Hempcrete

The effectiveness of hempcrete in the reduction of environmental and financial costs of residences in the Netherlands

Documentnummer: White Paper – DGMR
Datum: February 2023
Contactpersoon: Alexandra Vontetsianou

The study

Alexandra Vontetsianou, a MSc student in Delft University of Technology, had been curious regarding the potential of biobased materials in building constructions. The promising properties of hempcrete for the alleviation of modern environmental issues, had therefore caught her interest while searching for a potential topic for her MSc thesis.

During her study she investigated the potential of hempcrete by means of available research, interviews and hygrothermal simulations. She researched the applicational features of hempcrete, and its performances against those of industrialised options in energy, indoor comfort and environmental analysis. The findings of her research are presented in this paper.

The research question of her study was:

How effective is hempcrete at reducing environmental and financial costs while establishing indoor comfort in residences in the Netherlands in comparison to the design options of using aerated concrete blocks or sand-lime bricks?

The sustainability of the material

Hempcrete is a bio-aggregate based material produced by the woody core of hemp plant and a lime binder. It attributes its high sustainability to the environmental features that characterise both its components.

Hemp is a low demanding annual cultivation plant. Apart from its contribution to the biodiversity and its social aspects, it’s associated with many other benefits. It can be cultivated locally, in high density, various temperatures and neutral to alkaline soils (pH ≥ 6.5). It requires low amounts of water, no pesticides and its deep roots contribute to the health of soils. It has a high sequestration potential (1.84 kg of CO_2 per kg of dry hemp) and can revitalise soils that have been contaminated by heavy metals.

All the aforementioned make hemp an ideal aggregate for the potential mass production needs of the building sector.

Lime binders are also a sustainable solution in building applications. The production of lime is done in lower temperatures than that of cement. It is less energy demanding and includes the benefits of the carbonisation of lime, which happens during the life time of the material and leads to the absorption of CO_2 from the atmosphere.

Figure 1: The components of hempcrete.

According to studies, a 1 m^3 of hempcrete blocks can potentially sequestrate 470 kg of CO_2 and a negative carbon footprint of -0.15 kg CO_2/kg.

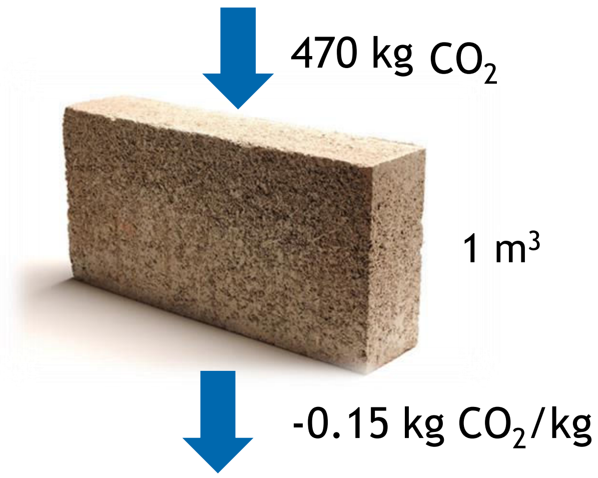

Figure 2: The sequestration potential of 1 m3 of hempcrete blocks.

Introduction

Biobased materials in time

Biobased materials have been omnipresent in our past. Natural and biodegradable materials had been used as building materials since centuries and accounted for the fundamental aspects of traditional architecture in different civilisations.

The sudden increase of the world’s population during the 19th century however, created the need for the rapid construction of shelters. The industrial revolution allowed the mass production of industrialised materials with significant structural capacities. The latter eventually led to the marginalisation of biobased materials, the consolidation of conventional industrialised options and the development of the modern industrialised cities.

Our industrialised present has been found to be associated with many modern environmental issues. The building sector currently accounts for the 35% of the global energy consumption, 40%-50% of the global amount of greenhouse gas emissions, and 40% of the global economy’s material use. The detrimental consequences of the sector have been acknowledged and universal measures have been already taken towards their limitation. A characteristic example is the Paris Agreement, which was signed by consensus in 2015.

