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Thermal performance of real-life in-situ cast lime hemp walls in Flanders

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Abstract. In order to meet the energy performance regulations for new buildings and to improve the energy performance of the existing building stock, a high amount of insulation materials will be needed in the coming years. Meanwhile, the demand for renewable materials and materials with a low environmental impact is increasing. In previous research, the ecological and hygrothermal potential of lime hemp as a building material has been shown. Besides incorporating a large share of renewable and fast-growing hemp shives, lime hemp combines thermal insulating properties and a high thermal inertia with a good moisture regulating behaviour. However, despite the growing interest in the material and promising lab results, the thermal performance in real conditions is still uncertain. Due to the lack of validated data for in-situ cast walls, rather conservative λ -values for lime hemp are currently compulsory used in energy performance certification calculations in Flanders, the Flemish region of Belgium.

In this paper, the results of a case study analysis of four real-life lime hemp projects are presented. The thermal performance of four dwellings with in-situ cast lime hemp walls (both new construction and renovation) is determined by in-situ measurements of the U-value. The measurements show that the in-situ U-value of the lime hemp walls is significantly better than the U-value that is calculated with the λ -value that is currently accepted by the Flemish Energy Agency. However, drying of lime is a slow process, resulting in initially higher U-values that gradually decrease in the first months after lime hemp application. Once dried, in-situ cast lime hemp walls can meet the Flemish energy performance requirements.

1. Introduction

In recent years, the energy performance requirements for both new construction and renovation are gradually becoming stricter, resulting in an increasing demand for and application of insulation materials. Due to the high raw material consumption and CO₂ emissions during the production of many building materials and the waste production at the end of the life cycle, there is a need to search for insulation materials that are (partially) renewable and have a low overall environmental impact.

Lime hemp is a building material that is produced by mixing the chopped woody part of the hemp plant (the shives) with lime, water and pozzolanic, cementitious or hydraulic lime additives. After hardening, a lightweight material is created with insulating properties, a high thermal inertia and a



moisture-regulating capacity [1]. Lime hemp can be used, for example, as an infill for timber frame constructions or as an internal or external insulation layer for existing walls. It can be cast in-situ in a formwork or sprayed as a thin layer on a wall surface. Prefabricated blocks or panels are also available on the market.

Various LCA-based studies show the ecological potential of lime hemp applications [2-6]. Although lime is used as a binder and CO₂ is released during the production of lime, it is found that construction components with lime hemp have a lower environmental impact than many conventional building materials [6]. Due to CO₂ storage through photosynthesis during the growth of the hemp plant and carbonation during the hardening of lime, more CO₂ is absorbed in a lime hemp wall than there is emitted during production. Furthermore, in contrast to many conventional insulation materials, lime hemp consists largely of renewable materials that can be grown locally. Compared to the cultivation of many other fibre crops, hemp cultivation is found to have a low environmental impact [7] and the different parts of the hemp plant (seeds, fibres, shives) can be used in various applications, e.g. in textiles, insulation panels, ropes, food, ...

Because of its potential ecological and hygrothermal benefits, there has been a growing interest in the material in recent years, both in research and in building practice. In France, where lime hemp has been used since the 1990s, many lime hemp projects have been realised [8]. In the United Kingdom, a number of prestige projects, such as the Renewable House in the BRE Innovation Park, the Wine Society Warehouse in Stevenage and the Hempcrete Museum Store of the Science Museum London in Wroughton resulted in an increased interest in the material [3]. In Belgium, the material is recently becoming more popular among self-builders, contractors and architects with a preference for "natural" materials or materials based on renewable raw materials.

Although the first laboratory investigations into lime hemp date back to 1997, the number of scientific publications on the material behaviour and the factors that influence the properties of lime hemp as a building material is recently growing. Many studies focus on the hygrothermal behaviour of lime hemp [1,9-15]. In addition to a moderate to good thermal insulation, the material is characterised by a high moisture buffer capacity. However, these researches are often situated on a material level and the material behaviour is evaluated in laboratory conditions. A validation of the in-situ performance of real-life applications is missing. Data on the actual drying times, the real thermal performance and the effective moisture buffer capacity of lime hemp in real-life lime hemp wall elements are needed to ensure a more widespread application of lime hemp in building practice. In this paper, a case study analysis of four real-life in-situ cast lime hemp walls is presented. The actual thermal performance is measured and compared with the thermal characteristics that are compulsory used in energy performance certification calculations in Flanders nowadays.

