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Dynamical interactions between heat and mass flows in Lime-Hemp Concrete

A. Evrard & A. De Herde
Architecture et climat – UCL, Louvain-la-Neuve, Belgium

J. Minet
Lhoist Recherche et Développement s.a., Nivelles, Belgium

ABSTRACT: In the last decades, sustainable aspects of human development as energy savings, comfort, health and life-cycles, led to an increased interest on new insulation materials. Lime-Hemp Concrete (LHC) is a light, porous and hygroscopic insulation material made out of hemp chips mixed with an appropriate lime binder. It can be use either to cover masonry walls or to fill timber frame structures, in old or new buildings. The paper first presents this innovative material on the basis of a thorough literature survey. Laboratory experiments were conducted in the Fraunhofer-Institut for Building Physics and corresponding transport and storage parameters are defined. Dynamical interactions between heat and mass flows in material's porous structure are then analyzed though numerical simulations.

1 INTRODUCTION

Sustainable aspects of human development can be improved in numerous fields. Some recent works in the field of Architecture contribute to help architectural designers to respect sustainable principles in their works. Global understanding of the whole building process is needed. Energy efficiency is one of the main domains of interest, but comfort, health, life-cycles... come close behind. In the last decade, the question of building material became therefore more and more important for architects and designers. Lime-Hemp Concrete (LHC) specificity could be approached through different sustainable principles since this innovative insulation material seems to have a positive global impact on the quoted domains. If many other researches can still be made on in this particular material, the present paper focuses on its transfer and storage parameters and on interactions between heat and moisture flows in its porous structure to assess its global energy efficiency.

Hemp chips were first introduced in buildings in France in the beginning of the nineties to lighten concrete mixture. If practitioners started with cement binder, better results were obtained with an appropriate lime basis binder. LHC is nowadays mainly used to cover masonry walls or to fill timber frame structures, in old or new buildings. It is also possible to use it to insulate roof or floor. First, a literature review presents previous studies on this material and other significant works on HAM modeling are referred. After a short description of main components, the wall-mixture used for the measured samples is presented. The laboratory experiments, conducted in Fraunhofer-Institut for Building Physics in Holzkirchen, and the definition of the main transfer and storage parameter that followed enabled us to analyze material's behavior through numerical simulations using WUFI® software. Simulated case studies first analyses the drying of a wall element and then describes its thermal and hygric response under heat variations. Its thermal performances are compared to those of other materials and it appears that some interactions between heat and mass flows, as latent heat effect, should not be neglected. Some phenomena, as air flow, hysteresis effect or time dependency of properties, were not taken into account in the simulations but their presumed effects on other flows are discussed.

2 LIME-HEMP CONCRETE

2.1 *Literature survey*

In 2003, an important synthesis of laboratory experiments made on LHC has been done (Evrard, 2003). The document gathered what was considered as the "state of the art". Four mixtures used by practitioners and studied in Arnaud & Cerezo (2001) are described. Their name is linked with the use they will fulfill as a "wall", "floor", "roof" or "plaster". These four mixtures were considered reliable only when using an appropriate lime binder. Besides interesting results presented in Chagneaud & Coquillat (2002), especially those on freezing behavior of wall-mixture, the most complete work on mechanical, thermal and acoustic properties of those four mixtures was done in Arnaud & Cerezo (2001). Mechanical properties were analyzed thoroughly and the material turns out to be non-structural and having important deformations with little stress. Accordingly to these results, LHC can only be used to fill or cover a structure with sufficient load capacity like a timber frame structure. Dry thermal conductivity of this composite material is assessed in Arnaud & Cerezo (2001) from the properties of each component by a "self consistent method". The synthesis work, Evrard (2003), pointed out that water content and sorption behavior were not taken into account in the model. Referring to wood properties, Evrard (2003) showed what could be expected for this material. Hygroscopic phenomenon, hysteresis and retarded sorption were announced. Hopefully, recent works, i.e. Cerezo (2005), introduced water content in the self consistent model and results are closer from measurements.

