Numerical evaluation of the impact of hemp lime concrete moisture-buffering capacity on the behaviour of relative humidity sensitive ventilation system

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ABSTRACT

Hemp Lime concrete (HLC) is a bio-based material, which knows currently a growing development. HLC is a low embodied energy material. It has an excellent moisture buffer performance and is considered as good indoor climate regulators. Recent field study has confirmed the ability of HLC to maintain hygrothermal conditions at winter and summer comfort levels.

On the other side, relative humidity sensitive ventilation systems help to save building heat energy by reducing the amount of the exhaust airflow during unoccupied periods or low activities depending on the level on the indoor relative humidity. Previous studies showed the ability of such systems to save energy without compromising IAQ throughout the whole year. They are widely used in new French residences. However, the moisture-buffering capacity of bio-based material such as HLC can modify the behaviour of humidity sensitive ventilation as it lessens the variations of indoor relative humidity.

The objective of this paper is to assess the impact of the moisture buffering capacity of hemp lime concrete on the behaviour of humidity sensitive ventilation system in single detached dwellings. A numerical approach based on the energy simulation tool TrnSys coupled to the multi-zone air-flow and contaminant transport model COMIS was used. A real case of HLC dwelling was studied. First, measured indoor relative humidity is compared to the simulated results in order to assess the moisture buffer model of Trnsys. Second, humidity sensitive ventilation system is added in order to analyse the dynamic interaction between the moisture buffering capacity of HLC and the performance of humidity sensitive ventilation system in terms of energy efficiency and indoor air quality. Results show that in the case of humidity sensitive ventilation, the moisture buffer capacity of hemp lime concrete helps to maintain the indoor relative humidity within the range of comfort zone between 40% and 60% through the whole year. They confirm that the use of moisture-buffering materials is a very efficient way to reduce the amplitude of daily moisture variation. However, the yearly average exhaust airflow is slightly higher, yet the heat load increase is less than 5%.

KEYWORDS

Coupled heat and air-flow simulation, Relative-humidity-sensitive (RHS), Humidity control, Moisture-buffering, Energy

1 INTRODUCTION

Hemp Lime concrete (HLC) is a bio-based material, which knows currently a growing development. HLC is a low embodied energy material. It has an excellent moisture buffer performance and is considered as good indoor climate regulators (Collet, 2012). Recent field study (Moujalled, 2015) has confirmed the ability of HLC to maintain hygrothermal conditions at winter and summer comfort levels while outside temperature and relative humidity (RH) daily variations are up to 15°C and 50% respectively. It has confirmed the global idea that bio-based materials are good indoor climate regulators. The measurements inside walls showed a high thermal inertia, which allowed them to dampen the daily variations by 90% and to delay the effects of peak values up to 11 hours.

On the other side, relative humidity sensitive (RHS) ventilation systems help to save building heat energy by reducing the amount of the exhaust airflow during unoccupied periods or low activities depending on the level on the indoor relative humidity. They are widely used in new French residences as they help to meet the requirements of the latest thermal regulation. Previous studies showed the ability of such systems to save energy without compromising IAQ throughout the whole year. Woloszyn (Woloszyn, 2009) has demonstrated that the combined effect of ventilation and wood as buffering material can help to keep the indoor RH at a very stable level, between 43% and 59%. Tran Le (Tran Le, 2010) has compared different ventilation strategies (with constant and variable ventilation rates) and he found that the use of a RHS ventilation strategy with hemp concrete can reduce energy consumption about 15% because of the decreasing of cold fresh air flowing into the room.

However, the RHS ventilation systems are designed for non-hygroscopic building materials. When used with hygroscopic materials such as HLC, the ventilation system operation can be modified by the moisture-buffering capacity of HLC as it lessens the variations of indoor relative humidity. Thus the RHS ventilation system would not function properly as designed and the building risks being under or over-ventilated.