2. Materials and methods

For the case study analysis, four cases are selected with commonly used wall compositions and lime hemp mixtures in Flanders (2.1). For these cases, the U-value of the lime hemp walls is measured in-situ (2.2). A theoretical U-value is calculated, based on the λ -values that are currently used in energy performance certification calculations in Flanders (2.3), and compared with the measured U-value.

2.1. Selection and description of the cases

Prior to the measurements, an inventory of lime hemp projects in Flanders was made to gain insights into the most commonly used lime hemp mixes and wall compositions for both new construction and renovation projects. Cases with in-situ cast lime hemp as well as with prefabricated blocks and panels were documented. In other countries, due to differences in legislation and local climatic conditions, other wall compositions might be more common. Also, lime hemp mixtures (type of lime and additives, composition, density) might slightly differ.

In this paper, commonly used in-situ cast lime hemp applications are analysed and an overview of the four selected cases is presented in Figure 1. When renovating half-timbered barns, lime hemp can be applied as insulation material between the existing wooden structure and finished by a plaster, so

that the typical character of the half-timbered structure can be retained (Case 1). As lime hemp is not a load-bearing material, in-situ cast lime hemp is often combined with a timber frame construction (Case 2). In case of renovation, lime hemp can be cast against an existing masonry wall, both as interior (Case 3) as well as exterior (Case 4) insulation.

As drying of lime hemp is a slow process during which the λ -value improves, all investigated lime hemp walls were cast at least 1 year prior to the measurements. However, the year of construction needs to be taken into account when analysing the results.



Case 1: Renovation (2016), existing half-timbered barn insulated with lime hemp (30 cm)



Case 2: New construction (2014), timber frame construction with lime hemp infill (38 cm)



Case 3: Renovation (2017), existing masonry wall with lime hemp interior insulation (27 cm)



Case 4: Renovation (2014), existing massive masonry wall with lime hemp exterior insulation (15 cm)

Figure 1. Overview of the four cases with in-situ cast lime hemp walls.

2.1.1. Wall composition. An overview of the wall compositions of the four cases is presented in Figure 2. Case 1 is an existing half-timbered barn that is insulated with 30 cm of lime hemp and finished with a plaster, both at the inside (loam) and outside (lime). The existing wooden structure is reinforced with a secondary timber frame construction. In Case 2, a load-bearing timber frame construction is combined with an in-situ cast lime hemp wall and finished with a plaster at the inside (loam) and outside (lime) of the wall. Wall heating is installed within the interior loam plaster, but the heating was switched off during the measurements of the in-situ U-value (2.2) to avoid interference with the measurements. In Cases 3 and 4, an existing brick masonry wall, with a thickness of resp. 28 cm and 29 cm, is insulated with lime hemp. In Case 3, the interior lime hemp insulation (27 cm) is applied within an existing oak structure (20 cm) that is reinforced with a timber construction (6-7 cm) and finished with a loam plaster. In Case 4, the wall is insulated at the exterior with 15 cm of lime hemp and finished with a lime plaster.

