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MOISTURE CAPACITY OF LOG HOUSES CAN IMPROVE THE INDOOR CLIMATE CONDITIONS

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Abstract *The hygroscopic capacity of timber can significantly improve the indoor conditions in log houses. Relative humidity of indoor air is, along with air and surface temperatures, a key factor for thermal comfort and also for perceived indoor air quality. The ability of timber to store moisture during indoor load periods and to release it back to the indoor air during unoccupied periods makes it possible to smooth down the indoor relative humidity variations by passive, structural means. This paper presents the numerical simulations carried out to study the effect of this moisture buffering effect in log houses compared to houses without available hygroscopic material.*

The numerical simulations were done using a room space model that integrates the structures, indoor air, and the ventilation, heating and cooling systems. The model solves the indoor temperature and humidity values using these dynamically changing heat and moisture flows. The analysis was done for Northern climate conditions (Helsinki, Finland) and the indoor loads corresponded to a case with two persons sleeping in one room. The ventilation was set constant (air change rate 0.65 1/h) and the room occupation and load conditions were repeated every night over the one year simulation period.

The results showed that when the room had four log walls, the moisture transfer between indoor air and walls was significantly higher than the moisture transport caused by ventilation. In the case with four log walls, the yearly average relative indoor humidity during occupation was 42 % RH and the maximum 69 % RH, while in the case with non-hygroscopic structures the average indoor humidity value was 51 % RH and the maximum 93 % RH. The maximum level for indoor comfort is typically 60 % RH. In a case with non-hygroscopic walls, the indoor humidity exceeded this limit value in about 20 % of the yearly occupation time, while in the log house it was about 10 % due to the moisture interaction of the walls. Also the lowest humidity levels during cold winter period were higher in the log house when compared to non-hygroscopic walls.

Utilization of the moisture capacity of structures to smooth down the indoor humidity conditions offers an effective passive method to improve the indoor air conditions in an energy efficient and sustainable way. The effect can be easily applied in log houses that have high hygroscopic capacity. This paper presents the potentials and sensitivity analysis of this application.

1. INTRODUCTION

The main function of a building is to maintain safe, healthy, comfortable and productive indoor conditions for the occupants. Relative humidity and temperature are the key factors for indoor thermal comfort conditions. High relative humidity levels of indoor air cause uncomfortable conditions and they may increase the risks for biological growth in structures. Too dry indoor air cause uncomfortable feeling and symptoms for the occupants. The objective is to maintain temperature and also the relative humidity level of indoor air under suitable conditions and to avoid fast and drastic changes in the conditions.

Often only the HVAC –system is considered to be responsible for indoor comfort conditions and the passive effect of structures is omitted. As well as the thermal capacity of structures can respond to the heat loads also the hygroscopic capacity of the building materials can smooth down the relative humidity variations of the indoor air during dynamic moisture conditions.

The effect of building structures on the indoor humidity and the perceived comfort conditions can be significant. However, this effect has not been properly utilized by design. The indoor conditions of log houses are often considered to be good, but this concept has not been properly proven. One of the key factors behind this concept may be the hygroscopic mass of the log walls that smooth down the indoor relative humidity variations during dynamic occupational moisture loads.

This paper presents the numerical study that was carried out to evaluate the moisture buffering effect of log house wall structures. The possibilities of hygroscopic log structures to improve the indoor conditions under cold, northern climate conditions were studied and analysed.

2. MOISTURE BUFFERING EFFECT OF BUILDING STRUCTURES

The effect of moisture capacity of structures on indoor humidity has been studied and presented by Simoson et.al. [1]. Also a Nordic method has been developed to measure and evaluate the effect of different materials and building components [2]. These findings and principles were used as background information when carrying out this work.

Moisture capacity of structures can have clear effects on indoor RH levels especially during daily variations and also under longer load periods. The moisture buffering effect supports the maintenance of indoor conditions in comfort zone. This does not decrease the need for ventilation, but it helps the system to react passively to moisture loads.

