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Determination of Moisture Buffering Capabilities of Common Furniture Materials

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Abstract. According to previous existing studies, the building materials can have a high impact on relative humidity fluctuations in a room by adsorption/desorption processes. The aim of this paper is focused to determine the influence of commonly used furniture materials to indoor air relative humidity. The measurements were performed in a controlled environment of the climatic chamber. During the measurements, a stable indoor temperature together with a constant air moistening was ensured. The indoor air parameters were measured with data loggers as well as the periodical weighting of materials was performed, to determine the moisture content of materials. The results showed that the common furniture materials have a very significant impact on indoor air relative humidity. The calculations of the influence were performed according to the mass balance equation comparing the predicted results without considering the influence of materials to the actual measured results from real case studies, therefore estimating the adsorption capabilities of these materials. The influence of these materials to the stabilization of indoor relative humidity can be expressed as a coefficient in mass balance equation depending on the type of material, area, and thickness of material, initial moisture content, and indoor air parameters. The findings of these results can be used in the design stage of indoor climatic systems to more precisely predict the relative humidity.

1. Introduction

Many common household activities like showering, cooking or floor mopping release bursts of water vapor in relatively short periods of time and can serve as a high moisture source for residential buildings [1]. However, it has been demonstrated by many researchers, such as Rode et al. [2], that the moisture is temporarily stored on surfaces and inside hygroscopic materials and is released only after the humidity in the room has lowered. Therefore, the amount of steadily released humidity, not the momentary rate of release, is the most important for long-term indoor humidity calculations. However, it is a complicated task to predict the possible moisture buffering by indoor materials as they are usually chosen only after the design stage and their buffer capacity varies depending on the moisture capacity, water vapor permeability, density and the period of the humidity variations. Therefore, it is necessary to make estimations of moisture buffering potential of the most commonly applied types of material and after knowing this data provide an averaged standard value of it depending on the building type, room type, and potential interior design.

According to Svennberg et al. [3] who simulated moisture buffering in a fully furnished room, the results showed that the largest impact on the variations in relative humidity on room level was seen when the more open materials such as textiles and paper were introduced into the climatic chamber. The experiment showed that there is a difference in the moisture buffering performance between the fully furnished test room and the empty test room. The two cases have approximately the same average RH (55% and 57% RH), but the RH measurements of the fully furnished room show a smaller variance in RH. During this study, it is also mentioned that calculation tools need to be modified to be able to handle, not only traditional building materials but also furniture. There is also a lack of data for the moisture properties of the surface materials in the indoor environment. In another full-scale study performed by Yang et al. [4] it was concluded that with the increase of ventilation rate the indoor humidity variation decreases, therefore, the moisture buffering effect is also reduced. The reduction of the moisture buffering effect is much more sensitive to the increase of ventilation rate when it is at a lower value.

Research by Olalekan and Carey [5] shows the importance of materials moisture absorption-desorption properties on the stability of indoor air parameters but also shows potential for energy consumption reduction up to 30%. The significant energy consumption reduction can be achieved by the use of hygroscopic materials in combination with precisely controlled HVAC systems. Similar results are proposed by Zhang et al. [6] which state that it is possible to reduce the total energy consumption by up to 25–30% when applying proper hygroscopic materials as the moisture buffer materials have a high performance in the climate that has a distinct humidity difference between day and night, and the outside air during the un-occupied period is dry enough to regenerate the buffer materials. The study of Woloszyn et al. [7] shows that the air exchange rate can be reduced by 30 – 40% thus reducing energy consumption from 10 to 17% in the winter time. The research by Huanga et al. [8] also shows problems on optimum design of ventilation systems for creating an optimal indoor relative humidity level. Therefore, a method to reliably predict and evaluate the relative humidity must be introduced.