To introduce this new porous material in HAM models as they are presented in Annex 24 of the International Energy Agency (Hens 1996), different transport and storage coefficients were still missing in those preliminary researches if we refer to the complete set of parameters presented in (Künzel 1995). Corresponding parameters were measured and first results were discussed in (Evrard 2005, Evrard & De Herde 2005). They were then measured following corresponding norms or with specific methods presented in Krus (1996): Pressure Plates, Nuclear Magnetic Resonance (NMR)... Numerous simulations in transient conditions are now possible. The presumed thermal and hygric behavior of the material has been introduced in Evrard & De Herde (2005), and interactions between heat and mass flows are detailed here after.

2.2 *Hemp chips*

Hemp chips come from the hemp fibers industry. Hemp can grow on a wide range of soil. One hectare of culture gives generally around 4 to 6 tons of chips. Hemp cultivation started very soon in history but chips were considered as a waste compared to fibers or seeds. Most of the time, they were burnt or used for animals bedding. Their introduction into buildings is a new opening for the hemp industry. This type of use can support development of this particular "industrial fiber crops" according to the wishes of European Commission (European Commission 1994).

Hemp chips are chemically very close from wood: they are mainly composed of cellulose (50%), followed by lignin (28%) and hemicelluloses (20%) (CERMAV-CNRS 1993). Their cellular structure is also similar to some hardwood (Betula, Populus...). A pronounced sorption behavior influences how to choose the binder and gives specific properties to final material.

Precise characterization of the chips is not easy because of their variability, but dust content may not exceed a maximum value which is not defined yet Evrard (2003). In addition, average particle length should be around 2 centimeters and it is better to remove fibers, at least partly, to enable a proper mixing. This description corresponds to the product Chanvribat® chosen in this research.

2.3 *Appropriate lime binder*

The use of cement or other highly hydraulic binders were tried by practitioners to bind hemp chips, but very few decisive results were obtained. The major problem observed is that few centimeters react properly on the surface of the drying material, and the rest of its thickness powders. Mould growth was also encounter when introducing plaster material (heated gypsum) in binder mixture or when building design was not appropriate.

Several researches can still be launched to examine in detail the effect of choosing one binder or another. This would help to understand how to get a fully reacted matrix, even for thick wall (up to 30 cm). Material's final performances could then be optimized as well as its global sustainability.

Almost 15 years of building experiments in France showed that rich lime is the most appropriate binder for this kind of use. Besides its interesting life cycle, five major reasons can be quoted: 1/ its chemical reaction needs dissolved carbon dioxide which is gradually given back through water exchange with hemp chips; 2/ even if its hardening is quite slow, its relatively high permeability to vapor allows thorough drying of hemp chips; 3/ its high pH protects hemp chips for a long time from mould growth or bacteria attack; 4/ its mechanical flexibility allows slight distortion without cracking and good toughness against shocks; 5/ its thermal conductivity is lower than classical cements.

Chemical transformation of rich lime is quite slow compared to what is expected nowadays building process. This rich lime basis gives thus better results if a part of hydraulic and puzzolanic binders are added (around one forth). Specific additives can also help to enhance desired properties: water repellency, air availability during chemical reactions, surface covering of hemp chips, etc. The use of pre-formulated binder appeared to be an excellent way to be sure of the uniformity of the results. The pre-formulated lime Tradical pf 70® corresponds to those criteria, even if it was first developed to be used in old buildings masonry. This particular binder was thus chosen in this research, as it was in many other laboratory measurements [2, 3, 4, 8].

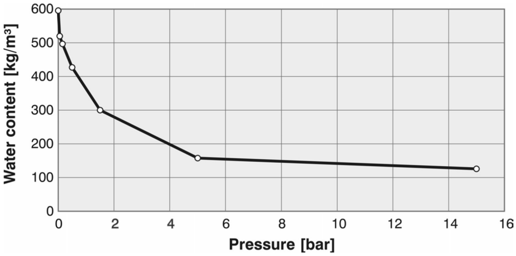

Figure 1. Water content of LHC – "wall" for different pressure.

