

Hempcrete Buildings: Environmental Sustainability and Durability of Two Case-studies in North and South Italy

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Abstract. *In the framework of Circular Economy policies aimed at reducing the consumption of raw materials, shives, as an agricultural by-product of hemp cultivation, have gained a renovated life in the construction sector. Its excellent thermal insulating properties permitted the development of new building materials to be used in various executive technologies. When shives are mixed with a mineral binder such as lime or cement, the mixture is usually referred to as hempcrete. In Italy, the use of hempcrete and the development of new production chains and implementation techniques dates back only to about the last decade, while other European countries have more long-lasting experiences (90s).*

In order to assess the potential benefits of hempcrete in the construction sector, its environmental performances were evaluated using the LCA methodology, by comparing four non-loadbearing representative walls, one made with hempcrete blocks and the others with more “traditional” materials. This research constitutes a solid basis for the development of future guidelines and/or regulations at national and international level in order to guarantee the maximum diffusion of this type of product. Then, a study has been carried out regarding the functionality of hempcrete blocks in masonry, layered with finishing plaster made of fine hemp shives, to evaluate the in-situ hygrothermal building performance. In particular, measurement methods were developed and analysis were carried out on two houses, one in northern Italy and one in southern Italy, and precisely in Sicily, focusing the study on the performances of the walls subjected to warm Mediterranean climates. Indeed, the literature on masonry behavior in hot Mediterranean climates is much scarcer than in cold climates.

Keywords: *Hempcrete, Hygrothermal Behaviour, Sustainable Materials, Mediterranean Climate, Durability.*

1 Introduction

The building sector has a major impact on the natural environment, so sustainable building materials have been developed to reduce the emission into the atmosphere of carbon dioxide

and polluting gasses typical of the process of production of traditional building materials. Among sustainable materials, the nature-based solutions are carbon negative and characterized by low-embodied energy (Murphy and Norton, 2008; Ip and Miller, 2012); in addition, they are able to improve the performances of a building envelope because of their remarkable insulating properties. Many bio-composite materials are produced introducing biomasses, residual of agricultural cultivation (e.g. hemp, straw, rice-husk), into traditional binders (e.g. lime, concrete). In this way, the new building materials exploit natural resources that would otherwise be wasted, being the by-product of agricultural activities (Liu *et al.*, 2017).

This study focusses on hempcrete which is produced introducing hemp shives into an hydraulic binder. The increasing utilization of this material is due to its characteristic hygroscopic properties which determine an improvement of the indoor environmental comfort as reported, for example, by Nordby and Shea (2013). The present research aims to investigate the performances of walls built using hempcrete blocks. The bio-blocks are not-loadbearing and they are used to insulate thermally external or internal walls or to divide internal spaces. The prefabricated blocks production developed in order to solve some issues typical of casting of hempcrete in situ; especially the hardening step which is critical as it significantly influences the homogeneity of the properties in the casted material. Hence, by producing blocks, it is possible to control the hardening phase and to improve the quality of the material (Elfordy *et al.*, 2008).

A preliminary evaluation of the environmental performances of a wall made with hempcrete blocks has been performed through LCA (Life Cycle Assessment) methodology according to EN ISO 14040-14044:2006 standards. A comparative assessment with different wall systems was started, preliminarily only at A1-A3 stages, i.e. product stage (EN 15804:2012 + A2:2019).

Then, this research develops experimental methodologies to investigate the hygrothermal behaviour of hempcrete during its service life, so it would be possible to evaluate its durability in situ. The measurements have been performed on walls built using the same type of hempcrete blocks in two residential houses in Sicily (southern Italy) and in Veneto (northern Italy).

2 Durability of Hempcrete

Durability has a crucial importance for building materials, few data exist about the durability of hempcrete in real structures because its utilization is relatively recent, it has been used in France from 1990s and in Italy only from 2000s. The first data collected on buildings have given good results, comparable to the performances of traditional materials (Clarke, 2002). The aim of this project is to perform field test in the two selected buildings, both in Sicily and in Veneto, to obtain information about the behaviour of hempcrete blocks. This would support the users in the utilization of the material. The interesting results on the performances of the material presented in this paper will be implemented with periodical tests to study the evolution of the performances of the material and its durability in residential structures.

The main concern about the durability of hempcrete is determined by the presence of vegetal material because the variation of moisture conditions can cause its degradation. Thus, a decrease of the performances of hempcrete and, possibly, a reduction of the salubrity of the environment could occur.