2. Methodology

For the analysis of moisture absorption by furniture eleven furniture samples were chosen. These samples were made of plywood material with either two larger or all sides laminated. They represent one of the most common materials that are widely used at households or at schools as a table or shelf material. During the experiment analyzed samples were placed in an airtight climatic chamber with non-existent air exchange rate and controlled moisture and heat gains (see Figure 1). The moisture content of indoor air was measured using the moisture and humidity loggers and regular weighing of sample materials was performed. The weighing data of measured samples was noted with intervals of several days. For each of the measurement set, five measurements were done to determine the average and mean square error. For the evaluation of moisture absorption by materials, a scale with the following parameters was used: weighing range 0.02g to 6kg. For the evaluation of moisture buffering capacity of heavy timber structures, the air temperature inside the climatic chamber was kept in the range of +23.0°C±2°C and relative humidity – 60%±5%. All measurements were performed using data logger HOBO U12-013 for registering of temperature and relative humidity. The measurement limits and accuracy class of meters were as follows: for temperature: -20°C to +70°C ±0.35°C, for relative humidity: 5% to 95% ±2.5%.

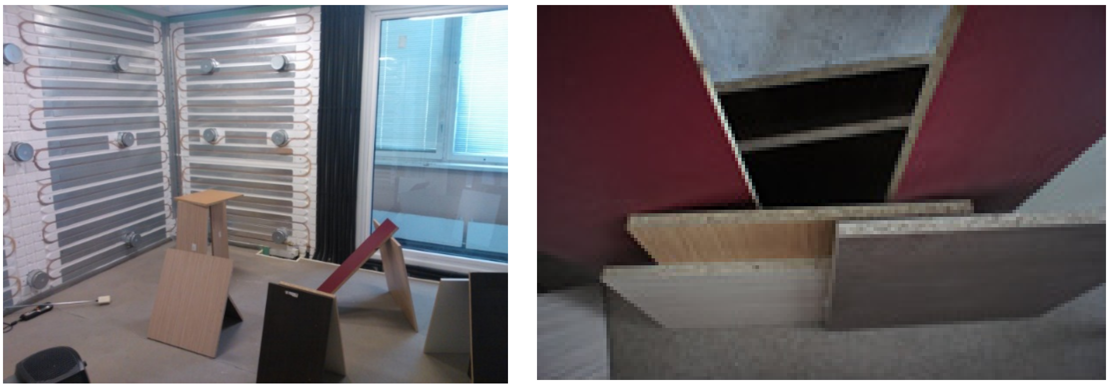

Figure 1. Analyzed samples and experimental setup of material moisture buffering evaluation

The dimensions and the initial weight of the observed samples are shown in Table 1.

Table 1. Parameters of analyzed furniture samples at the start of the experiment

Sample Nr.	Size a·b·c (mm)	Volume (m^3)	Surface area (m^2)	Initial weight (g)	Comment
1	415x395x18	0.00295	0.357	2017.6	
2	548x403x18	0.00398	0.476	2614.3	
3	695x294x18	0.00368	0.444	2425.8	
4	630x313x19	0.00375	0.430	2355.4	
5	564x84x20	0.00095	0.121	591.37	
6	863x215x18	0.00334	0.410	2202.2	
7	545x350x17	0.00324	0.412	2329.2	All sides laminated
8	565x305x18	0.0031	0.376	2084.7	
9	563x502x18	0.00509	0.604	3355.0	
10	595x595x16	0.00566	0.746	3945.6	All sides laminated
11	444x442x18	0.00353	0.424	2253.8	

During the experiment, the overall capacity and rate of moisture absorption by materials were analyzed. The materials were left at the climatic chamber for as long as the mass kept noticeably increasing. The relative humidity was maintained by use of a commercial humidifier. For the given material samples the measuring period was about three months.

The obtained results are applied to determine the influence the materials have on the relative humidity. As the existing studies by Karl and Rode [9] as well as by Korjenic et al. [10] shows, most of the moisture, which is released into the room across short time periods at first is absorbed on the surfaces and absorbent materials, and only then released into the air. Thus, stabilizing the moisture content in the air and therefore the calculation methods must take into account some averaged amount of moisture release during the day or even week rather than the momentary rate of release. The exact amount of absorbed moisture varies in each individual case depending on the objects in the room and their materials.