The objective of this paper is to assess the impact of the moisture buffering capacity of hemp lime concrete on the dynamic behaviour of humidity sensitive ventilation system in single detached dwellings through a numerical approach based on the energy simulation tool TRNSYS coupled to the multi-zone air-flow and contaminant transport model COMIS.

2 METHOD

A numerical approach based on the energy simulation tool TRNSYS coupled to the multi-zone air-flow and contaminant transport model COMIS was used. A real case of HLC dwelling was studied. First, measured indoor relative humidity is compared to the simulated results in order to assess the moisture buffer model of TRNSYS. Second, humidity sensitive ventilation system is added in order to analyse the dynamic interaction between the moisture buffering capacity of HLC and the performance of RHS ventilation system in terms of energy efficiency and indoor air quality.

2.1 Studied building

The simulation case is based on a real 2-floor single-detached dwelling that hosts 5 people and has a surface of 250 m^2 (Figure 1). It is located close to Perigueux in South West to France. Its envelope is made of 30cm thick HLC sprayed into walls of timber frame structure. HLC is also used in roof and intermediate floor in 10cm and 15cm thickness respectively. The walls are internally and externally protected with lime-sand plasters. The composition of the walls is presented in Table 1.

A pellet boiler coupled with 12.6 m² of solar collectors provides energy for heating and domestic hot water. The heat is distributed in the house through radiant floor at the ground level and radiant walls at the top level. A balanced ventilation system with heat recovery is used for air renewal. The total air renewal is 0.3 h^{-1}.

The building was monitored between February and December 2012. Temperature and Relative Humidity (RH) were measured in each room with 15 minutes time step.

Figure 1: View of the south façade of the building

Table 1: Wall composition

Wall	Composition	U value
External Wall	3 cm lime sand plaster + 30 cm HLC + 2 cm lime sand plaster	0.28 W/(m^2.K)
Ceiling	2 cm OSB + 10 cm HLC + 21 cm cellulose wadding + 2cm roof tile	0.15 W/(m^2.K)
Floor	4 cm concrete + 7cm Polyurethane + 4cm concrete	0.26 W/(m^2.K)
Windows	Low emissivity double-glazing with wooden frame	1.1 W/(m^2.K)

Mechanical RHS ventilation is studied following technical agreement specifications (CSTB, 2009). It is composed of humidity sensitive air-inlets in main rooms and humidity-controlled air-outlets in service rooms. Besides, it enables boosting airflow rate in the kitchen (135 m^3/h) during cooking and in the toilets (30 m^3/h). Table 2 presents the characteristics of the RHS ventilation system.

Table 2: RHS ventilation system characteristics

System	Inlets		Outlets		
	Living room	Bedrooms/office	Kitchen	Bathroom	Toilet
RHS	2 x (6-45 m^3/h) at RH 45-60%	6-45 m^3/h at RH 45-60%	10-45 m^3/h at RH 24-59% (135 m^3/h; 30’)	10-40 m^3/h at RH 36-66%	5 m^3/h (30 m^3/h; 30’)

Moisture vapour and sensible heat schedules were created for each zone according to the activities of a 5-person family (2 adults and 3 children) - activities related to human metabolism and domestic. For each schedule, the amount of water vapour and sensible heat were calculated hour by hour based on the values given by (Richieri, 2013).

Dwelling is supposed to be heated from 1st October to 20th May with an 20.4°C ambient temperature during occupied period (18h-9h on weekdays and all the week-end). Set point temperature is 3°C reduced during unoccupied period (weekdays).

2.2 Simulation tools

The energy simulation tool TRNSYS is coupled to the multi-zone air-flow and contaminant transport model COMIS. This coupling allows the calculations of heat transfer, airflow and pollutant transport (e.g., moisture) in a multi-zone building under transient boundary conditions. Besides, it enables dynamic modelling of closed-loop control for different systems (especially RHS ventilation system) and humidity buffering of porous materials. Figure 2 presents the coupling between TRNSYS and COMIS.