Data about the durability of hempcrete can be collected carrying out laboratory tests, some studies have simulated possible critical situations, typical of the service life, but field tests are recommended to increase the knowledge about the material. The effects of biological attack by bacteria or fungi have been studied by inoculating microorganisms into the material. Periodic measurements along two years have been carried out by Walker *et al.* (2014) after the abundant introduction of bacteria; the results show that microorganisms, even those able to live in alkaline conditions, did not proliferate and degradation did not occur. Moreover, the alternating high and low values of humidity, typical of Mediterranean climate, further limit their permanence into the material. The alternation of wet and dry periods is fundamental to avoid the biological degradation: high humidity favours the spread of fungi or bacteria on the surface of hempcrete reducing the hygrometric performances of the wall while low humidity allows the penetration of microorganisms inside the material reducing the water vapour permeability (Arizzi *et al.*, 2016). The importance of testing even after several months is underlined by Marceau *et al.* (2017) who have found the conditions necessary for the mould growth: high relative humidity (around 98%) and pH lower than 10. The pH of hempcrete decreases due to the carbonation process, for this reason a long-term monitoring would allow to investigate the behaviour of the material in critical conditions. Some biocide treatments as γ irradiation of hemp shives, addition of anti-microbial or nanoparticles able to increase the resistance to bacteria or fungi have been proposed (Arizzi *et al.*, 2016).

Beside the growth of microorganisms, the moisture content influences also the density and, consequently, the thermal conductivity of the material. Hence, proper ventilation and correct selection of the protective coating, are crucial to preserve the properties of hempcrete besides to counter the biological degradation (Marceau *et al.*, 2017). The resistance to freeze-thaw cycles is good, no cracks or modification of the microstructure have been detected for a year on hempcrete blocks, characterized by different hemp-to-lime ratios, after 10 freeze-thaw cycles in conditions near saturation (RH around 90%). Carbonation reduces the vulnerability to freeze-thaw cycles because the formation of calcium carbonate reduces the porosity of hempcrete and hence the amount of water absorbed (Walker *et al.*, 2014). Furthermore, tests of exposure to salt (NaCl) performed by Walker *et al.* (2014) and Arizzi *et al.* (2016) did not provoke degradation of blocks and no effloresce was detected. If salt precipitates on the surface, it is easily removed by rainfall while, if absorbed, the hygroscopic behaviour helps in weathering through natural wet-dry cycles. Therefore, the weathering of salt is less aggressive in hempcrete than in other inorganic porous materials (e.g. stone, mortar).

3 Life Cycle Assessment

In recent years, the interest for hemp-based building materials has increased also due to their expected positive environmental performances (Ingrao *et al.*, 2015). However, few LCA

studies have evaluated different hempcrete wall technologies: spray (Boutin *et al.*, 2006; Pretot *et al.*, 2014) sprayed hempcrete with timber frame support (Ip and Miller, 2012; Pretot *et al.*, 2014) and blocks. A preliminary environmental assessment of the hempcrete technology is given here by evaluating a representative wall made with hempcrete blocks. Recently, the environmental performances of an Italian hempcrete block (Arrigoni *et al.*, 2017) as well as hemp cultivation (Zampori *et al.*, 2013) have been carried out.

In order to assess the environmental sustainability of hempcrete blocks used in non-load bearing walls, three additional alternatives have been selected and compared at the level of materials production (A1-A3, EN 15804:2012+A1:2019): masonry bricks, expanded clay bricks and aerated autoclaved concrete (AAC) blocks with cement-lime mortars. The comparison is based on 1 m² of vertical non-load-bearing wall (Functional Unit). Data for alternative bricks are taken from Environmental Product Declarations (EPDs) of selected producers (Aversa *et al.*, 2019; Margutti and Pennati, 2018). The impact categories selected are those reported in the EPDs and the method used to evaluate the environmental burden of the four walls is CML 2001 (Guinée and Lindeijer, 2002).

In Figure 1, the results of the four walls in seven impact categories are compared. The hempcrete wall solution has very positive performances in six out of seven impact categories. This preliminary LCA is highly promising, especially considering that only the first life cycle stages of the building are included in the analysis. Further benefits will certainly come from the use stage and end-of-life. Moreover, a detailed LCA study of hempcrete blocks is being carried out to take into account production improvements occurred in the last year.