3. Results

3.1. Moisture absorption in furniture materials

During the experimental process, the weighting of materials was performed, on average, one time a week. As it can be seen by Figure 2 the overall mass of analyzed materials increased, which indicates an increase in moisture content.

To make assumptions on how the indoor relative humidity influences materials and vice versa both the relative mass change must be measured and mass change according to the surface area must be calculated.

As it can be seen by Table 2 the mass of analyzed samples changed by about 0.8 to 1.0 % at the end of the three-month period. Although this may seem like negligible increase, it influences humidity noticeably. The absolute water vapor content in the climatic chamber was kept at around 350g at +24°C making relative humidity of 60% and in total the materials absorbed 230g of the water vapor content during the three-month period. This means that the absorbed humidity amount is equal to 66 % of the total water vapor mass in the air. On average the mass increased by 0.55 g/m^2/day if relating the mass increase to the surface area of materials.

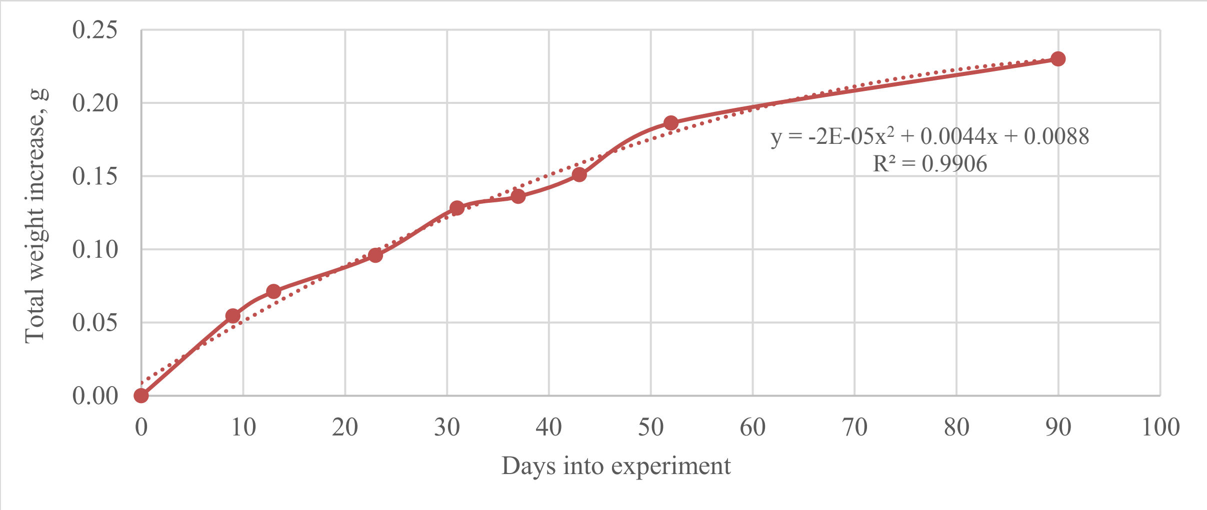

Figure 2. Change of summary weight of all analyzed samples during the experiment

Table 2. Relative mass changes and the ratio of mass change to the surface area of analyzed furniture samples

Sample Nr.	The weight of the material sample, g			Relative difference, %	Mass change/ surface area, g/m^2
	At the start	At the end	Difference		
1	2017.6	2034.3	16.70	0.83%	46.78
2	2614.3	2637.04	22.74	0.87%	47.78
3	2425.77	2448.7	22.93	0.95%	51.61
4	2355.4	2376.62	21.22	0.90%	49.32
5	591.37	597.1	5.73	0.97%	47.48
6	2202.23	2220.16	17.93	0.81%	43.74
7	2329.17	2350.74	21.57	0.93%	52.36
8	2084.73	2105.28	20.55	0.99%	54.66
9	3354.97	3386.66	31.69	0.94%	52.50
10	3945.6	3970.54	24.94	0.63%	33.43
11	2253.77	2277.74	23.97	1.06%	56.48