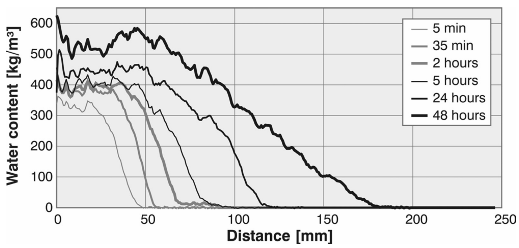

Figure 2. Water absorption measured with NMR.

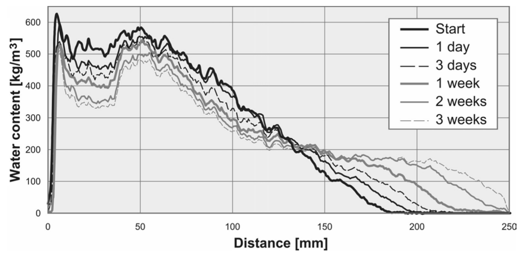

Figure 3. Water redistribution measured with NMR.

3 LABORATORY MESUREMENTS

3.1 *Samples description and known parameters*

Parameters presented in this paper result of measurements on three years old samples made with Tradical pf 70® binder and Chanvribat® hemp particles. Component quantities correspond to wall-mixture (Evrard, 2003): one bag of Chanvribat® (20 kg) for two bag of Tradical pf 70® (44 kg) and approximately 70 liters of water. For those samples, binder's carbonatation and drying were considered as completed.

3.2 *Dry density and porosity*

As presented in a previous paper (Evrard & De Herde 2005), some measurements have already been realised on the same type of samples. Mean dry density of wall-mixture is $\rho_s = 480\,kg/m^3$ and total porosity is very high, 71,1%, according to helium pycnometer measurements on dry samples.

3.3 *Moisture storage*

Mean value of moisture storage for sorption in the hygroscopic region at 23°C was also defined in Evrard & De Herde (2005) at 32, 50, 65, 80 and 93% of RH (respectively around 15, 22, 31, 36 and 45 kg/m^3), as well as free saturation and maximal water content (respectively 596 and 711 kg/m^3).

A pressure plate apparatus allowed determining the water content of wall mixture in capillary region at 23°C. As Figure 1 illustrates, the water content was measured for different pressure: 0.05, 0.15, 0.5, 1.5, 5 and 15 bar (which gives respectively 520, 497, 427, 300, 158, 126 kg/m^3). With Kelvin's law, each pressure step can be linked with an equivalent relative humidity (respectively 99.996%, 99.989%, 99.963%, 99.889%, 99.631% and 98.897%).

The complete sorption curve (from 0 to 100% RH) of wall mixture can thus be defined and used in WUFI® simulations. It appeared that moisture equilibrium were reached slower than with mineral materials and a slight hysteresis between sorption and desorption was observed. Those two phenomena will be neglected in this paper.

Absorption (Fig. 2) and redistribution (Fig. 3) of liquid water have been measured with NMR apparatus which gives distribution of water through the samples. The four samples used were 25 cm long and lateral sides were tight (side ~4 × 4 cm, dry mass ~250 g). For absorption, samples were placed vertically in 1 cm of water. For redistribution, samples were wrapped in aluminium foil. It is interesting to notice on Figure 2 that free saturation on the wet side barely reached after 48 h.

3.4 *Moisture transport parameters*

3.4.1 *Water vapor permeability*

As presented in Evrard & De Herde (2005), water vapor permeability of wall-mixture is considered to be constant. The coefficient of vapor diffusion resistance is $\mu_s = 4{,}8$. Apparent coefficient of vapor diffusion resistance can vary, but this is due to liquid transfer (surface diffusion) superimposed on vapor diffusion (Krus 1996).