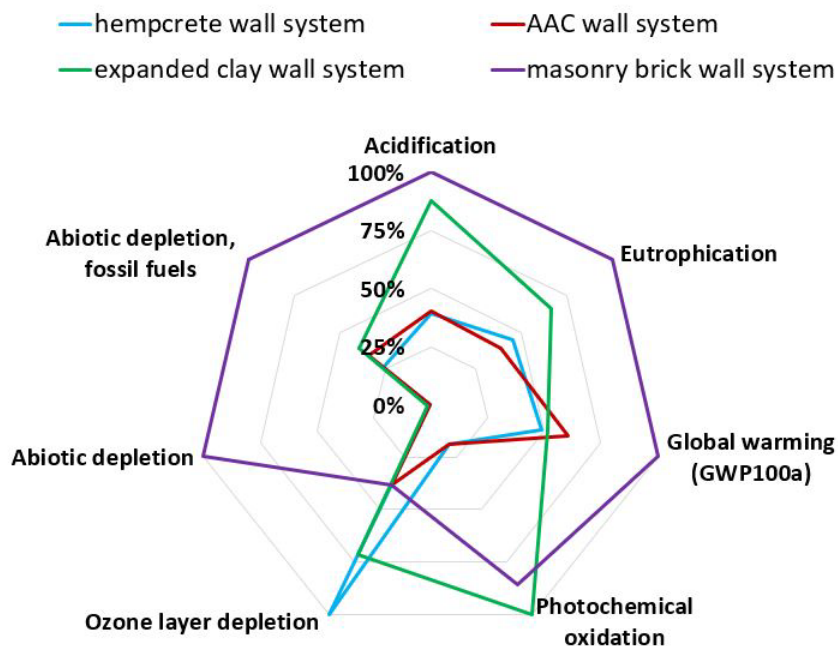


Figure 1. Wall systems comparative LCA assessment at the product stage A1-A3.

4 Case Study

The experimental methodology to perform the field measurements that allow to determine the hygrothermal performances of hempcrete walls has been tested in laboratory on a 1m² wall, built in hempcrete blocks, introduced in a climatic chamber. Known temperature cycles have been applied to simulate hot temperate climates (Aversa *et al.*, 2019). The test wall had been built employing the same type of blocks used in the perimeter walls of the detached houses in Sicily (Serradifalco, CL).

Currently, the data collected in the Sicilian campaign have been elaborated, the reference standards are UNI EN 15026:2008 and UNI EN ISO 13788:2013. The measurements have been performed on the South-West, South-East and North-West walls for 13 days (in August) during which the inhabitants were not present to exclude the influence of the air conditioning system. The wall system is 400mm thick (Figure 2): the hempcrete blocks have a thickness of 360 mm, the ratio between dolomitic lime and hemp shives is 3:1; the plaster is premixed, constituted by hydraulic lime NHL 5 and it has thickness of 20 mm both on the internal and on the external face of the walls. The bedding mortar is characterized by a dolomitic lime-to-hemp shive ratio of 3:1.



Figure 2. Wall system: 1-plaster (thickness: 20 mm); 2-hempcrete blocks (thickness: 360mm); 3-bedding mortar.

Temperature and humidity sensors have been applied on the walls (see Aversa *et al.*, 2019) while the outdoor weather conditions have been measured by a weather control unit. The temperature and humidity of internal and external surfaces of the North-West wall, detected during the period of analysis, are plotted in Figure 3.

Regarding the relative humidity, on the internal wall an average value of 67% has been measured while the external value shows variations in between 40% and 100%, due to some rainy days during the monitoring period. Hence, the behaviour of the wall is good, the damping has been higher than 80%. Also, the thermal response has been good, the average temperature measured on the internal wall has been 26°C (with variations of $\pm 1.5^{\circ}\text{C}$) in

response to the variations of external temperature between 15°C and 35°C. Likewise humidity, the damping is higher than 80%. The offset between internal and external humidity is of 6 hours, relatively to the maximum peak of humidity, while the offset was around 8 hours in laboratory tests (Aversa *et al.*, 2019).