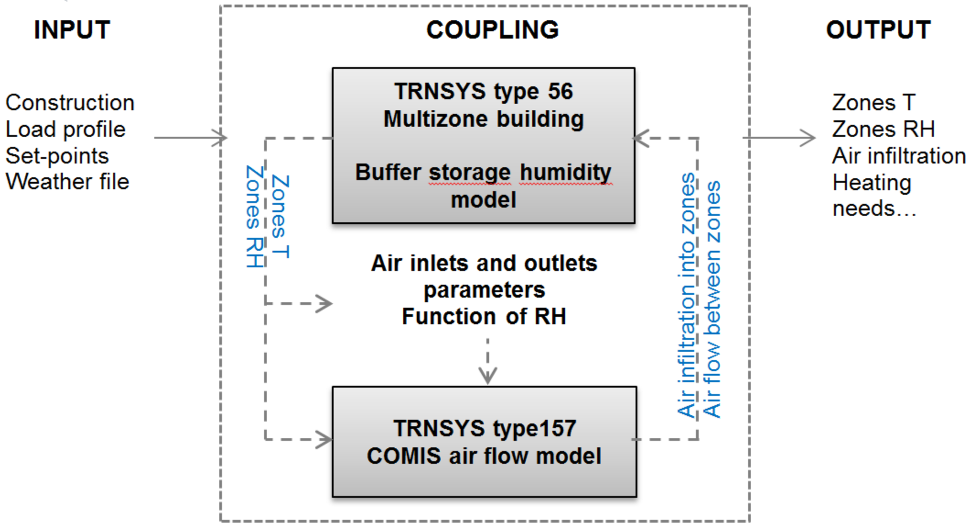

Figure 2: Overview of coupling between TRNSYS and COMIS-model

2.2.1 Air flow model

The building is considered as a zone network linked by airflow components such as cracks on envelope, inlets and outlets of ventilation systems, and internal circulations between 8 zones representing the different rooms of the dwelling. For each main room, inlets are located in accordance with plans, positioned at 2.2 m height. Specific behaviour of humidity sensitive inlets is modelled as defined in Table 2.

Leakages are distributed over the 338 m² building envelope (A_{Tbat}). In each zone, two cracks have been defined on external walls at 0.63 m and 1.88 m height, and one crack on the ceiling at 2.5 m height as described in (Richieri, 2013). The cracks characteristics are as follows:

- fixed 0.65-flow exponent,
- flow coefficient calculated from the global building air permeability $Q_{4pa\text{-}surf}$ (0.6 $m^3/(h.m^2)$) proportionally to the ratio of the façade area to the total envelope area A_{Tbat}.

The zones are interconnected by 90 cm wide doorways considered closed during simulations. To ensure air circulation from dry to wet rooms, each doorway is considered with a 1 cm undercut for all inner doors. The door undercut is modelled as a large crack with 0.5 flow exponent.

The Cp values are considered in accordance with the AIVC guide on ventilation for the case of shielding conditions “surrounded by obstructions” (Liddament, 1996).

2.2.2 Buffer storage humidity model

In TRNSYS two models are available for the calculation of the moisture balance. The first, called effective capacitance humidity model (EC), is a simplified model which considers sorption effects with an enlarged moisture capacity of the zone air. The second, called buffer storage humidity model (BS), is a more sophisticated model which offers a surface and a deep moisture buffer in the walls of the zone (SEL, 2007). A short description of the equations, assumptions and limitations of both models are given by (Steeman, 2010) and (Woloszyn, Kalamees, 2009). The buffer storage model is based on the effective moisture penetration depth model and is divided into a surface and a deep layer to account for both short-term and long-term exchanges, e.g. daily and yearly variations. The moisture penetration depth can be calculated from the material properties and the cycle of the periodic humidity variation as given in (Steeman, 2010). It is in the order of several millimetres for daily variations and centimetres for yearly variations. Each layer is characterised by the following parameters:

- ξ : gradient of sorptive isothermal line of surface/deep buffer [kg_{water} /$kg_{material}$ /RH],
- d : penetration depth of surface/deep buffer [m],
- β : the exchange coefficient between zone and surface storage for the surface buffer, and between storage and deep storage for the deep buffer [kg/(h.m^2)].

