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Benchmarking the Environmental Impact of Green and Traditional Masonry Wall Constructions

Corinne Gauvreau-Lemelin[1] and Shady Attia[2]

[1] University of Sherbrooke, Canada, corinne.gauvreau-lemelin@usherbrooke.ca
[2]Sustainable Buildings Design Lab, Dept. UEE, Applied Sciences, Université de Liège, Belgium

Abstract: In Belgium, the most common approach for nearly Zero Energy Buildings is to comply with the locally modified version of the German Passive House (PH) Standard that requires a very low conductivity of exterior walls. The conventional PH brick constructions are dominated by building materials with high environmental impact including concrete blocks, firebrick and petrochemical insulation materials that produce a great amount of greenhouse gases (GHG). Moreover, there are very few studies that assessed the holistic environmental impact of conventional wall compositions against ecological wall compositions. Therefore, this research compares a traditional Belgian representative wall against a hemp block wall, according to the PH standard. The environmental impact of each wall is quantified through a life cycle assessment. The final results indicate that the hemp wall reinforced with a wood skeleton has a much lower impact on the environment: up to 60% reduction on total primary energy, 72% on climate changes, 93% on eutrophication, 61 % on ozone layer depletion and 74% on acidification. Future work may refine the assessment process. The study provides novel and significant findings that can inform building owners, architects and contractors and encourage them to choose environmentally friendly masonry wall compositions.

Keywords: Life cycle assessment (LCA), embodied energy, hemp wall, zero energy buildings, decision making

Introduction

In 2004, the European Union committed to reduce cement consumption by 85% before 2050. Concrete constructions represent about 5% of the CO^2 emitted by human activities. More specifically, Belgium consumes nearly 6.5 million tons of cement every year (Febelcem, 2014). Thus, the country has to set up new eco-construction techniques to reduce its cement consumption and, consequently, its CO^2 emissions (Attia et al. 2011). Using green materials such as hemp can be an alternative path (Attia 2016). Nevertheless, to measure the significance of its impact, it has to be quantified. This study uses a simulation of a traditional Belgian wall and a wood-bearing hemp wall, both in accordance with the Passive House (PH) Standard. These two walls are quantified by the life cycle analysis (LCA) of their materials and, then, compared. The objectives of the study are to:

- Define the traditional Belgian wall and quantify its environmental impacts.
- Quantify the environmental impacts of a wood-bearing hemp wall.
- Analyse and compare the two quantifications.

As the literature review shows, the traditional wall has rarely been defined and its quantification barely completed. Furthermore, the comparison between two functional walls is rare. The LCA approach on the two facade walls, traditional and hemp, has never been utilized in past research, hence the significance of the present study.

Belgium is comprised of three independent regions namely, Flanders, Wallonia and Brussels Capital Region (BCR). BCR has set the PH as a mandatory building energy efficiency standard for all new constructions since 2015. The Walloon Region has the mandate to reach the PH Standard by 2020 (Service Public de Wallonie, 2012). This implies modifying current regulations, such as decreasing the envelope's conductivity and as a consequence increasing the wall's insulation and thickness (Attia and Mlecnik 2012). The increase in thermal resistance causes a decrease of the energy consumption in the dwelling, but it also requires the use of a greater quantity of materials, which of course has a direct impact on the environment. Depending on the material, more or less energy is required in the life cycle. For instance, the actual traditional Belgian materials constituting the walls have considerable environmental impacts (Broun and Menzies, 2011 and Kumar Singh et al. 2016). Therefore, we must find alternative materials to decrease the impact and still satisfy construction industry demands.

This paper aims to inform construction and building industry professionals of the distinctions between traditional walls and a hemp wall. The results obtained give credit to the non-traditional hemp assembly. The demonstration of the superior environmental properties is meant to promote its application to housing sector. However, this study does not include the costs or the time involved in the construction, which can be decisive factors for the client. This paper identifies the knowledge gap in the state of the art. Then, the methodology describes how the environmental assessment calculations were made. Each case study is presented in detail. Finally, the achieved results are discussed according to each wall type separately and then compared.