3.4.2 *Liquid transport coefficient*

In future researches NMR results will enable us to assess precisely the liquid transport coefficient for absorption D_{ws} and for redistribution D_{ww}, as well as their moisture and time dependency. In the meanwhile, these coefficients were approximated on the basis of water absorption coefficient ($A = 7{,}5 \cdot 10^{-2}\,kg/m^2 \cdot \sqrt{s}$) using Künzel method in Künzel

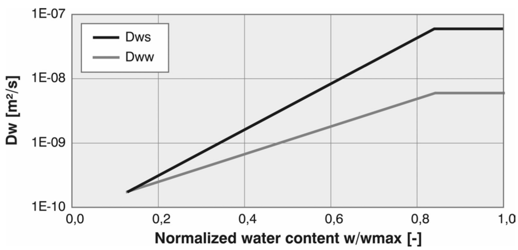

Figure 4. Approximation of the liquid transport coefficient for absorption D_{ws} and redistribution D_{ww}.

Table 1. Mean dry thermal diffusivity α_s and Effusivity ξff_s for different type of materials.

Material	α_s $10^{-7} \cdot m^2/s$	ξff_s $J/m^2K\sqrt{s}$
LHC – "wall"	1,5	286
Wood	1,4	350
Cellular concrete	3	330
Mineral wool	13,3	35
CEM concrete	6	1700
Bricks (baked clay)	3,1	831
Motionless water	1,4	1556
Motionless air	260	5
Steel	148	11700

(1995) (see Fig. 4). The figure expresses that liquid transfer is neglected for low water content and that coefficient for redistribution is much lower than for absorption.

3.5 *Thermal transport and storage parameters*

Dry value of wall-mixture's thermal conductivity was measured on three samples. The mean value is $\lambda_s = 0{,}12$ W/mK. A linear increase of 1,52% per additional % of mass content was presented in Evrard & De Herde (2005). Its dry thermal capacity is $c_s =$ 1550 J/kgK (Evrard & De Herde 2005).

Two other thermal parameters were defined in Evrard & De Herde (2005) to compare thermal performances of LHC to those of other materials. Different values are presented in Table 1. First, the thermal diffusivity α, expressed in m^2/s and defined by the ratio $\lambda/\rho c$. It is very low for LHC compared to other materials. The smaller it is, the longer the material takes to heats up. Then, the thermal "Effusivity" ξff, expressed in $J/m^2K\sqrt{s}$ and calculated by $(\lambda\rho c)^{1/2}$. It is not very high for LHC. The bigger it is, the more energy is needed to higher material's temperature. But a low ξff is responsible of a fast changing of surface temperature and of warm feeling when touching the material.

4 DYNAMICAL INTERACTION'S

4.1 *Transient phenomena*

To study dynamical interactions between heat and mass flows in this porous and hygroscopic material, it is necessary to analyze its behavior in transient conditions that represent more accurately dynamical change of inside and outside climate.

The following simulations will enhance the fact that permanent transfer is only reached after a certain time depending on material properties. During this time, flux is not as high as it is expected. For heat transfer, this time lapse appeared to be relatively long for LHC. Time needed for hygric equilibrium is also dependent of storage and transfer parameters of each material. Those topics will be referred in terms of thermal and hydric inertia.

4.2 *Varying moisture storage parameters*

Retarded sorption and hysteresis phenomena are more significant in LHC and wooden materials than in mineral materials. Actual water content thus depends on time and hygrothermal history of the material. Equilibrium water content is usually different than the one actually reached. Numerical model becomes quite complex when these phenomena are taken into account and numerous time consuming laboratory measurements are needed to validated its accuracy. As presented here before, this paper will neglect these phenomena, using a straight forward link between water content and relative humidity in the simulations.

4.3 *Water content dependency of parameters*

As previously introduced, material properties take different values depending on water content of the material. Density of LHC is for example approximately twice bigger at free saturation than for dry state. Water content also influences thermal conductivity and capacity, as well as liquid transfer parameters. Combined parameters, as thermal diffusivity and Effusivity, therefore also vary. Those variations imply evident interactions between heat and moisture transfer. They are integrated in the following simulations.