The results (see Figure 3) about ratios of mass changes to surface areas of the analyzed material samples show that they are very similar for all the cases except for one (sample nr.10). The marked bars represent the samples that have all the sides laminated. It was expected that these samples would absorb less moisture as the laminate serves as a barrier that limits the vapor influence. However, the results are inconclusive as one of these samples showed higher resistance to the moisture in the environment while the other absorbed the same amount of water vapor as non-laminated samples.

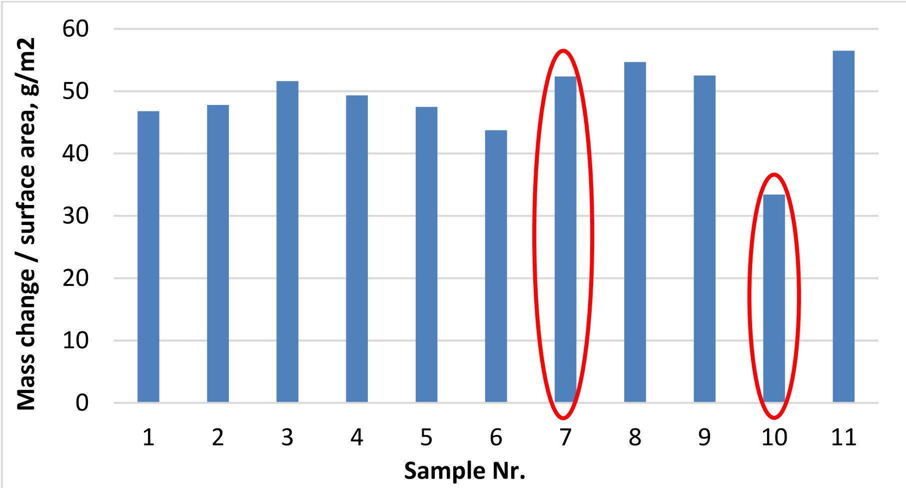

Figure 3. The ratio of mass change and surface area of sample materials

3.2. Relative humidity prediction method taking into account moisture buffering effect

As the previously provided equation (1) for moisture prediction presented in a paper by Borodinecs and Zemitis [11] did not give satisfactory results and did not reliably predict the relative humidity level (see Figure 4) the equation must be changed by implementing factors representing the moisture buffering effect.

$$G_{in}(t) = G_{out} + (G_0 - G_{out}) \cdot e^{-n \cdot t} + (1 - e^{-n \cdot t}) \cdot \frac{G_{prod.}}{n \cdot V} \tag{1}$$

