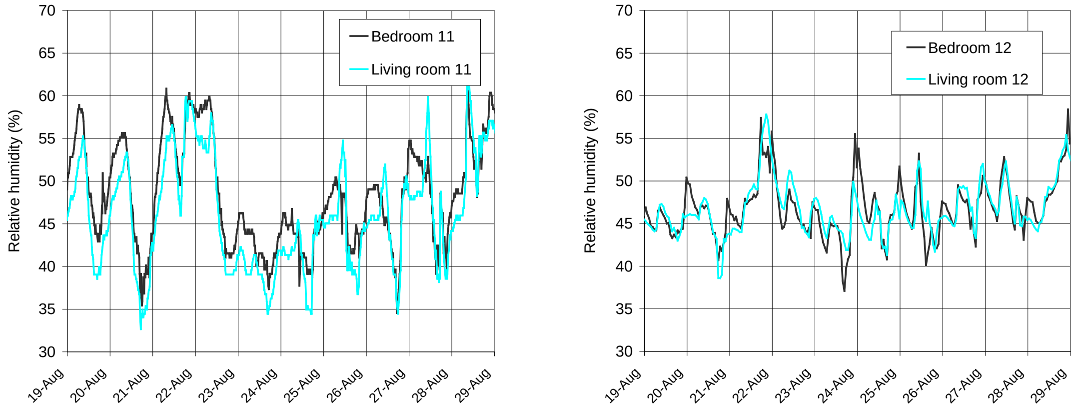


Fig. 12 Relative humidity during one week in building 11 (left) and in building 12 (right)

The difference between relative humidity in the bedroom and living room during night time was not so significant in the building 3 (high thermal and moisture capacity) as in buildings with low moisture capacity, Fig 11 and Fig 12. Building 6 with low thermal but high moisture capacity also did not have clear differences in daily behaviors between bedroom and living room, Fig. 13.

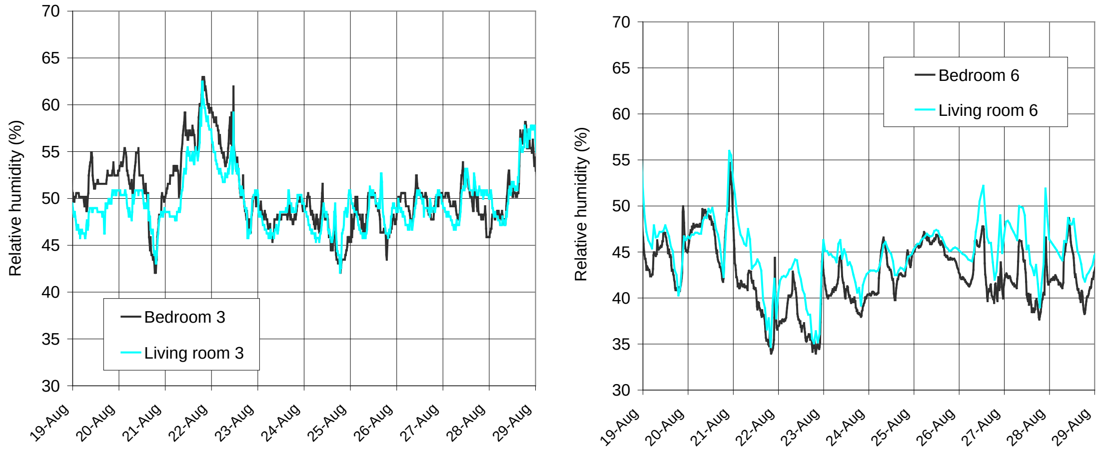
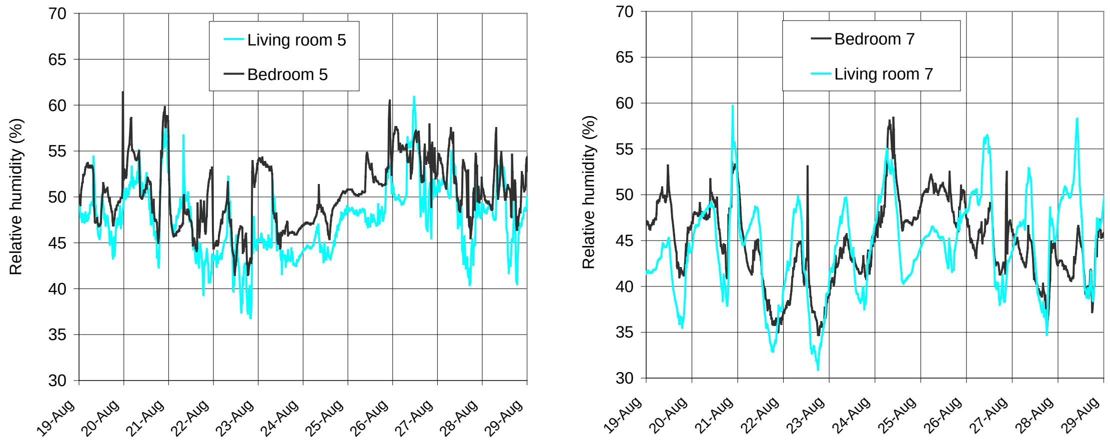