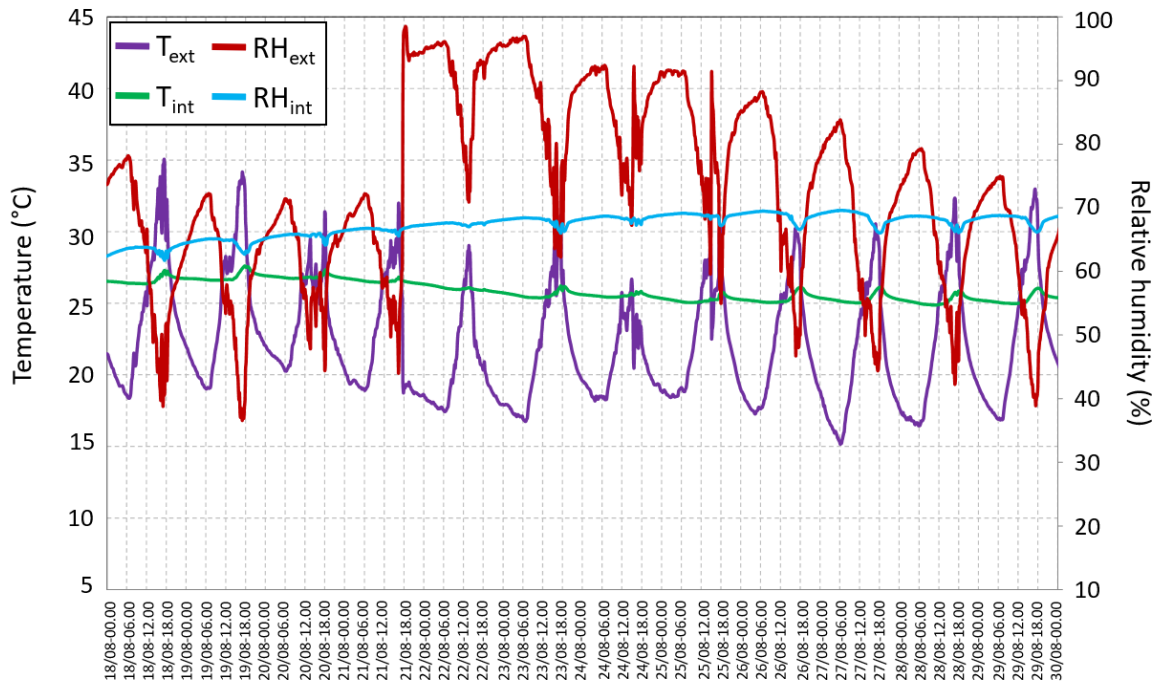


Figure 3. Temperature (T) and relative humidity (RH) measured on the internal (int) and external (ext) faces of the North-West wall of the house in Sicily during the 13 days of analysis.

The implementation of the results with the numerical simulations and the new experimental campaigns will enrich the knowledge about the behaviour of hempcrete in a detached house. This will be implemented by the measurements carried out in Veneto. The case-study in Sona (VR) is different from the Sicilian because hempcrete has been applied only in a room, during the renovation of the building. In this case, the data will provide information both on the performances of hempcrete into a different climate than the Sicilian one and on the behaviour of the material when installed in combination with other materials.

5 Conclusions

This study shows the promising performances of hempcrete blocks both in terms of environmental sustainability and hygrothermal properties. The preliminary environmental assessment through LCA is highly encouraging and seems to confirm what has been already

demonstrated in the recent literature, i.e. that the use of hempcrete blocks has a beneficial effect on relevant impact categories. Furthermore, some of the advantages of the hempcrete are not clearly evidenced in the first life cycle stages of a building, in terms of energy saving and recyclability at the end-of-life.

The first evaluation of the hygrothermal performances of hempcrete blocks in the Sicilian climate is positive. The indoor temperature and humidity were almost constant during the analysis period without the utilization of ventilation, air-conditioning systems or air exchange. Further measurement in situ will allow to understand the evolution of the material performances in time. Thus, the durability of hempcrete will be evaluated together with the possibility to install it in place of traditional materials, especially when sudden climatic variations occur, or higher humidity and continuous rain conditions verify.

Moreover, the availability of residential houses for in situ measurements will allow the evaluation of energetic behaviour of the buildings and the evaluation of the environmental performances of the material when applied in construction works. Also, the effects on the indoor comfort will be investigated i.e. humidity and temperature of the internal spaces will be measured.

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References

- Arizzi, A., Viles, H., Martín-Sánchez, I. and Cultrone, G. (2016). Predicting the Long-Term Durability of Hemp-Lime Renders in Inland and Coastal Areas Using Mediterranean, Tropical and Semi-Arid Climatic Simulations. *Science of the Total Environment*, 542, 757-770. doi:10.1016/j.scitotenv.2015.10.141.
- Arrigoni, A., Pelosato R., Melià, P., Ruggieri, G., Sabbadini, S., Dotelli, G. (2017). Life Cycle Assessment of Natural Building Materials: The Role of Carbonation, Mixture Components and Transport in the Environmental Impacts of Hempcrete Blocks. *Journal of Cleaner Production*, 149, 1051–1061. doi:10.1016/j.jclepro.2017.02.161.
- Aversa, P., Daniotti, B., Dotelli, G., Marzo, A., Tripepi, C., Sabbadini, S., Lauriola, P., Luprano, V. A.M. (2019). Thermo-Hygro-metric Behavior of Hempcrete Walls for Sustainable Building Construction in the