Table 3 shows the values of the parameters for the HLC of the studied case. The gradient of sorptive isothermal line is calculated from the sorption isotherms curves for HLC given by (Tran Le, 2010). The penetration depths are calculated with a cycle of one day for the surface buffer and 365 days for the deep buffer as indicated above.

Table 3: Defintion of the parameters of the buffer storage humidity model

	ξ	**d [mm]**	**β [kg/(h.m^2)]**
Surface storage	0.06	7.3	3
Deep storage	0.06	140.2	1

3 RESULTS

3.1.1 Comparison of simulation models with measurement results

In the first step, the simulation tool was compared against experimental data in order to evaluate the two moisture balance models of TRNSYS. Indoor relative humidity was calculated with the effective capacitance model (without buffering) and buffer storage model (with buffering) using a balanced ventilation system as in the real case.

Figure 3 shows an example of indoor air RH for a typical week during winter. The measured RH is stable and varies slightly around 40%. The daily variations of the calculated RH are more important with both models, especially for the effective capacitance (EC) model without buffering. The buffer storage model (BS) helps to reduce the amplitude of daily moisture variations and the discrepancy between the calculation and the experiment.

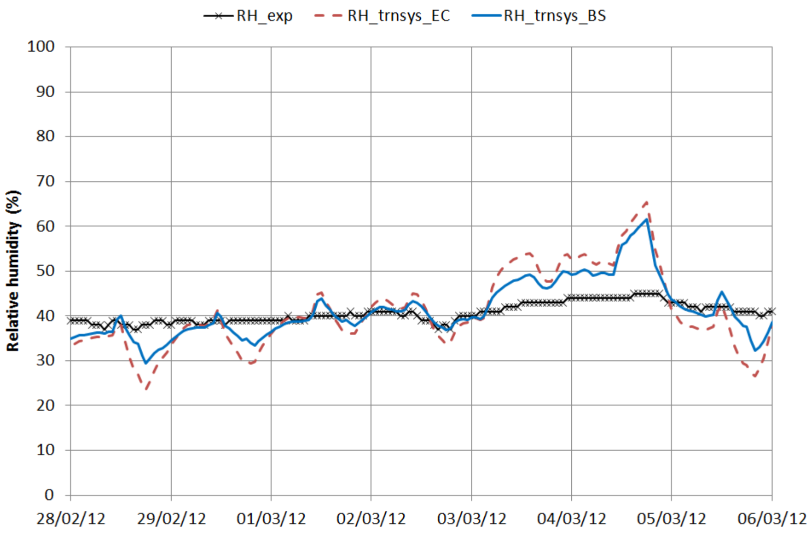

Figure 3: Comparison of measured indoor RH with simulation results for the effective capacitance model without buffering (EC) and the buffer storage model (BS)

3.1.2 Impact of buffer storage humidity on RHS ventilation system operation

In this part, the balanced ventilation system is replaced by RHS ventilation system which is modelled as defined in Table 2. In order to evaluate the impact of buffer storage humidity of HLC, the calculations were made with the EC model (without buffering) and BS model using the parameters as described in Table 3.

Figure 4 compares the variations of calculated RH between both models for the living room and the main bedroom. Globally both models present the same mean values of RH (between 45% and 55%), but the variations of RH with the EC model are more important than the BS model. As expected, the moisture buffering capacity helps to reduce the variation of the indoor RH.