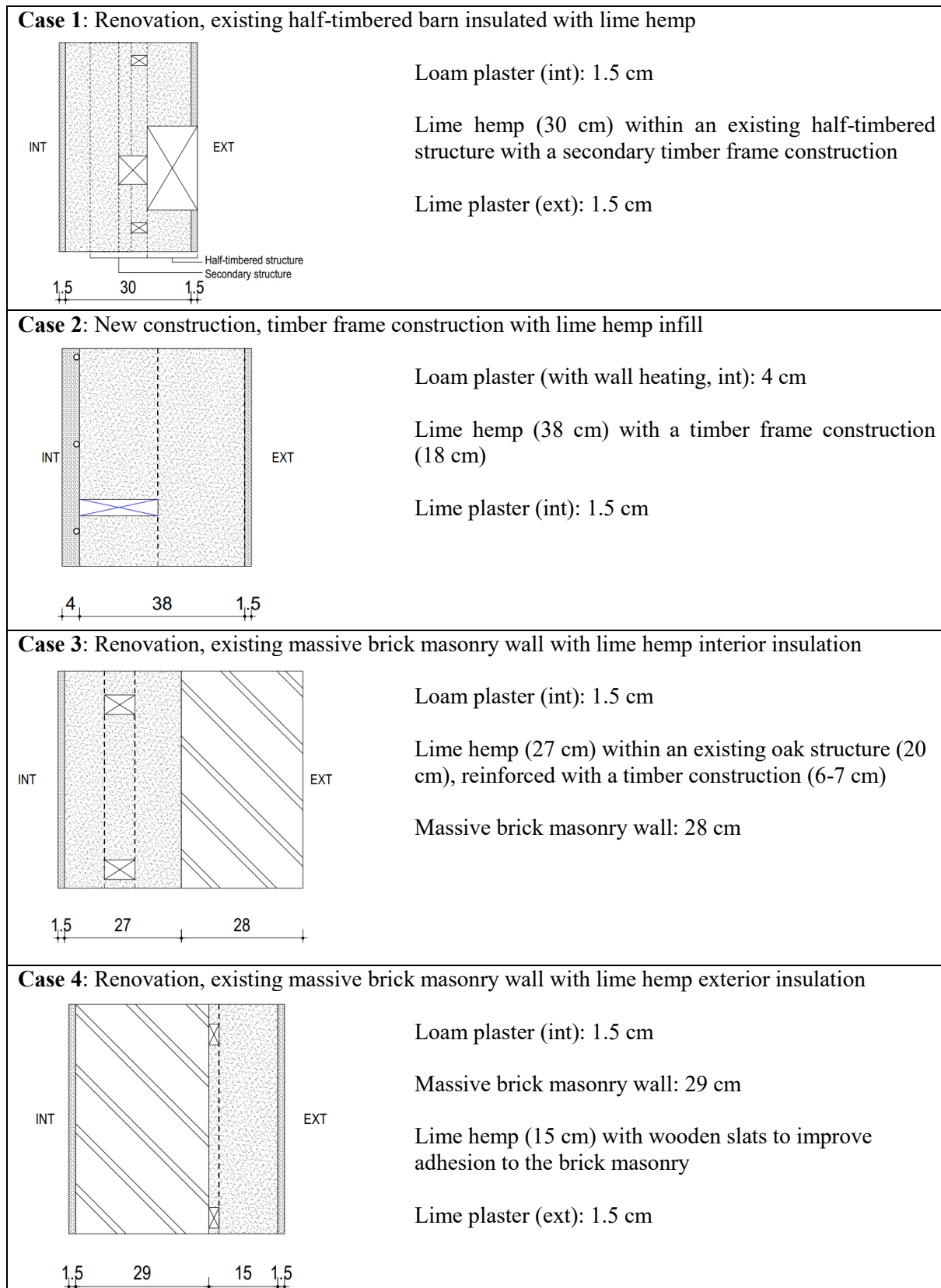


Figure 2. Overview of the wall compositions for the four cases.

2.1.2. Lime hemp mixture. For all cases, the same lime hemp mixture, that is commonly used in Flanders, was applied (Table 1). The hydrated lime Supercalco® 97 (Carmeuse) has an average composition of 97.1% Ca(OH)₂, 0.546% MgO, 0.1% SO₃, 1.21% CO₂ and 0.71% free water. Wolf Jordan Hempad+ is an additive that improves the adhesion and accelerates the hardening of the hydrated lime (Ca(OH)₂). It consists of a mix of natural pozzolans, fine clay and small amounts of organic material.

Table 1. Mix composition of the lime hemp mixture used in the four cases.