3. OBJECTIVES OF THE WORK

The objective of this work was to evaluate numerically the effect of hygroscopic log house building structures on the indoor relative humidity conditions. The analysis was done for a bedroom space of a house and the results were compared with similar structures that had vapour tight inside surface layer. The thermal performance properties were similar in all the cases.

4. INDOOR AIR COMFORT AND RELATIVE HUMIDITY

According to the indoor climate classification in Finland [3], the relative humidity values in the best indoor climate class is in the area 25 – 45 % RH during winter conditions. During summertime the upper limit of the humidity level can be exceeded. ASHRAE [4] sets 60 % RH to be the upper limit of the comfortable indoor relative humidity.

Comfort areas for different indoor temperature and relative humidity levels have been presented by Leusden and Freymark [5]. These comfort areas are used, for example, in building simulation model WUFI Plus [6] that was applied in the analysis of this study.

The analysis results are evaluated based on these indoor comfort criteria. Relative humidity has an effect also on the perceived air quality and very high relative humidity levels of indoor air may cause biological growth in structures. In this work only the indoor thermal comfort was studied and the other risks were omitted.

5. NUMERICAL STUDIES

The numerical simulations were carried out using WUFI Plus model [6].

5.1. WUFI Plus simulation model

This is a whole building simulation model that solves for the heat and moisture balances in buildings. It solves all the wall, roof and basement components and the indoor conditions with different heat and air conditioning approaches. In this case the indoor conditions of a single room space were simulated for one year. The structures are handled using a building physical approach for 1-dimensional multilayer components.

5.2. Room space studied in the simulations

In this case a bedroom of a small house was studied. The floor area of the bedroom 13.4 m^2, it was a corner room with two exterior walls facing east and north and two interior walls facing the same indoor conditions as the room used in this study. The room had one north facing 3-glased window and a door at the southern interior wall.

The log walls were massive laminated logs glued together from two or more pieces of glued pine planks with either vertical, horizontal or cross seams. The exterior walls were 204 mm thick and the internal walls 134 mm thick.

The floor structure had two concrete layers and 200 mm EPS between them. The temperature of the ground was assumed to vary during the year having sinusoid form: The average temperature was + 8 ^oC, the amplitude 6 ^oC and the maximum level on August 15th. The ceiling structure was light weight and there were similar indoor conditions above it. Both the floor and ceiling structures had additional internal diffusion resistance S_d = 100 m, so that these structures did not have any practical effect on the indoor humidity conditions.

The ventilation flow rate of the room was 6 dm^3/s which corresponding to about 0.65 1/h air change rate of the room space. Air change rate 0.5 1/h is the set minimum level in Finland for living spaces, if the design is not based on the amount of people in the room [7]. Ventilation was exhaust ventilation and the supply air was taken in at outdoor conditions.

Heating of the room space was assumed ideal without delays and the set minimum temperature level was +21 °C. There was no cooling and the indoor air could exceed the set temperature level when the heat gains exceeded the heat losses.

5.3. Indoor and outdoor load conditions

The outdoor climate was presented using of Helsinki reference year hourly values for temperature, relative humidity and driving rain. The temperature varied between -30 °C and +28.5 °C and the average value was 4.3 °C. The indoor loads (based on [8]) for a bedroom occupied with two persons are given in Table 1.

Time	Description	Heat flow, W	Moisture flow, g/h
07:00 – 21:00	No occupation	0	0
21:00 – 22:00	1 person + lights and devices	321	59
22:00 – 23:00	2 persons + lights and devices	610	246
23:00 – 07:00	2 persons sleeping	202	86

Table 1. Daily indoor heat and moisture loads.

The additional heat and moisture loads were mainly those from the indoor space (Table 1). The solar heat gains through the north facing window were marginal and the effect of the driving rain hitting the outer surface of the exterior walls had quite limited effect on the indoor humidity due to the moisture flow that was mainly outwards.

5.4. Material properties

The material properties used for logs were those given for pine heartwood (510 kg/m^3) in WUFI. The prominent properties when studying the moisture buffering effect are the sorption isotherm and water vapour diffusion resistance of pine (Figure 1).