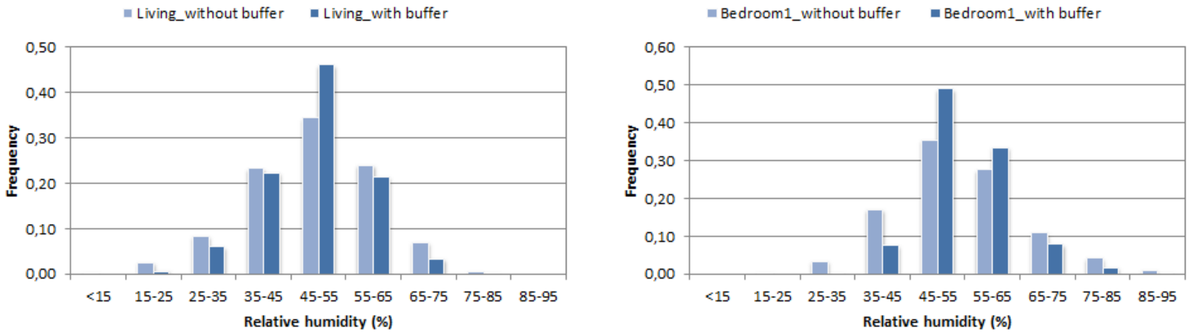

Figure 4 : Comparison of variations of calculated RH for the living room (left) and main bedroom (right)

Figure 5 shows the comparison of the variations of the total airflow rate between the two models. The mean value of the BS model is slightly higher than EC model (99 m^3/h against 97 m^3/h), whereas the extreme values (min and max) are more important for the EC model.

In the case of airflows above 160 m^3/h, the histogram shows that the variations are similar for both models. Indeed the higher airflow rates are imposed by the boosting airflow of the ventilation system and are independent from the humidity.

For the lower values, the airflow rates are more often in the extreme ranges for EC model than BS model. On the contrary, the airflow rates are more often in the middle ranges for BS model than EC model. Indeed, RH values of BS model fall more often within the functioning limits of air inlets and outlets (RH 45-60% for the living room inlet and RH 24-59% for the kitchen outlet) and thus the lowest airflow rate is rarely applied.

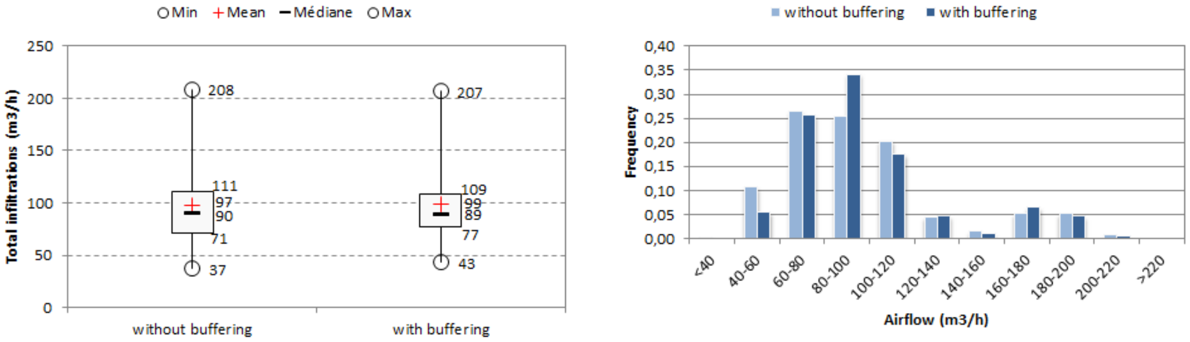

Figure 5: Comparison of total airflow rate between the cases without buffering (effective capacitance model) and with buffering (buffer storage model)

Figure 6 and Figure 7 compare the evolution of RH and airflow rate in the main bedroom between EC and BS models during a typical week in winter. For BS model, the daily variation of RH is about 20% against more than 40% for EC model. This confirms that the moisture buffer capacity of the BS model helps to reduce the spread between the minimum and the maximum values of RH as in real case. Therefore the lowest airflow rate (10 m^3/h) is rarely applied with BS model as shown on Figure 7.