4.4 *Link between temperature and RH*

When air with a given vapor content heats up, its vapor capacity rises because saturation pressure is increased with increasing temperature following an exponential law. If we consider a constant air pressure and no redistribution of outside air, we can assume a constant partial vapor pressure. This means that relative humidity, which is defined by the ratio between partial pressure and saturation pressure, can be lowered quite strongly for a slight rise of temperature. As presented, equilibrium water content of the materials is here considered to depend only on the relative humidity. A change of temperature will thus also imply a change of water content and leads to another fundamental interaction between heat and moisture transport illustrated in the simulated cases.

4.5 *Condensation and latent heat*

A very important topic in building physic is the possible occurrence of interstitial condensations inside building envelopes. Considering the link between temperature and relative humidity, it is quite easy to understand that saturation, and then condensations, depend on both heat and moisture flows. Furthermore, if some condensations appear, phase changing of water, from vapor to liquid, will generate latent heat. Temperature of the material will locally increase and heat flow will have to adapt. Of course, evaporation inside the envelope's porous structure or on its surface will have opposite effect.

4.6 *Convective flow*

Air flow also interacts with heat and moisture transport and storage. Indeed, this convective phenomenon generates variation of local enthalpy inside the material. Nevertheless, the software WUFI® 4.0 used to simulate the following cases does not take air flow into account and this element of dynamical interactions is left for future investigations.

5 SIMULATED CASE STUDIES

5.1 *Drying*

The studied building elements start from a wet situation after their implementation. If we refer to Task1 of IEA24 (Hens 1996), the first question is therefore "does it dry or not", even before knowing "will interstitial condensation occur?". This first case study shows the drying of a 25 cm wall element in LHC (at 20°C) not yet covered with finishing materials. Ambiance at both side are fixed to 20°C and 80% RH. From NMR measurement's observations, we chose to start with a uniform water content of 400 kg/m^3 (and not with free saturation as we would do for CEM concrete) because the material is implemented in less than 2 hours (and sometimes less) after components are mixed.

As Figure 5 shows, the element dries out completely. If the time needed for thorough drying seems long (~2 years), it has to be compared with the drying time of a 25 cm CEM concrete element in equivalent conditions which would take almost 18 years to reach hygric equilibrium. In practice, finishing materials (lime plaster

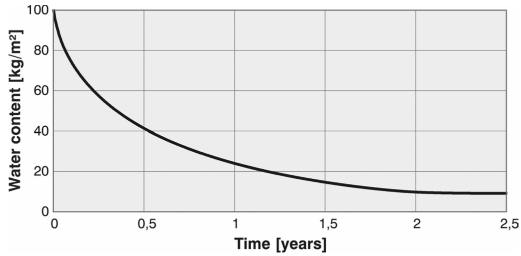

Figure 5. Evolution of water content of a 25 cm wall element in Lime-Hemp Concrete.

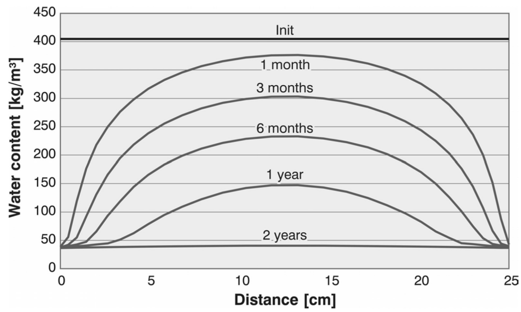

Figure 6. Water content profile of a 25 cm wall element in Lime-Hemp Concrete.

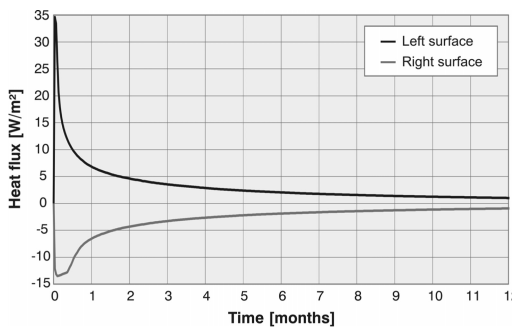

Figure 7. Heat flux through surfaces of a 25 cm wall element in Lime-Hemp Concrete.

or wood cladding, see Evrard & De Herde 2005) can be realized after a few months, depending on climate conditions. As a matter of fact, Figure 6 indicates that first centimeters beneath element surfaces dry quite fast. The slight difference between both sides comes from the use of different heat transfer coefficients on the surfaces. Left surface (outside) was assigned a thermal resistance of 1/17 m^{2}K/W, and right surface (inside), a thermal resistance of 1/8 m^{2}K/W.