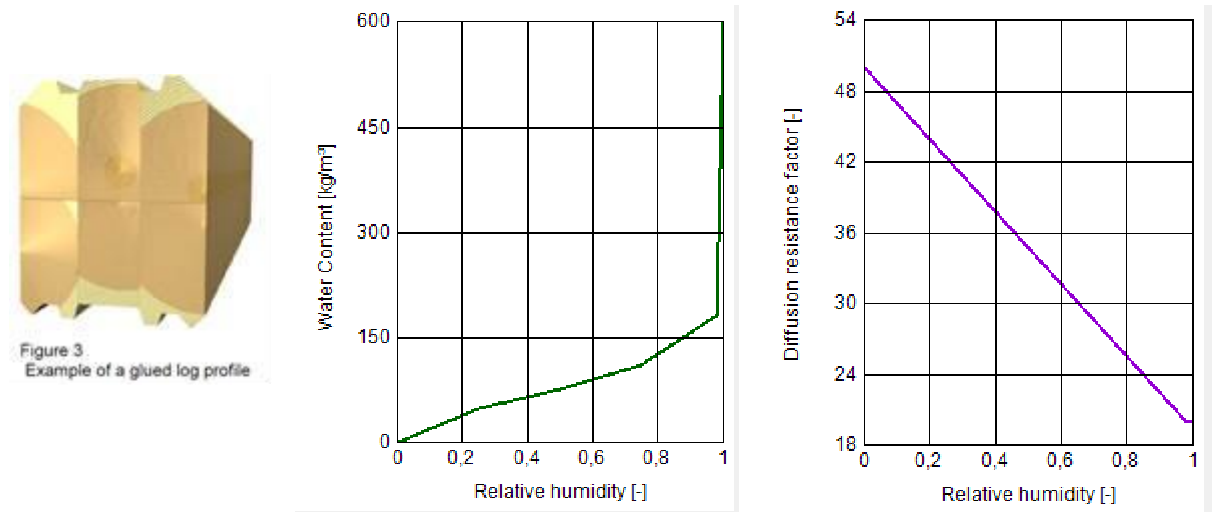

Figure 1. Laminated log (left) and the sorption curve and diffusion resistance for pine.

5.5. Case studies

The indoor relative humidity levels were compared in four cases (Table 2). The only difference between the cases was the vapour diffusion resistance of the inside surfaces of the walls.

The surface diffusion resistance of the log walls was solved from the convection coefficient. When the additional resistance had value S_d = 20 m, there was practically no moisture transfer between the wall and indoor air. This case was called 'V*apour tight'*. When all the log walls were open for diffusion, the case was called '*Log 4'*. Case '*Log 2'* corresponds to vapour open exterior walls, but vapour tight interior walls. In case *'Log 4_s'* there was a surface treatment on the inside surface of all the four log walls. This treatment created an additional S_d = 0.2 m diffusion resistance corresponding to relatively vapour open paint layer.

Case identification	Description	Diffusion resistance of exterior walls S_d, m	Diffusion resistance of interior walls S_d, m
Vapour tight	All inside surfaces are vapour tight	S_d = 20 m	S_d = 20 m
Log 4	Four log walls	S_d = 0	S_d = 0
Log 2	Two exterior log walls	S_d = 0	S_d = 20 m
Log 4_s	Four log walls with surface treatment	S_d = 0,20 m	S_d = 0,20 m

Table 2. Numerically analysed cases. The given surface diffusion resistance values are additional to the normal mass transfer resistance of wall surfaces.

6. RESULTS AND ANALYSIS

The moisture flow rates between the wall structures and indoor air were compared to that caused by ventilation (Figure 2). In vapour tight case ventilations is the only way to remove the additional moisture from indoor air. When there are four log wall surfaces open to indoor air, the moisture flow between indoor air and structures exceeds that of ventilation. During occupational periods the moisture transfer takes place from indoor air to log structures. During the unoccupied period there is moisture flow from structures back to indoor air.