Literature review

This section presents the literature review structured under two axes: 1) the lack of studies conducted on the Belgian traditional wall. In order to compare a hemp wall to a traditional wall, we must know what a traditional Belgian wall comprises and how it can be assessed from an environmental impact perspective. 2) The second axe focuses on the hemp wall and its environmental effect. No previous studies were made comprising both types of walls.

Traditional Belgian wall

Since the 1980s, the traditional Belgian walls type can be characterized by an insulated cavity wall. The walls are divided into a layer of terracotta bricks and a layer of cinderblocks set apart with an insulating material and often a layer of air (Mlecnik et al. 2011). The book "*Isolation thermique des murs par l'intérieur des murs existants en brique pleine*" (Evrard et al., 2011) confirms the model and the Belgian Building Research Institute (BBRI) (2012) describes a similar wall. The BBRI defines it as a cavity wall with an external brick leaf, a PUR insulation, 14 cm cinderblocks and an internal plaster finish (CSTC, 2013).

Moreover, no environmental impact assessments have yet been conducted on the typical Belgian wall. Many studies have been conducted on the materials constituting the wall (Evrard et al. 2010, Trachte 2012). Although it is very interesting to analyse the life cycle of materials individually, it turns out to be even more convenient when those are combined into a useful product. The sum of the inputs shows the environmental value of the final usable product as it is done in the present study.

Hemp wall

The increase of the insulation layer thickness is the key of the PH standard. Yet, if this is realized with petrochemical materials conventionally used (Extruded Polystyrene (EPS) or Expanded Polystyrene (XPS)), environmental issues are likely to surface. Hence, the transition to bio-sourced materials is relevant. For instance, in the last 30 years, the insulation made of natural fibres such as hemp hatched on the Belgian market. The dichotomy between the environmental impacts of hemp and traditional materials has to be quantified to determine its merit. The life cycle analysis is the appropriate tool.

Many European LCA were conducted on the use of hemp for dwellings. Those most linked to the present study are showed in Table 1. The four studies (Boutin et al., 2006; Guévorts and Roïz, 2014; Ip and Miller, 2012; Pretot et al., 2014), were done according to ISO 14040 principles on a 1 m² wall. The lifespan used is 100 years. Although the case studies present similarities, there are large variations in wall thickness. Therefore, the thermal resistance is different from one to another. For the construction methods, while Boutin and al.(2006), Guévorts and Roïz (2014) and Pretot and al. (2014) use a pulverized hemp-lime wood bearing wall, Ip and Miller (2012) is the only study that deals with a non-bearing wall made of molding between temporary shuttering. Only one of those studies adds an external coating, making it more realistic for common use. In the other cases, it is not possible to use the wall as it is, without the finishing.

Table 1. Comparison of Hemp wall characteristics and performance based on literature review

Title	Life cycle assessment of a hemp concrete wall: Impact of thickness and coating (Collet et al., 2011)	Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK (Ip and Miller, 2012)	[Life cycle analysis of a concrete hemp-lime wall made from aggregates of the Walloon company ChanvrEco] (Guévorts and Roïz, 2014)	[Environmental characteristics study of hemp through the analysis of its life cycle] (Boutin et al., 2006)
Wall type	Bearing wall	Non-bearing wall	Bearing wall	Bearing wall
Surface (m²)	1	1	1	1
Thickness (cm)	27	30	35	26
Constructive method	Pulverised hemp on wood frame wall. Hemp-lime coating inside and lime-sand coating outside.	Molding between temporary shuttering. No coatings.	Pulverised wall on wood frame wall. No coatings.	Pulverised wall on wood frame wall. No coatings.
Materials (kg):				
- Tradical PF70 ©*	55.3	50	61.04	54.5
- Hemp hurds	21.5	30	32.64	24.8
- Water	77.3	75	53.04	37.2
- Wood	20	4.6	9.91	5.5
- Sand	17.1	-	-	-
- Steel	-	-	0.03	-
Thermal transmission coefficient U (W/m².K)	0.36	0.19	0.20	0.42
Life span (years)	100	100	100	100

* Mix of hydrated lime, hydraulic lime and pozzolan

Methodology

This section presents the methodology that went through three important steps: the literature review, the definition of the case studies and the LCA inventory.