Fig. 13 Relative humidity during one week in building 3 (left) and in building 6 (right)

Buildings 5, 7, 8 and 9 had a low thermal capacity and a high moisture capacity. Buildings 5 and 7 had mechanical exhaust ventilation, and buildings 8 and 9 had mechanical supply and exhaust ventilation. It seems that the fluctuation of relative humidity is smaller in the buildings with mechanical supply and exhaust ventilation, Fig 14. In these buildings with moisture capacity, there was no significant differences in relative humidity in living room and bedroom during night time.



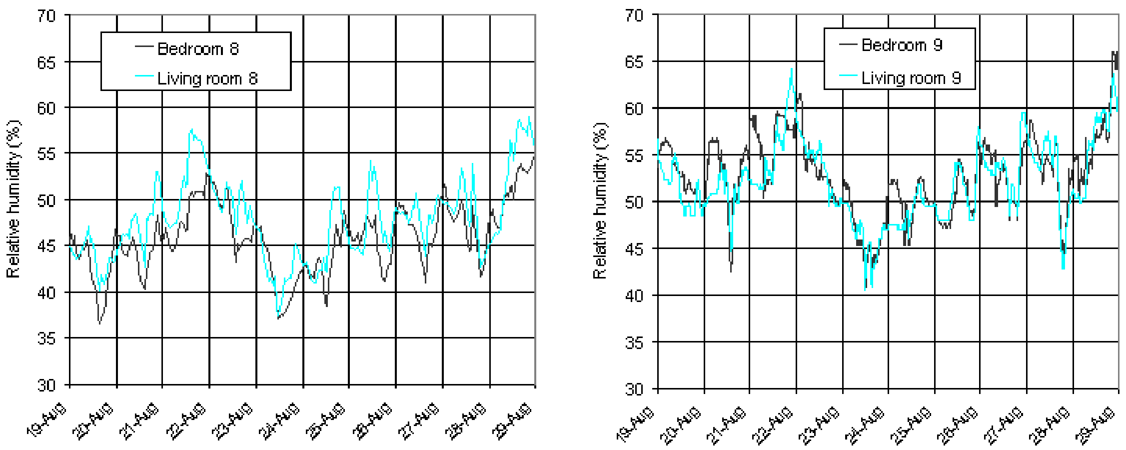


Fig. 14 Relative humidity during one week in building 5 (left top), in building 7 (right top), in building 8 (left bottom), in building 9 (right bottom)

IV. CONCLUSIONS

The variation in relative humidity in the bedrooms has a wide range, however, when the levels of absolute humidity were compared, the differences were small. In August the absolute humidity was under 9-9.5 g/kg in 50% of the time in all studied constructions.

The difference between minimum and maximum absolute humidity was the most obvious in building 11 and the least obvious in building 12 ;both buildings had a low thermal and moisture capacity. It seemed that the temperature had a stronger effect on humidity in the buildings than the moisture capacity of the construction.

When the values of predicted percentage of dissatisfied were compared, the lowest values were achieved in buildings with lowest temperatures in August. The buildings with high thermal capacity did not always have the lowest temperatures but the location of the building and the amount of solar radiation were probably more important factors.

Although there were no significant differences in duration curves of relative humidity between the studied constructions, the differences were clear when the daily behaviour was studied. A construction with a low moisture capacity could not bind the moisture flow from inhabitants in the bedroom during night time, and the relative humidity was higher in the night time. In buildings with moisture capacity the daily difference between bedroom and living room was not significant.

ACKNOWLEDGMENT

This study was funded by Finnish Funding Agency for Technology and Innovation, and Finnish wood industry which are greatly acknowledged.

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