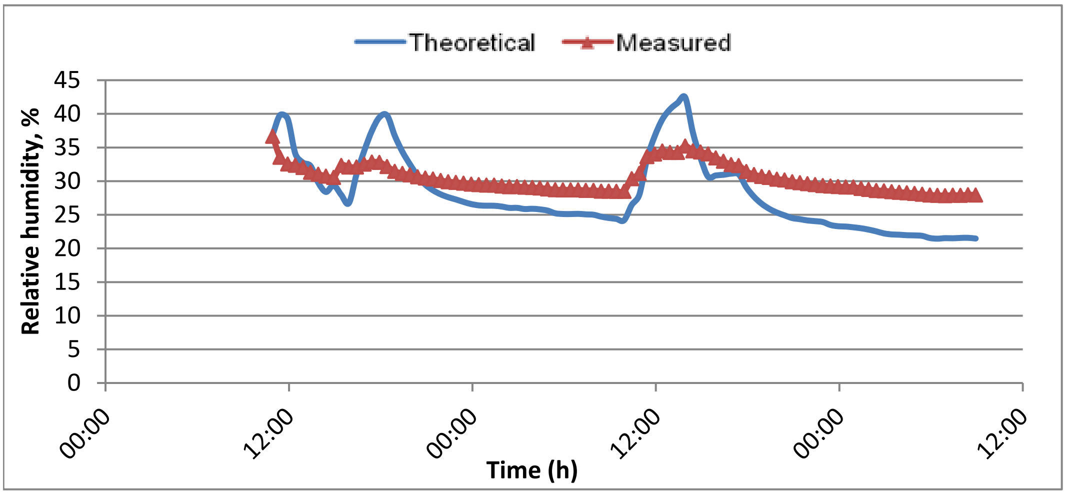

Figure 4. Theoretically predicted and measured relative humidity in office without taking into account moisture buffering effect

The change of equation is done by dividing the produced moisture load sources in the room into two different types – rapid production of moisture and smooth production of moisture. For each of them a coefficient, expressed as *a* and *b*, that limit the influence and changes the ratio between them needs to be determined. Therefore, the equation was changed to the following:

$$G_{in}(t) = G_{out} + (G_0 - G_{out}) \cdot e^{-n \cdot t} + (1 - e^{-n \cdot t}) \cdot \frac{(G_{smooth.} \cdot a) + (G_{rapid} \cdot b)}{n \cdot V} \tag{2}$$

The exact limiting coefficients in each case will vary depending on the room type, possible moisture sources, and interior materials. During further calculations, the moisture introduced by ventilation, produced by people, plants, and pets is considered to be smooth and moisture produced through floor mopping, showering, clothe drying and dishwashing is considered to be the rapid type. Moisture generation from people is assumed to be 21 g/h, by an average sized plant 0.15 g/h and by cloth drying 340 g/h for a 7-hour period after the start of drying for half full washing machine. For the rest of moisture sources values according to existing researches are used.

To validate the method, the measured data from previous studies were used. In the scope of them, the relative humidity and temperature were measured in an office room and bedroom while the moisture sources were also noted. Afterward, the humidity was calculated according to temperature and compared to the measured values. The applied coefficients were determined both by trial and error method as well as by taking into account measurements about moisture buffering potential of indoor materials. The limiting coefficients are different for the bedroom and office cases as the indoor environment is not the same. In the case of the office room, the coefficient for smooth moisture sources (G_{smooth}) was taken 0,87 and for rapid sources (G_{rapid}) 0,50, while in case of the bedroom they were 0,84 and 0,74 respectively.

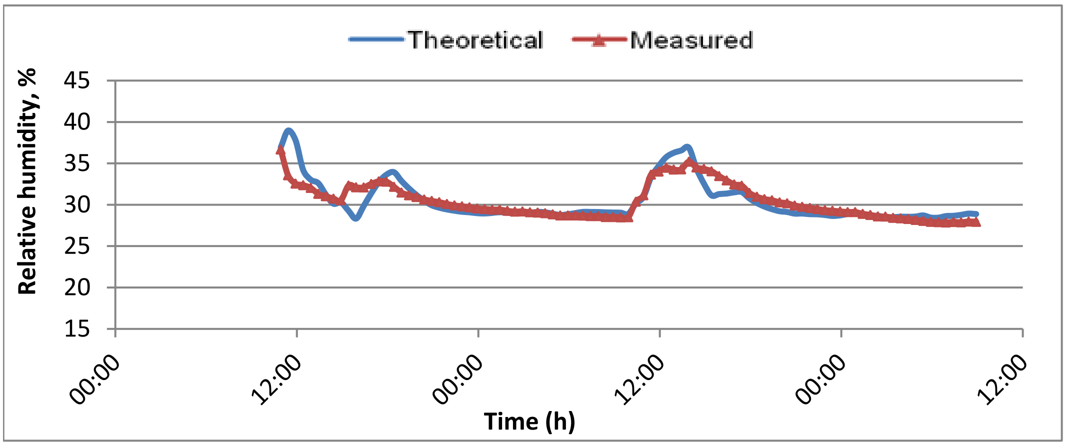

Figure 5. Theoretically predicted and measured relative humidity in office including moisture buffering effect