The daily relative humidity variations during one typical week in October are presented in Figure 3. The daily variation of the relative humidity values (difference between maximum and minimum) was with vapour tight surfaces about 22 – 27 % RH, and the maximum humidity values were 73 % RH during this week. In the case with four log walls the daily relative humidity values stayed below 55 % RH and the daily variation was 7 – 8 % RH. With two log walls the maximum values were below 60 % RH and the daily variations were 9 – 13 % RH. If there was surface treatment (additional S_d = 0.2 m diffusion resistance) on the log surfaces, the maximum humidity levels of the indoor air could reach 65 % RH and the daily variations were 16 – 20 % RH.

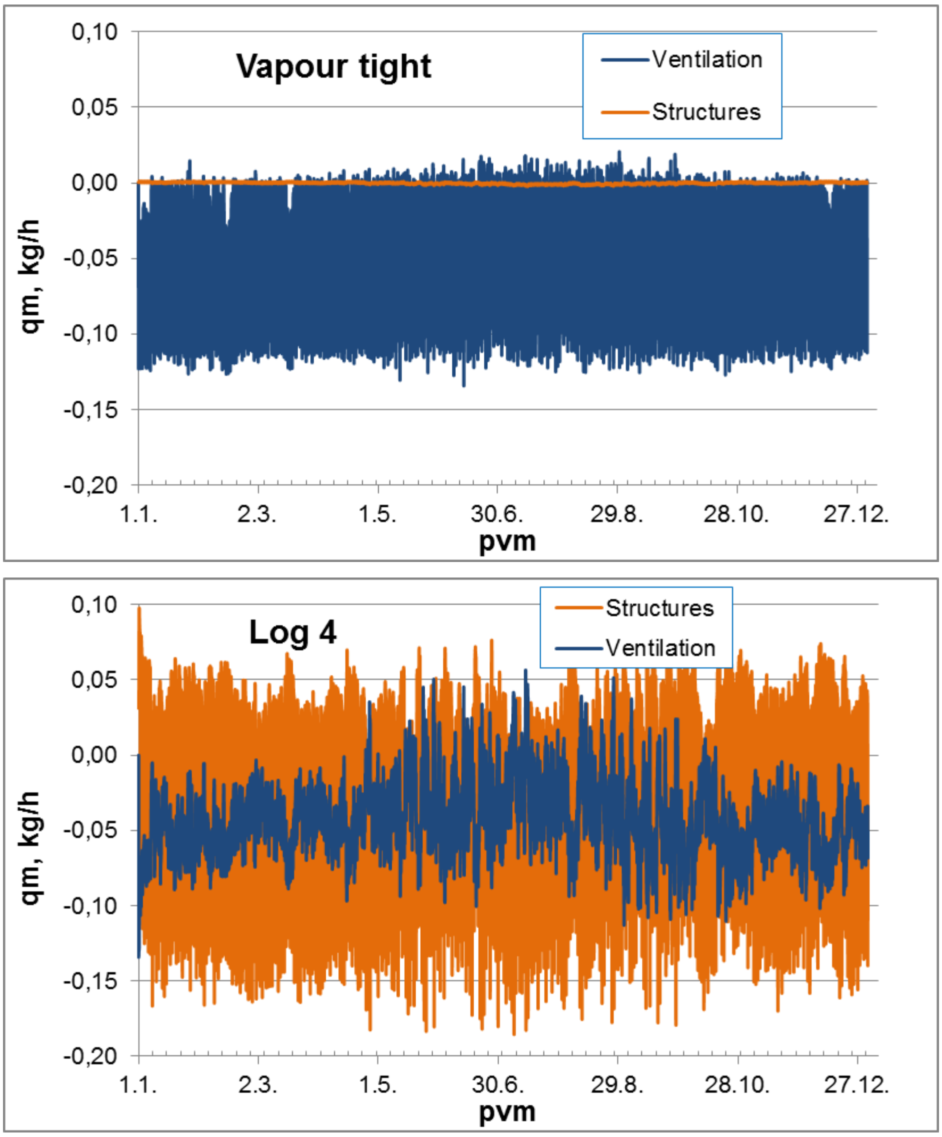

Figure 2. Moisture flow rates between indoor air and structures and that caused by ventilation. Cases having vapour tight structure surfaces (above) and four log walls (below). Negative value means that moisture is removed from indoor air.