- Mediterranean Area. *IOP Conference Series: Earth and Environmental Science*, 296(1). doi: 10.1088/1755-1315/296/1/012020.
- Boutin, M.P., Flamin, C., Quinton, S., Gosse, G. (2006). Study on the Environmental Characteristics of Hemp through the Analysis of its Life Cycle (in French). Ministry of Agriculture, Agrifood, and Forestry, Paris, France.
- CEN (2019). *EN 15804:2012 + A2:2019 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*.
- CEN (2006). *EN ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework*.
- CEN (2006). *EN ISO 14044: Environmental Management – Life Cycle Assessment – Requirements and Guidelines*.
- Clarke, S. (2002). Final Report on the Construction of the Hemp Houses at Haverhill, Suffolk. *Suffolk. Building Research Establishment, Watford 2002 (209)*, 209–717.
- Elfordy, S., Lucas, F., Tancet, F., Scudeller, Y. and Goudet, L. (2008). Mechanical and Thermal Properties of Lime and Hemp Concrete ('hemcrete') Manufactured by a Projection Process. *Construction and Building Materials*, 22 (10), 2116–2123. doi: 10.1016/j.conbuildmat.2007.07.016.
- Guinée, J. B., and Lindeijer, E. (2002). *Handbook on life cycle assessment: operational guide to the ISO standards*. Netherlands: Springer Science & Business Media.
- Ingrao, C., Lo Giudice, A., Bacenetti, J., Tricase, C., Dotelli, G., Fiala, M., Siracusa, V., Mbohwa, C. (2015). Energy and Environmental Assessment of Industrial Hemp for Building Applications: A Review. *Renewable and Sustainable Energy Reviews*, 51, 29–42. doi:10.1016/j.rser.2015.06.002.
- Ip, K. and Miller, A. (2012). Life Cycle Greenhouse Gas Emissions of Hemp-Lime Wall Constructions in the UK. *Resources, Conservation and Recycling*, 69, 1–9. doi: 10.1016/j.resconrec.2012.09.001.
- Liu, L. F., Li, H. Q., Lazzaretto, A., Manente, G., Tong, C. Y., Liu, Q. B. and Li, N. P. (2017). The Development History and Prospects of Biomass-Based Insulation Materials for Buildings. *Renewable and Sustainable Energy Reviews*, 69 (July 2016), 912–932. doi:10.1016/j.rser.2016.11.140.
- Marceau, S., Glé, P., Guéguen-Minerbe, M., Gourlay, E., Moscardelli, S., Nour, I. and Amziane, S. (2017). Influence of Accelerated Aging on the Properties of Hemp Concretes. *Construction and Building Materials*, 139, 524–530. doi:10.1016/j.conbuildmat.2016.11.129.
- Margutti, M. and Pennati, A. (2018) *Definition of methods for the control of quality and for the correct laying and management of hemcrete blocks*, MSc Thesis, Politecnico di Milano, Milan, Italy.
- Murphy, R. J. and Norton, A. (2008). Life Cycle Assessments of Natural Fibre Insulation Materials Final Report. *11th International Conference on Non-Conventional Materials and Technologies, NOCMAT 2009*, no. February: 79.
- Nordby, A. S. and Shea, A. D. (2013). Building Materials in the Operational Phase: Impacts of Direct Carbon Exchanges and Hygrothermal Effects. *Journal of Industrial Ecology*, 17 (5), 763–776. doi: 10.1111/jiec.12046.
- Pretot, S., Collet, F. and Garnier, C. (2014). Life Cycle Assessment of a Hemp Concrete Wall: Impact of Thickness and Coating. *Building and Environment*, 72, 223–31. doi:10.1016/j.buildenv.2013.11.010.
- UNI/TS 11300-1 (2008). *UNI EN 15026: Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation*.
- UNI/TS 11300-1 (2013). *UNI EN ISO 13788: Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation*.
- Walker, R., Pavia, S., and Mitchell, R. (2014). Mechanical Properties and Durability of Hemp-Lime Concretes. *Construction and Building Materials*, 61, 340–348. doi:10.1016/j.conbuildmat.2014.02.065.
- Zampori, L., Dotelli, G. and Vernelli, V. (2013). Life Cycle Assessment of Hemp Cultivation and Use of Hemp-Based Thermal Insulator Materials in Buildings. *Environmental Science and Technology*, 47 (13), 7413–20. doi:10.1021/es401326a.