Such measures are reflected on the revision of old directives and the creation of stricter environmental regulation. The Netherlands has also followed the trend towards a more sustainable future by setting its environmental targets and implementing environmental requirements in its current regulation.

The scientific society has been motivated by the dire need for a change and found potential in biobased materials as hempcrete. On the other hand, industrialised materials appear to fall short of biobased options in terms of sustainability and environmental preservation and conceivably will flounder to cope with the environmental goals of future standards, which indicates that:

A transition towards a biobased future may be closer than we expect.

Biobased Past

Multistorey cob buildings in Shibam.

Traditional Dutch buildings in Zaanse Schans

Industrial Revolution

. . .

Industrialised Present

Modern cities (Rotterdam)

?

. . .

Biobased Future

Townhall of Voorst (Hempcrete building)

Figure 3: Biobased materials in time.

The main properties

Hempcrete is a non load bearing material. Its is characterised by a compressive strength that can reach up to 1 MPa. It attributes its beneficial properties to its high porosity (70-85%) and distinguishes itself from other building materials due to its hygrothermal perfomances.

It has a low thermal conductivity and a significantly high specific heat capacity, which is able to provide the benefits of thermal mass while incorporating the benefits of a low density. Its remarkably low water vapour resistance factor contributes to the indoor humidity control and the establishment of indoor comfort. Its acoustic properties are also considerable in building applications.

In comparison to other biobased materials, hempcrete is fire safe and reaches class B,si,d0 in the relevant classification. It is also durable, since the presence of lime creates unfavorable conditions for biodegradation.

It can be found in three main forms: poured, sprayed or as prefabricated blocks. Alexandra focused on the prefabricated block form, which requires less specialisation and a lower construction time, while simulataneously incorporates the advantages of a monitored mechanised production such as homogenised end products with known properties and lower costs.

General Properties	
Density (kg/m^3)	300-600
Porosity (%)	70%-85%
Mechanical Properties	
Compressive Strength (MPa)	<1 MPa
Modulus of elasticity (GPa)	0.7-0.16 GPa
Hygrothermal Properties	
Thermal conductivity (W/mK)	0.07-0.11
Specific Heat Capacity (J/Kg K)	1300-1600
Water Vapour Resistance (-)	2-5
Moisture Buffer Value (g/m^2%RH)	≈ 2.8
Acoustic Properties	
Mean Absorption coefficient (Unrendered)	0.27-0.85
Sound reduction index (rendered 20 cm wall)	≈ 40 dB
Fire safety	
Fire class	✓ class B s1, d0, ✓ s1: highest class for the smoke evaluation ✓ d0: highest class in the relevant assessment
Durability	
	✓ Not prone to degradation by salt exposure ✓ Binders with greater hydraulicity → resistance to freeze thaw ✓ Alkalinity of the lime → no insects ✓ Absence of nutrients → no growth of micro-organisms ✓ Repeated absorption and desorption of moisture without degradation due to high permeability and hygroscopicity

Figure 4: The main properties of hempcrete.

The applicational features

The standardisation

- Hempcrete is an unstandardised material. For building applications in the Netherlands a per case assessment is required. The requirements of such assessement are set each time by the Dutch local authorities.

- The lack of such standardisation hinders the creation of an ETA (European Technical Assessment) which can be used as a reference for the composition of DoPs (Declaration of performances) for the hempcrete products. However, steps towards the standardisation of the prefabricated blocks have been taken. European certification methods (e.g. ATG certification) already exist and provide proof on the performances of the material in its prefabricated form.