Hemp shives	21-22 kg
Hydrated lime Supercalco® 97	25 kg
Additive - Wolf Jordan Hempad+:	3 kg
Water	40 l

The water/binder mass ratio is 1.4 and the hemp/binder mass ratio 0.75. However, as the mixes were prepared on site, small variations in the actual composition could occur. In many Flemish projects with in-situ cast lime hemp, the home owner assists with lime hemp casting by collaborating with a contractor or, in some cases, acts as a self-builder after following a workshop on lime hemp construction. Many home owners mention that the possibility to be involved in the application process is one of the advantages of lime hemp construction and a way to lower the construction cost. In Cases 1 and 4, the home owner collaborated with a contractor, whereas in Case 3, the lime hemp was applied by the home owner himself after following a workshop. In Case 2, the lime hemp was cast by a professional contractor. Although lime hemp casting is rather easy, due to the limited experience of the home owners, small variations in the degree of compaction of the hemp shives might occur, resulting in less evenly filled walls with slightly varying hygrothermal and drying characteristics.

2.2. In-situ U-value measurements

To evaluate the thermal performance of the in-situ cast lime hemp walls, the U-value is measured in-situ according to the ISO 9869-1 (2014) standard [16]. A Hukseflux TRSYS01 with two heat flux sensors HFP01, one with a 10 m and one with a 20 m cable, and two matched thermocouple pairs, one with a 10 m cable and one with a 20 m cable, are used. All measurements were done during the winter of 2018-2019. Due to the moisture buffering capacity of lime hemp and the seasonal difference in moisture transfer throughout the walls, the moisture content and, as a consequence, the heat resistance of the walls might be subject to small seasonal fluctuations. However, wintertime is the most relevant period for heat loss measurements. Due to the large heat capacity of the thick lime hemp walls, the measuring period was between 14 and 16 days and the apparent thermal transmittance is estimated by the dynamic analysis method, prescribed in Annex B of the ISO 9869-1 (2014). For all cases, the thermal transmittance or U-value is measured at two positions on the wall and the average value is determined.

2.3. Calculation of the theoretical U-value

For all cases, a theoretical U-value for the lime hemp walls is calculated, based on the λ -values that are currently compulsory used in energy performance certification calculations in Flanders (Table 2).

The total thermal resistance of the wall R_T is calculated by the following formula:

$$R_T = R_{si} + \sum R_i + R_{se} \text{ with } R_i = d_i / \lambda_i$$

R_i (m²K/W) is the thermal resistance, d_i the thickness (m) and λ_i (W/mK) the thermal conductance of each layer as proposed by the Flemish Energy Agency. R_{si} (m²K/W) is the internal surface thermal resistance (0.13 m²K/W) and R_{se} (m²K/W) the external surface thermal resistance (0.04 m²K/W). As the exact position and dimensions of the timber frame constructions within the walls are not known, these are not taken into account in the theoretical calculation of the thermal resistance. This might lead to a small overestimation of the theoretical thermal resistance of the wall, as timber wood can be assumed to have a slightly higher λ -value than the assumed 0.12 W/mK for lime hemp.

The thermal transmittance or U-value (W/m²K) is given by $U = 1 / R_T$

Table 2. Overview of λ -values that are currently used in energy performance certification calculations in Flanders for the materials used in the four cases.

		d (m)	λ (W/mK)
Case 1	Loam plaster	0.015	2.0
	Lime hemp	0.300	0.12
	Lime plaster	0.015	1.2
Case 2	Loam plaster	0.040	2.0
	Lime hemp	0.380	0.12
	Lime plaster	0.015	1.20
Case 3	Loam plaster	0.015	2.0
	Lime hemp	0.270	0.12
	Massive brick masonry	0.280	1.16
Case 4	Loam plaster	0.015	2.0
	Massive brick masonry	0.290	1.16
	Lime hemp	0.150	0.12
	Lime plaster	0.015	1.2

3. Results

Based on the λ -values that are currently compulsory used in energy performance certification calculations, the theoretical U-values of the lime hemp walls are calculated (3.1) and compared with the results of the in-situ U-value measurements for the four cases (3.2).