However, drying do not implies just moisture flow. As we introduced, this progressive decrease (evaporation) in water content leads to a latent heat effect that Figure 7 illustrates with evolution of heat flux through surfaces of the element. Positive value corresponds to flux going from left to right. These heat fluxes are exclusively due to latent heat of evaporation. They also imply changes in surface temperature, but these variations are small (i.e. left surface temperature is 19,5°C after around 15 days and slowly goes back to 20°C after that). These observations attest interactions between heat and moisture flows when simultaneous transfer is considered.

5.2 *Sudden cooling*

The second case study was defined to illustrate that permanent heat transfer is not immediately obtained and to show presumable hygric effect of a thermal variation. For this theoretical case, three 25 cm elements of plain material are compared: one in LHC, the other in cellular concrete ("Cell"; $\lambda_s = 0{,}12$ W/mK), and the last one in mineral wool ("Mwool": $\lambda_s = 0{,}04$ W/mK). These elements are of course not realistic, but they are defined to build elements of comparison between those materials. Temperature and humidity on the left side of the elements correspond to outside conditions and those on right side to interior's one. On both sides and through the elements, initial temperature is 20°C. Saturation pressure is assessed to be 2338 Pa at this temperature. Initial relative humidity is defined to be 80% outside and 50% inside. Initial partial vapor pressure can thus be estimated to be 1870 Pa outside and 1169 Pa inside. The initial distribution of humidity in the element corresponds to hygric equilibrium in these conditions. From the first time step, outside temperature is lowered to 0°. At this new temperature, saturation pressure decreases to 611 Pa. If vapor pressure is considered to stay constant in outside air, relative humidity theoretically rises until saturation and some condensations occur because this new saturation pressure is smaller than initial vapor pressure on this side. Outside relative humidity is then fixed to 100% for the rest of the simulation. Inside conditions are left constant.

For the LHC element, the simulation distinguished results obtained when latent heat effect is taken into account ("+") and when it is neglected ("−"). This latent heat comes from moisture variation through the element. Permanent heat transfer is obtained when heat flux takes a constant value and thus when water content of the element gets to a new equilibrium.

Figure 8 illustrates heat flow going trough interior surface. Negative value means heat is given from inside environment to the element. Simulations confirmed that the time needed to reach permanent transfer is longer for materials with a small thermal diffusivity. In the LHC element, the flux reaches 95% of the permanent transfer value after around 64 hours without latent heat effect and after 100 hours with it, whereas it takes only ∼30 hours for cellular concrete

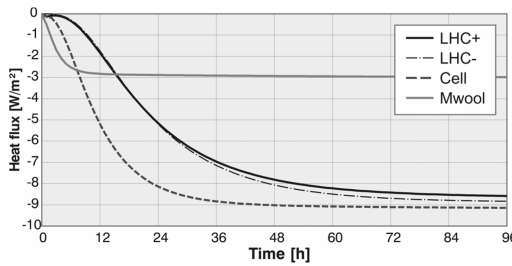

Figure 8. Heat flux through interior surface of 25 cm wall elements in LHC, cellular concrete (Cell) and mineral wool (Mwool).

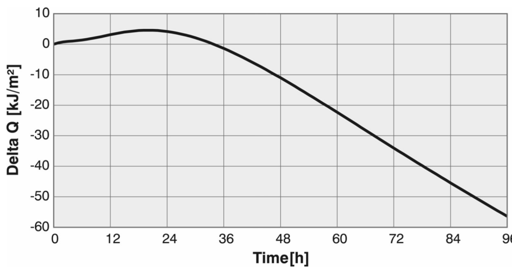

Figure 9. Evolution of difference between total amount of energy given from inside environment to LHC element with and without latent heat effect.

element and ∼12 hours for the mineral wool element (there were no significant latent heat effects).