Finally, the heating needs were calculated for both models. For BS model, the heating needs are 16.2 kWh/(m².year) against 15.6 kWh/(m².year) for EC model. The moisture buffer capacity results with a slight increase of heating needs (around 4%) because the slight increase of cold fresh air flowing into the dwelling.

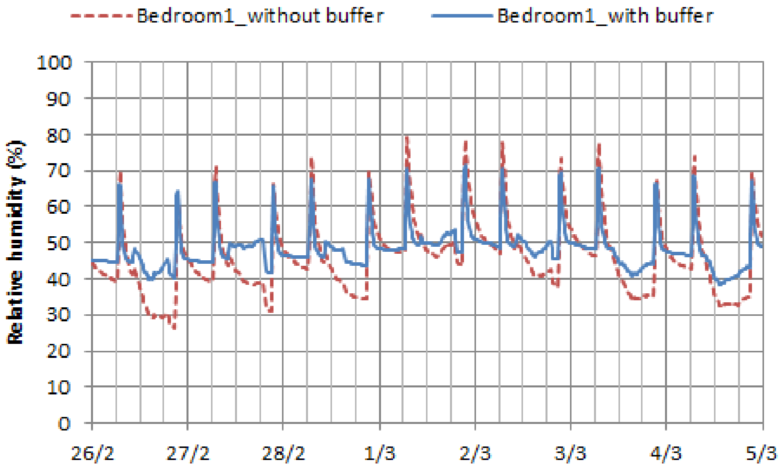

Figure 6: Comparison of the evolution of RH in the main bedroom between the cases without buffering (EC model) and with buffering (BS model)

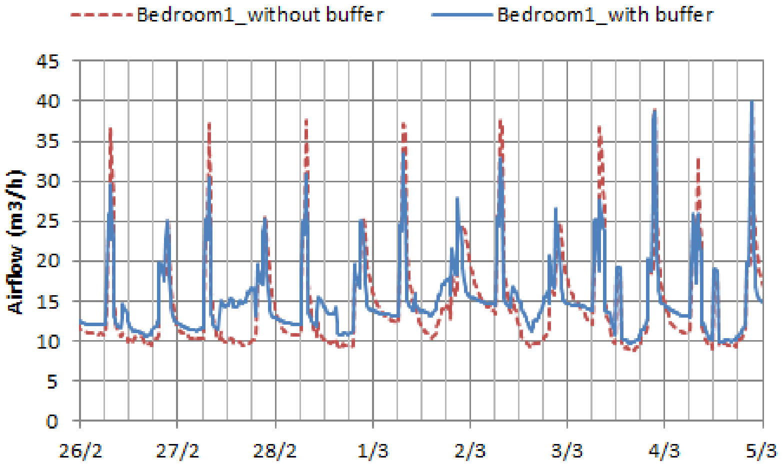

Figure 7: Comparison of the evolution of the airflow rate in the main bedroom between the cases without buffering (EC model) and with buffering (BS model)

4 CONCLUSIONS

A coupled multi-zonal model TRNSYS-COMIS has been developed to study the impact of the moisture buffering capacity of hemp lime concrete on the behaviour of relative humidity sensitive ventilation system in single detached dwellings based on a real case. Results show that the moisture buffer capacity of HLC helps to maintain the indoor relative humidity within the range of comfort zone between 40% and 60% through the whole year. They confirm that the use of moisture-buffering materials is a very efficient way to reduce the amplitude of daily moisture variation. The combination of the moisture buffering of HLC with relative humidity sensitive ventilation system modify slightly the functioning of the ventilation system by increasing moderately the yearly average exhaust airflow, which results by a slight increase of heat losses by air renewal (less than 5%).

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