3.1. Calculation of the theoretical U-values

In the Flemish product database for energy performance certification calculations (EPBD-database), prefabricated lime hemp blocks that are commonly used in Flanders, are registered with λ -values between 0.071 W/mK (Isohemp) and 0.077 W/mK (Chanvribloc). Up to now, in Flanders, no validated λ -values for in-situ cast walls are available and rather conservative λ -values are compulsory used in energy performance certification calculations. Due to the lack of data on the actual performance of in-situ cast lime hemp in real-life applications, the Flemish Energy Agency (VEA) considers lime hemp to be a light concrete with a λ -value of 0.12 W/mK, based on its volumetric mass density.

In Table 3, the theoretical R_T - and U-values are presented. With the currently accepted λ -value of 0.12 W/mK for lime hemp, none of the cases meets the current energy performance requirements in Flanders ($U_{\max} = 0.24$ W/m²K). According to these calculations and with the wall compositions of Figure 2, lime hemp would not be suited as insulation material for new construction and for renovations for which a building permit is required.

Table 3. Overview of the theoretical R_T - and U-values, based on the λ -values that are currently used in energy performance certification calculations in Flanders.

	R_T (m ² K/W)	U (W/m ² K)
Case 1	2.69	0.37
Case 2	3.37	0.30
Case 3	2.67	0.37
Case 4	1.69	0.59

3.2. In-situ measurements of the U-value

To estimate the actual energy performance of the walls, the U-value is measured in-situ. The comparison between the in-situ measured U-value and the theoretical U-value is presented in Figure 3. All lime hemp walls are found to have significantly lower measured U-values than theoretically calculated. In Cases 1 and 2, the U-value of the walls meets the (current) Flemish legal requirements ($U_{\max} = 0.24 \text{ W/m}^2\text{K}$). In Case 3, the maximum U-value is only slightly exceeded. Only in Case 4, with a wall with a rather small layer of lime hemp (15 cm), the measured U-value is much higher than legally allowed in case of new construction or renovation for which a building permit is required.

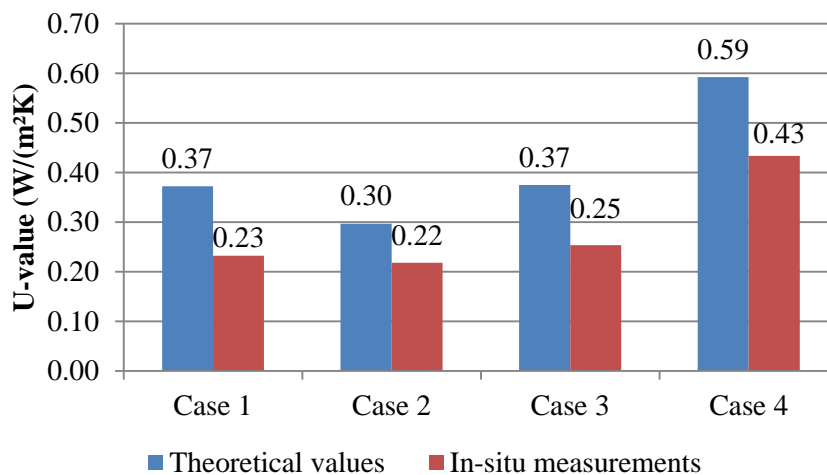


Figure 3. Comparison between the theoretical U-value, based on the λ -values that are currently used in energy performance certification calculations in Flanders, and the in-situ measured U-value.

4. Discussion and conclusions

In literature, the ecological potential of lime hemp as a building material has been shown and promising lab results for the hygrothermal performance of lime hemp walls are found. Concerning the thermal conductivity, λ -values for lime hemp ranging between 0.05 and 0.19 W/mK are reported, depending on several factors, such as the type of binder and additives, the amount of hemp shives, the mix density, the moisture content,... [12-15]. Collet and Pretot [15] have found a significant increase of the thermal conductivity (more than 50%) when the density of the mixture increased by 2/3. On the other hand, when the moisture content changed from dry state to 90% RH, the thermal conductivity increased by less than 15-20%.