First and foremost, this study defined the Belgian traditional walls and processed an LCA of construction materials. It led to the conclusion that the traditional and hemp walls had to be evaluated with the LCA under the same Passive House Standard conditions (PMP 2017).

Secondly, before defining the walls and launching the LCA, it was crucial to set the Functional Unit (FU), flows and the system's boundaries. Then, the case studies could be precisely defined and their life cycle reference flow as well. This was the qualitative part of this research. For the traditional wall, the literature review and a local expert interviewed determined and confirmed the case (Gauvreau-Lemelin 2016). For the hemp wall, the case is a model proposed by the manufacturer of hemp concrete block named: Isohemp (2017) in Belgium.
After setting the reference flows, the LCA data was compiled. Data collected directly from Belgian manufacturers was prioritized. Information unavailable from the manufacturers came from INIES (INIES, 2013), a French database collecting Environmental Product Declarations (EPDs), since there is no Belgian database yet (Passer et al. 2015 and Trachte 2017). Any information not provided by the previously mentioned sources were extracted from EcoInvent v2.2 (Frischknecht et al., 2005) accessible on OpenLCA (GreenDelta GmbH, 2006). The life cycle scenarios were adapted to fit the study's needs and be compatible with ISO 14040 and ISO 14044. During the study, a local LCA expert was interviewed to review, revise and verify the input and output data (Gauvreau-Lemelin 2016). The chosen environmental impacts was for those construction materials whose flow data was complete.

Accuracy

The lack of Belgian data sources is a key factor. In fact, only 28% of the data was retrieved from Belgian manufacturers. As for the rest, 29 % is from the French database INIES and 43% is from the EcoInvent database. Because not all calculations were completed under Open LCA, it was difficult to evaluate the significance of the global environmental and generate accurate estimations. This means that the current study is limited to the comparison between both walls, however, global quantified scale of the environmental impact is unknown.

Case studies

With the aim to perform a comparative study between a traditional Belgian wall and a hemp wall, this section presents the characteristics of the performed LCA. The functional unit has to be the same for both compared walls. The functional unit of a product system is a quantified description of the performance requirements that the product system fulfils. In this study, the Functional Unit (FU) is a 1 m² bearing wall with a thermal resistance U of 0.13 W/m²K and a 100-year life span.

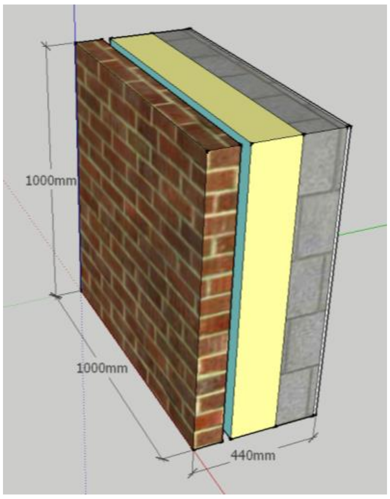
Traditional wall

This section describes the traditional wall's materials and the quantity used. The hollow wall is illustrated and the flow presented in Table 2. The traditional wall has a total thickness of 440 mm and a mass of 397.13 kg. An air layer of 3 cm between the terracotta bricks and the insulation panels (PUR) assure airtightness. This wall has a thermal resistance of 0.13 W/m².K.