Diffusion open log walls could significantly reduce the maximum relative humidity levels of the room air and the daily variations caused by the internal moisture loads were reduced more than to half when compared to the case with vapour tight structure surfaces. Both the reduction of maximum humidity levels and the ability to maintain smoothly varying humidity conditions enables comfortable indoor conditions.

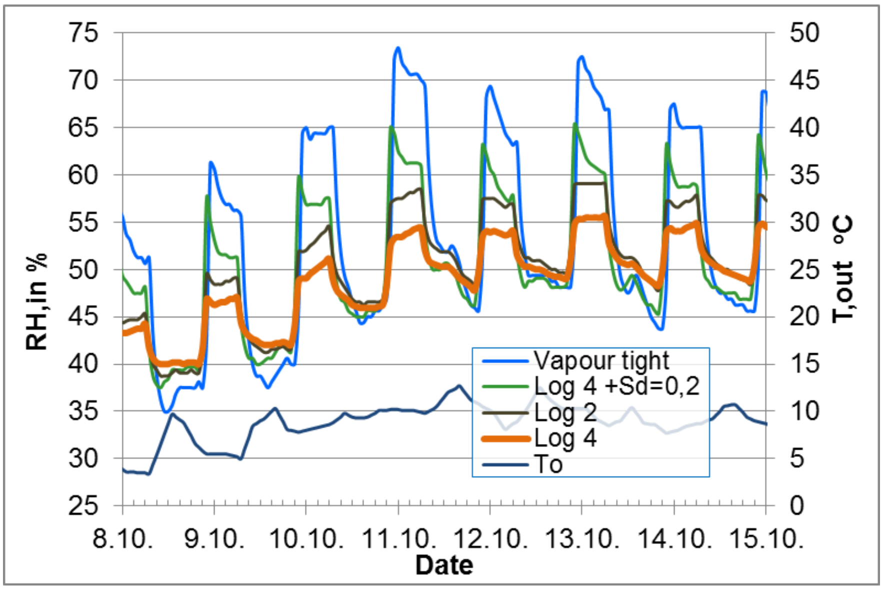

Figure 3. Daily relative humidity variations and outdoor temperature values during one week.

The positive effect of log walls on the hourly comfort conditions [5, 6] of the indoor air during one year can be seen in Figure 4.