As the density of the mixture has a major impact on the thermal conductivity, but not only depends on the mix composition but also on the degree of compaction or tamping on site and the quality of execution, in this research, the actual thermal performance of four real-life in-situ cast walls with commonly used lime hemp mixes was studied. The in-situ measured U-value was found to be significantly better than the U-value that is calculated with a λ -value of 0.12 W/mK, that is currently accepted for Flemish energy performance certification calculations. Although the in-situ measurement of U-values can not to be used to collect data in the context of the energy performance regulation or the energy certification of buildings, the results show that further investigation of the actual thermal performance of in-situ cast lime hemp walls would be very valuable. A validated λ -value that better reflects the actual thermal performance of in-situ cast lime hemp and that is accepted by the Flemish Energy Agency for energy performance certification calculations is needed for a more widespread application of lime hemp.

However, the following aspects need to be taken into account. When lime hemp is cast in situ, especially with the help of home owners or self-builders, small variations in the mix compositions and the degree of compaction might occur that have an impact on the actual thermal performance of the wall. Secondly, during the drying process of lime, the λ -value gradually improves. All cases were monitored at least 1 year after casting, so it can be expected that, during the initial stage of the drying process, they did not meet the legally required U-value yet. However, higher thicknesses of the lime hemp layer would slow down the drying process even more. In further research, the actual drying time of lime hemp walls will be investigated. Additionally, the thermal summer comfort is investigated by monitoring the indoor climate in the cases and questioning the thermal comfort of the residents.

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References

- [1] Evrard A 2008 *Transient hygrothermal behaviour of lime-hemp materials* Doct. Diss. (UCL)
- [2] Boutin M, Flamin C, Quinton S and Gosse G 2006 Etude des caractéristiques environnementales du chanvre par l'analyse de son cycle de vie (Ministère de l'agriculture et de la pêche France) p 102
- [3] Ip K and Miller A 2012 Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK *Resour Conserv Recycl.* **69** 1-9
- [4] Nordby A S and Shea A D 2013 Building materials in the operational phase: Impacts of Direct Carbon Exchanges and Hygrothermal Effects *J. Ind. Ecol.* **17** 763-76
- [5] Pretot S, Collet F and Garnier C 2014 Life cycle assessment of a hemp concrete wall: Impact of thickness and coating *Build Environ.* **72** 223-31
- [6] Ingrao C, Giudice A Lo, Bacenetti J, Tricase C, Dotelli G, Fiala M, Siracusa V and Mbohwa C 2015 Energy and environmental assessment of industrial hemp for building applications: A review *Renew. Sust. Energ. Rev.* **51** 29-42
- [7] Van der Werf H M 2004 Life cycle analysis of field production of fibre hemp, the effect of production practices on environmental impacts *Euphytica* **140** 13-23
- [8] DRIEA IF/SBDEC and Construire en Chanvre 2014 *Matériaux de construction à base de chanvre* p 59
- [9] Latif E, Lawrence M, Shea A and Walker P 2015 Moisture buffer potential of experimental wall assemblies incorporating formulated hemp-lime *Build Environ.* **93** 199-209
- [10] Colinart T, Lelievre D and Glouannec P 2016 Experimental and numerical analysis of the transient hygrothermal behavior of multilayered hemp concrete wall *Energ. Buildings* **112** 1-11
- [11] Rahim M, Douzane O, Tran Le A D, Promis G and Langlet T 2016 Characterization and comparison of hygric properties of rape straw concrete and hemp concrete *Constr Build Mater.* **102** 679-87
- [12] Gourlay E, Glé P, Marceau S, Foy C and Moscardelli S 2017 Effect of water content on the acoustical and thermal properties of hemp concretes *Constr Build Mater.* **139** 513-23
- [13] Benfratello S, Capitano C, Peri G, Rizzo G, Scaccianoce G and Sorrentino G 2013 Thermal and structural properties of a hemp–lime biocomposite." *Constr Build Mater* **48** 745-754
- [14] Walker R and Pavia S 2014 Moisture transfer and thermal properties of hemp–lime concretes *Constr Build Mater.* **64**(Supplement C) 270-276
- [15] Collet F and Pretot S 2014 Thermal conductivity of hemp concretes: Variation with formulation, density and water content *Constr Build Mater.* **65**(Supplement C) 612-619
- [16] ISO 9869-1:2014. *Thermal Insulation - Building Elements - In-Situ Measurement Of Thermal Resistance And Thermal Transmittance - Part 1: Heat Flow Meter Method*