Hemp wall

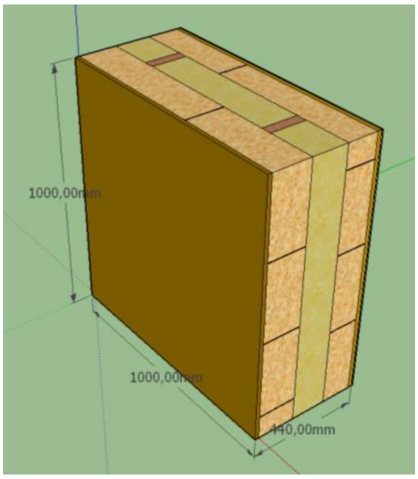
This section describes the materials of the hemp wall and the quantity used. The total thickness of the hemp wall is 446 mm and its mass 154.15 kg. This wall has a thermal resistance of 0.13 W/m².K (de Mahieu 2016).

Table 2. Reference flow of the traditional wall



Layer	Height (m)	Length (m)	Quantity	Thickness (mm)
Clay bricks	0,065	0,21	58,5	100
Mortar	1	1	-	100
Air gap	1	1	-	30
Polyurethane	1	1	-	160
Cinder blocks	0,19	0,39	12,31	140
Mortar	1	1	-	140
Plaster coating	1	1	-	10
Anchors	-	-	3	-
TOTAL	-	-	-	440

Table 3. Reference flow of the hemp wall



Layer	Height (m)	Length (m)	Quantity	Thickness (mm)
Lime plaster	1	1	-	6
Hydraulic lime plaster	1	1	-	15
Hemp block	0,3	0,6	5,489	150
Adhesive mortar	1	1	-	150
Hemp wool	1	1	-	140
Bracing	-	-	-	-
Wood frame	1	0,08	-	140
Hemp block	0,3	0,6	5,489	120
Adhesive mortar	1	1	-	120
Clay plaster	1	1	-	15
Mesh	1	1	2	0
Anchor	-	-	-	1
TOTAL	-	-	-	446

Results

This section presents the case study results. The seven impacts evaluated are presented in Table 4. Figure 1 illustrates the results in a characterized form. In the case of total life cycle, carbon emissions intensity constituting about 92.92 $kgCO^2$ equivalent for the traditional wall and about 26.45 $kgCO^2$ equivalent for the hemp wall, there is very significant difference. Attention should be paid to the fact that the use of concrete and petrochemical insulation material has a very high environmental impact on carbon emissions. Further interpretation of the results can be found in the following section.

Table 4. Study results

Environmental impact	Units	Traditional wall Total	Hemp wall Total
Total primary energy	MJ	1451,04	576,98

Renewable energy	MJ	53,82	172,44
Non-renewable energy	MJ	1397,22	404,54
Climate change	kg equivalent CO2/UF	92,92	26,45
Atmospheric acidification	kg equivalent SO2/UF	3,52E-01	9,21E-02
Ozone layer depletion	kg equivalent CFC-11/UF	5,23E-06	2,02E-06
Eutrophication	kg equivalent PO43-/UF	2,54	0,17