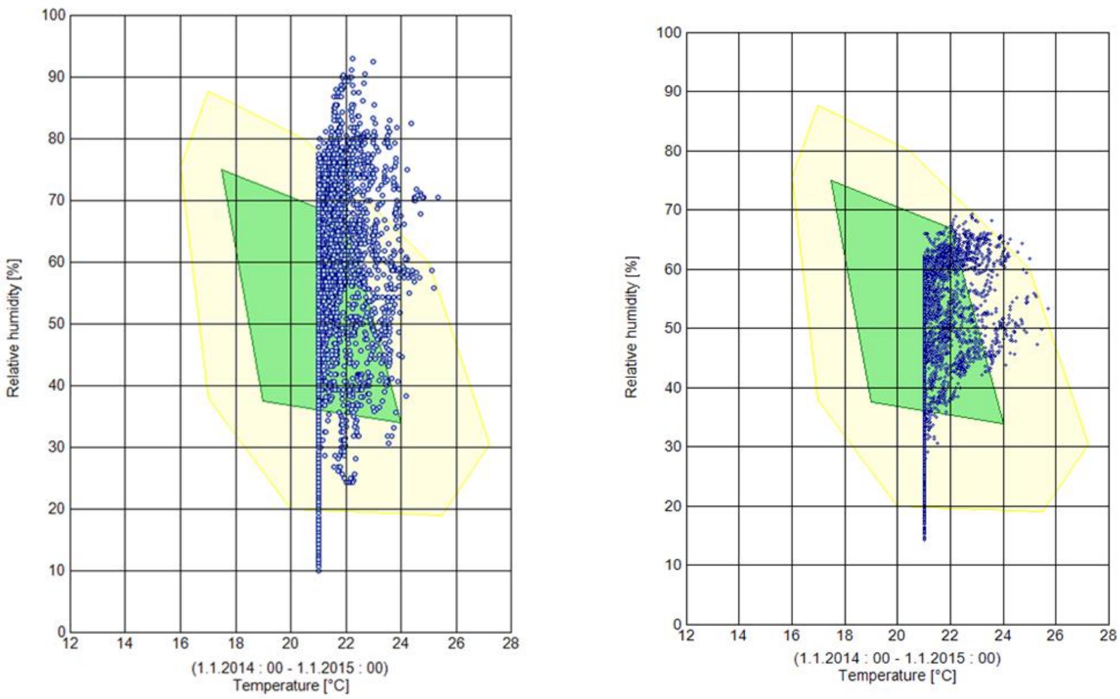

Figure 4. The hourly solved indoor temperature and relative humidity conditions and comparison to comfort conditions. Case *Vapour tight* is on the left side and *Log 4* on the right side. Green area corresponds to comfortable conditions and the light yellow to 'still comfortable' conditions [5].

The log structures reduced significantly the very high relative humidity levels of the indoor air and helped to maintain the conditions mainly in comfortable or nearly comfortable area.

Figure 5 represents the distribution of the hourly relative humidity values during one year in *Vapour tight* –case and *Log 4* –case. Each relative humidity area represents 10 % RH range. For example the lowest presented area 10 % RH corresponds to relative humidity values from 5 % RH to 15 % RH. Frequency corresponds to the incidence hours of each RH area compared to yearly total hours. This figure shows how the log structures can cut down high relative humidity values and keep the conditions mainly in the comfort level. Also very low indoor humidity levels can be avoided when having log walls. The yearly maximum indoor relative humidity was 69 % RH in the *Log 4* -case and 93 % RH in the *Vapour tight* –case.