Integration of the curves presented in Figure 8 points out that total amount of energy given from inside environment 24 hours after the thermal shock is lower for the LHC element (in both case ∼190 kJ/m^2) than for the two other elements (410 kJ/m^2 for "Cell" and 220 kJ/m^2 for "Mwool"). This amount of energy corresponds to the energy demand to keep inside conditions constant and results show the importance of considering the response of materials under dynamical conditions to assess their thermal performances. Indeed, if thermal conductivity of LHC seems quite high compared to what is commonly expected for insulation materials, this case study thus confirms that thermal performances of LHC in transient conditions are rather high. Results obtained in Evrard & De Herde (2005) with thermal cycles led to the same observation.

"Delta Q" can be defined by the difference between the total amount of energy given from inside environment to LHC element when latent heat effects is considered, Q_{LHC+}, and when it is not, Q_{LHC-}: "Delta Q" $= Q_{LHC+} - Q_{LHC-}$. If it is negative, the latent heat effect implies some energy savings. On Figure 9, it appears that "Delta Q" is positive (4,2 kJ/m^2) for the 36 first hour. Latent heat effect thus implies, in this case, a slight increase of the energy demand to keep inside environment conditions constant. This is due

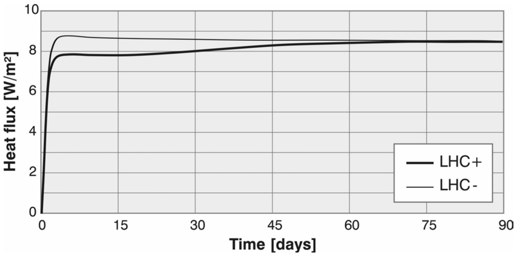

Figure 10. Heat flux through interior surface of a LHC, with ("+") and without ("−") latent heat effect.

to slight evaporation (absorbing latent heat) close to outside surface. As a matter of fact, initial vapor pressure in this zone of the element is higher than the new vapor pressure of outside saturated air. Some of the water contained in the material's porous structure is changed into vapor and a vapor flow toward outside environment is initiated. When excessive vapor pressure in the outside part of the element has been adapted, moisture distribution through the element can slowly evolve towards the equilibrium that corresponds to new boundary conditions. Water content has now to increase, and this slight condensation of vapor inside the element's porous structure produces some latent heat that contributes to heat transfer and lowers energy demand. After 96 hours, the difference "Delta Q" is $-56\,kJ/m^2$. Considering that $2283\,kJ/m^2$ is given after that time from inside environment to the envelope when latent heat effect is not taken into account, this economy of 2,5% is thus not significant, event if it is not negligible.

5.3 *Sudden heating*

The same case study, but with a thermal shock that rises outside temperature from 20 to 40°C leads to similar observations. Again, this case is rather theoretical but gives good indication of materials behavior in transient conditions and of corresponding relation between heat and moisture transfer. Vapor pressure outside is also considered to be constant (1870 Pa), and adapted outside relative humidity becomes 25% since saturated pressure is 7383 Pa at 40°C. Inside conditions are left constant.

Hygric equilibrium is faster to settle in this case: water content of the element reaches a constant value about 3 months after thermal shock. This comes from the fact that difference in relative humidity through the element, which is the driving force of hygric transfer in WUFI® model, is bigger.

Figure 10 illustrates heat flows at interior surface and shows that latent heat effect is more significant in this case. In the simulated LHC element, the flux reaches 95% of the permanent transfer value after around 50 hours when latent heat effect is not taken into account, but only after 850 hours (∼35 days) when it is. It also appears that heat flux on interior surface reaches a maximum after 5 days without latent heat effect. The steady decrease of heat flux that follows is due to changes in heat conductivity but these changes do not have a significant influence in this case.