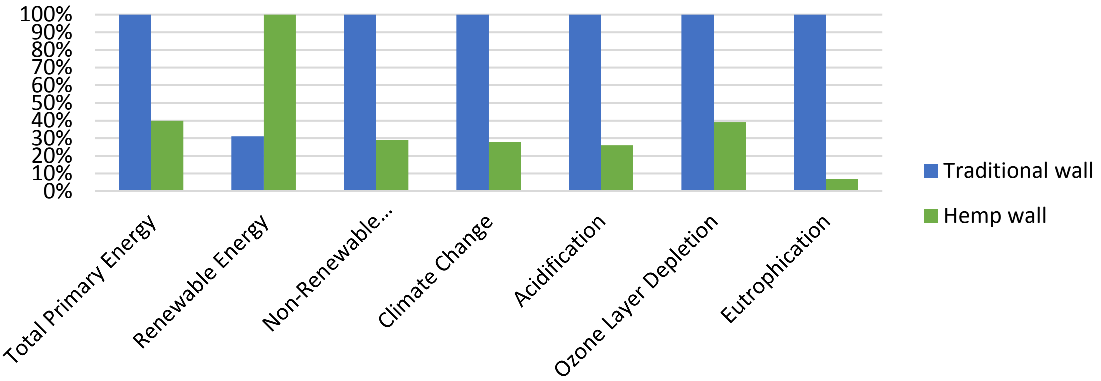


Figure 1 . Environmental Impacts Characterization

Discussion

This section discusses the results obtained in the last section. First, the highlights of the traditional wall, the hemp wall and the comparison of both case studies are presented. Then, the results are compared to other studies.

Study highlights

For the first case study, the traditional wall, the energy required in the life cycle scenario comes principally from the terracotta bricks and the PUR. The non-renewable energy is close to 26 times higher than the renewable energy. The raw materials transformation for PUR, the terracotta bricks manufacturing and the transport of the materials are the three factors causing not only the high non-renewable energy requirement, but also the atmospheric acidification and the climate change. The ozone layer depletion is linked to terracotta bricks and cinderblocks production. Phosphates released from the gypsum production are responsible for eutrophication.

For the second study case, the hemp wall, the energy required in the total life span of the wall comes generally from raw materials weighted as biomass, thus renewable energy. The non-renewable energy requirement comes from the polyester fibre used in the hemp wool (EVEA, 2015), the material's transport, the nuclear energy in the electricity and the coal used in the transformation of the bracing's steel. Transport is the largest cause of increase in climate change, the atmospheric acidification and the ozone layer depletion. The eutrophication is linked to the use of fertilizers in hemp cultivation. The characterization presented in Figure 1 demonstrates that the choice of the hemp wall has numerous environmental benefits. For the hemp wall, the only impact that is higher is renewable energy. The embodied energy is still 60% less when compared to the traditional wall. As for the other impacts, the hemp wall is up to 72% lower regarding climate change potential, 74% in acidification, 64% in ozone layer depletion and 93% in eutrophication. It is consequently proofed that the hemp wall has less of an environmental impact.

Implications for research and practice

We tried to find similar studies and research to compare the results of our findings. However, for the traditional wall, since there is no previously performed LCA, it is not yet possible to establish a comparison. We found recently the study of Delvenne that conducted a life cycle analysis and life cycle costs of regenerative materials for residential buildings (2016), however, the results are still initial. For the hemp wall, there are many similarities with the LCA of other studies. However since none of the previous studies were conducted according to the PH Standards, it is very difficult to compare the results with those of the present study. Therefore, future research should explore similar constructions and studies outside Belgium (for example the UK) and investigate the impact of using this type of construction on the rest of the building (i.e. is there a reduction in load on the foundations for one of the walls, do they require more mechanical fixing or service chases. We did also not review the airtightness, which is another vital component of PH.

Conclusion

This comparative study confirmed the initial hypothesis stating that the hemp wall would have a minor environmental impact compared to the traditional wall, according to the quantification realized. An important dichotomy in the two case studies was identified. The characterization presented has clearly showed the hemp wall's environmental advantages. Table 4 and Figure 1 illustrate the most important outcomes of the present study. The substantial efforts in place to reduce heat loss and electricity consumption in Belgian houses, by increasing the insulation layer alone, is futile on a global scale, if accomplished using conventional materials. To follow the path drawn by the European Energy Performance of Building Directive, which focus mainly on operational energy of buildings, will result in increasing the environmentally and ecological crisis, unless we refrain from using conventional construction methods.

This paper opens the door to greater comparative studies between different types of walls. Hemp is only one among many other ecological materials to exploit. A database providing "complete" wall constructions would be a great improvement, as a classification of the walls according to their environmental properties would be achievable. This tool would shed light on ways to further sustainable development in the construction sector. Finally, the reproduction of this study in a few years from now would increase the accuracy of the obtained results, since the availability of Belgian data should be more diverse, accurate and comprehensive.

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