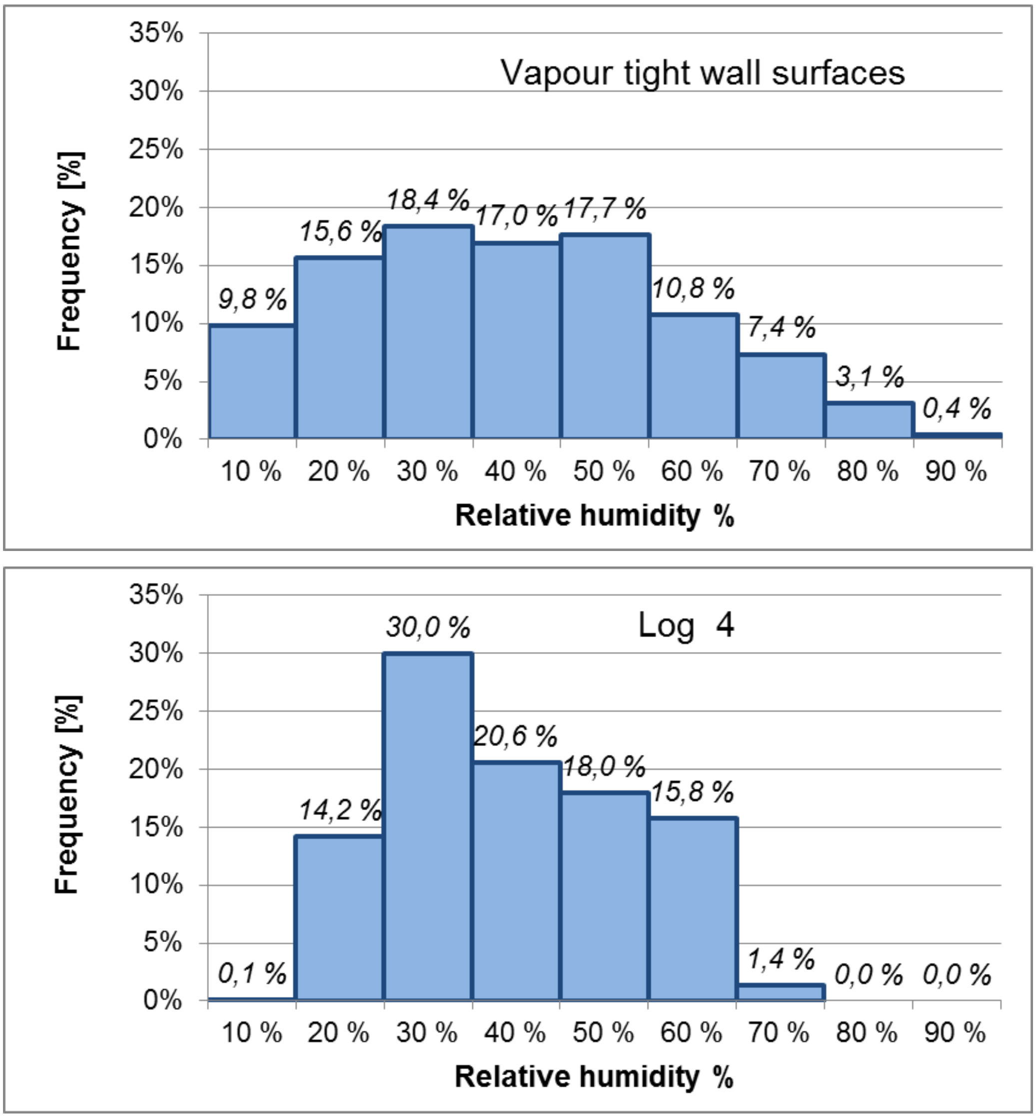

Figure 5. Incidence of different relative humidity areas during one year in Vapour tight –case (above) and Log 4 –case (below).

In the *Vapour tight* –case the numerically solved indoor relative humidity could decrease below 15 % RH during the unoccupied period and this represents about 10 % of the time. In *Log 4* –case the indoor relative humidity conditions remained above 15 % RH practically all the time. Very dry indoor conditions affect the perceived indoor conditions when the entering the room.

7. CONCLUSIONS

This paper presents the numerically analysed study on how the log wall structures can help to maintain comfortable indoor humidity conditions in a bedroom occupied by two persons every night. The bedroom was 13.4 m^2 and it had constant ventilation flow rate corresponding to 0.65 1/h air changes. The outdoor climate was that of Helsinki, Finland, representing cold northern conditions. The comparison was made between massive log wall structures and a case that didn’t allow the utilization of the moisture capacity of structures.

The results showed that the log wall structures had a significant positive effect on the indoor relative humidity conditions. The hygroscopic mass of the log structures smooth down the changes of the indoor relative humidity during the dynamic changes of internal moisture and heat loads. This moisture buffering effect helps to maintain the indoor conditions in comfortable zone by cutting down the incidence of high and very low relative humidity conditions.

The daily variations of the relative humidity values could be 30 % RH in the reference case with no available moisture capacity and in the case with four log walls this daily variation was typically below 10 % RH.

The yearly maximum level of indoor relative humidity was 24 % RH lower with log walls than in the case with no available moisture capacity. Also, with log walls the incidence of high, above 60 % RH indoor conditions was about half of that in the reference case.

Inside surface treatment of the log walls typically attenuates the potential to utilize the hygroscopic mass of structures. The diffusion resistance of the treatment should be known and kept as low as possible to make use of the moisture buffering effect.

The results show how the moisture capacity of log house structures can be used to maintain smoothly changing indoor humidity conditions in comfort zone. This passive method supports the HVAC systems to create and maintain comfortable indoor conditions. The log walls allow suitable performance properties for practical application of the moisture buffering system in buildings.

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