As previously discussed, vapor pressure in the element has to adapt to the new boundary conditions. Vapor is released from the element to outside environment. Water content decreases until the new equilibrium, producing some latent heat. After 96 hours, the effect of latent heat has lowered the energy given from the envelope to inside environment from $2261\,kJ/m^2$, when latent heat effect is not taken into account, to $2045\,kJ/m^2$. This "Delta Q" of $217\,kJ/m^2$ means an economy of the cooling energy needed to keep interior conditions constant of 9,6%. This observation confirms once again that latent heat effect should not be neglected when thermal performance of LHC is assessed.

6 DISCUSSION

These first simulations were defined to show that Lime-Hemp Concrete (LHC) wall-mixture, have high thermal performances under transient conditions. Next step will be to introduce a complete wall element (with lime plaster or wood cladding) in simulations were boundary conditions are real climatic data.

A specific combination of hygrothermal parameters gives strong thermal and hygric inertia to LHC. A high thermal capacity, with a medium density and a quite low thermal conductivity correspond to a low thermal diffusivity and a relatively low Effusivity. These elements help to create a comfortable environment in winter as well as summer conditions. The present paper focused on heat flux on the interior surface, but evolution of their surface temperatures also contributes to this comfort feeling. The same observation can be made on hygric parameters, were a high hygric capacity, combined to high vapor permeability allows these materials to regulate inside air humidity.

In the presented case studies, latent heat effects appeared to be a small but not negligible complement to the thermal load quality of those envelopes. Transient condensations and evaporations in the material porous structure should then not be considered as problematic right away. Precise limit in quantity and duration have to be defined but the first case study showed that their drying is not a problem and no accumulation of condensed water was encountered in the second case study.

The previous simulations also enlighten the relation between temperature and relative humidity, and its effect on heat or moisture flows. Of course, vapor pressure of outside air is not constant as we considered, and this relation between temperature and relative humidity of outside air is thus not accurate. A good understanding of the link between those two parameters is fundamental to understand material response and to analyze hygrothermal behavior of this kind of building element in real climatic conditions.

Interactions between heat and moisture flows with air flow are evident. Air passing through or along an element can lower or increase its temperature and influence its water content depending on its own temperature, humidity or velocity. Air flow can increase, reduce or even stop vapor flow. Its driving force is a gradient of air pressure. Controlling the actual gradient between outside and inside surfaces of an envelope to obtain specific air flow through it, and thus enhance a "dynamical insulation effect", seems quite difficult in building practice. In addition, the porous element should then be considered as a permanent filter, accumulating dust and other particles from outside or from inside. Still, material's air permeability should be measured in future research to assess the natural flow going through an element in normal climatic conditions and its presumed influence on heat and moisture flows.

7 CONCLUSIONS

Lime-Hemp Concrete is a new and innovative insulation material. It is mainly use to fill timber frame structures or cover masonry wall. Its global sustainability can still be studied in many ways, but a very good balance is assumed when life-cycles (energy of production, recycling . . .), comfort or health is considered. The different case studies presented in this paper assess that the use of this material can contribute efficiently to save energy when heating or cooling inside environment of buildings. As building science showed up in the last decade, its hygroscopic behavior (sorption and desorption), have positive effects that can be enhanced if moisture effect are controlled.

Although some hygrothermal parameters, as liquid transfer coefficient or thermal conductivity for high moisture content, have still to be defined and validated, simulations can already be made with good accuracy. WUFI® software was chosen for the numerical simulations since it allows to model accurately dynamic interactions between heat and moisture flows in the material by allowing the possibility to consider latent heat and transient heat and mass transfer. Air flow, retarded sorption and hysteresis effects are not taken into account in this model but future researches will detail them thoroughly.

As it appears, knowledge on LHC is not yet complete, but laboratory measurements, in parallel with building practice, contributes year after year to understand and control this material's specificity. Fast development of its use, mostly in French buildings, in the last years gives good hope of its spreading in the rest of Europe and even further. We are convinced that this development will contribute to define a sustainable architectural environment for following generations.

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