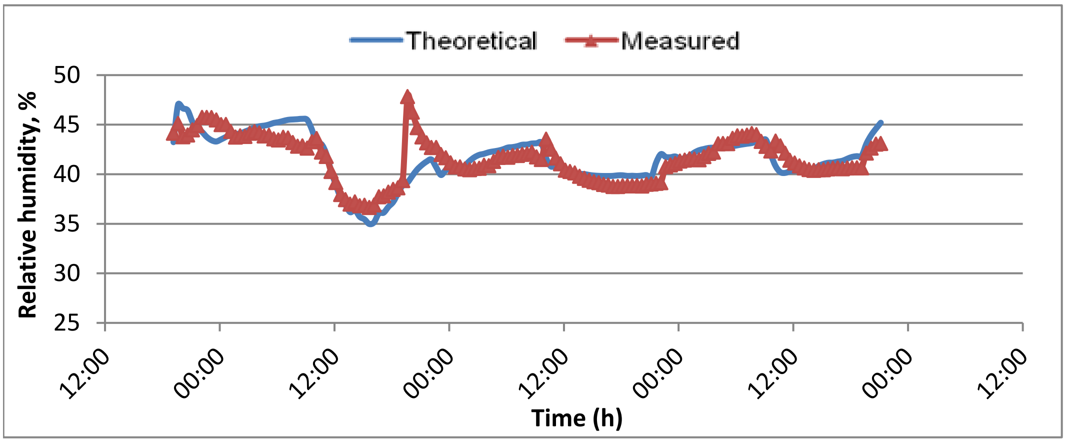

Figure 6. Theoretically predicted and measured relative humidity in the living room including moisture buffering effect

As the results (see Figure 5 and Figure 6) shows the proposed method by adding coefficients that limit the moisture production influence gives improved prediction accuracy. The predicted rates of relative humidity fluctuations are represented with a closer relation to actual measured data than previously. However, they still tend to overvalue the moisture source effect. To further improve the prediction accuracy more data needs to be gathered and standardized coefficient values depending on room type must be given to applying during the building design stage. This would allow for a relatively quick and accurate way of predicting indoor relative humidity.

4. Conclusions

Measurements of common furniture material moisture buffering potential were performed. During these experiments, it was found that they influence indoor moisture by absorbing some part of it into their volume. Comparison between laminated and non-laminated samples was performed, but the results were inconclusive about the lamination influence on absorption properties of the material. Further case studies to express the absorption factor for each given situation as single non-dimensional coefficients dependent on the type of premise, the amount of furniture in it, ventilation system properties must be done.

Precision for predicting relative humidity can be improved if absorption and desorption processes are taken into account and average moisture gains for prolonged periods are used. By updating the method by introducing additional moisture buffering factors the results greatly improved. Such factors should be defined for various room types by performing an additional set of measurements. The results showed that the method, although gives a more realistic representation of the actual measured relative humidity, still can not predict all the fluctuations caused by local humidity sources.

The application of given method can be used to determine the optimum air exchange rate in new low-energy buildings to provide the necessary relative humidity level by using the minimal volume of fresh air to reduce total energy consumption.

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Appendix A. Nomenclature

Table A1. Used symbols and their explanation in the paper

Symbols	Explanation
V	room volume, m^3;
n	air exchange rate;
G_{out}	moisture in outdoor air, kg H_2O/m^3;
G_{in}	moisture in indoor air, kg H_2O/m^3;
G_0	initial moisture in indoor air, kg H_2O/m^3;
G_{smooth}	smoothly produced moisture, kg H_2O/m^3;
G_{rapid}	rapidly produced moisture, kg H_2O/m^3;
a	the coefficient of indoor material influence to smooth moisture production;
b	the coefficient of indoor material influence to rapid moisture production.

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