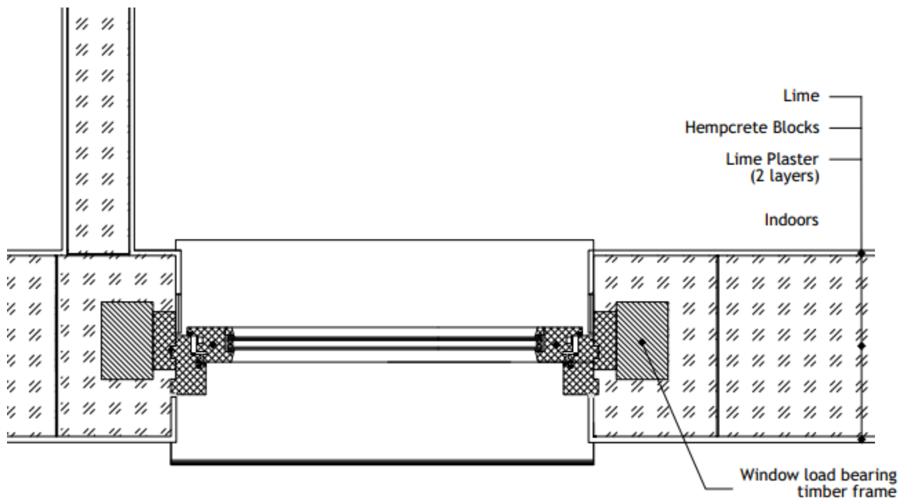

Figure 5: Hempcrete block application - Window detail.

The application

- The application of hempcrete in the form of prefabricated blocks resembles to that of conventional non load bearing masonry. Contractors are already familiarized with a such construction method and thus can easily learn how to apply the material in brief workshops.

- However, when constructing with hempcrete blocks some aspects should be considered:

  - Hempcrete is nonloadbearing so a structural frame is required for the support of loads and openings.

  - Hempcrete should be protected from capillary moisture rise.

  - In order to take advantage of its beneficial moisture regulation properties breathable renderings should be chosen. Such renderings can be lime or clay renderings.

  - Hempcrete is alkaline, so the latter should be considered when it is in contact with steel.

  - Breathable water vapour rendering may need to be applied in driving rain facades.

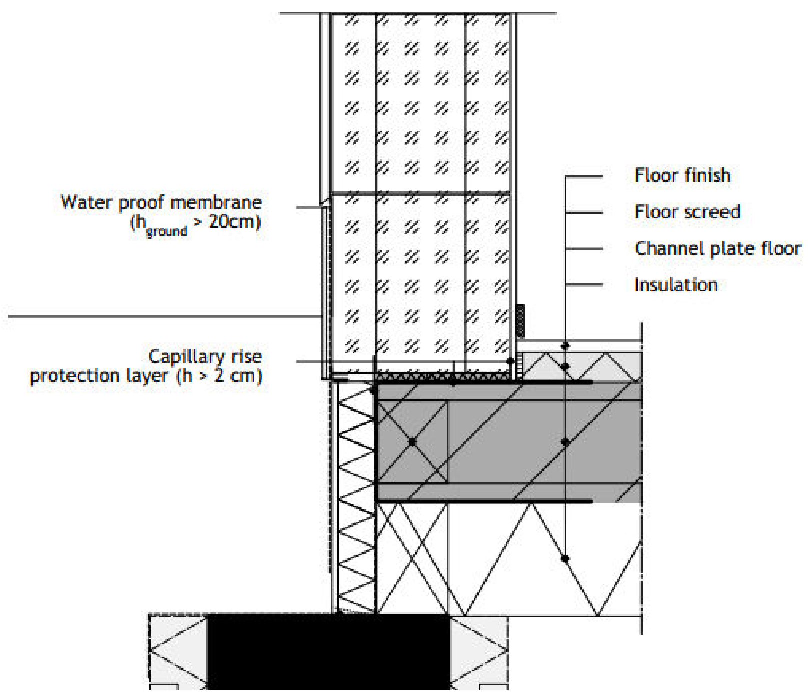

Figure 6: Hempcrete block application - Ground floor detail.

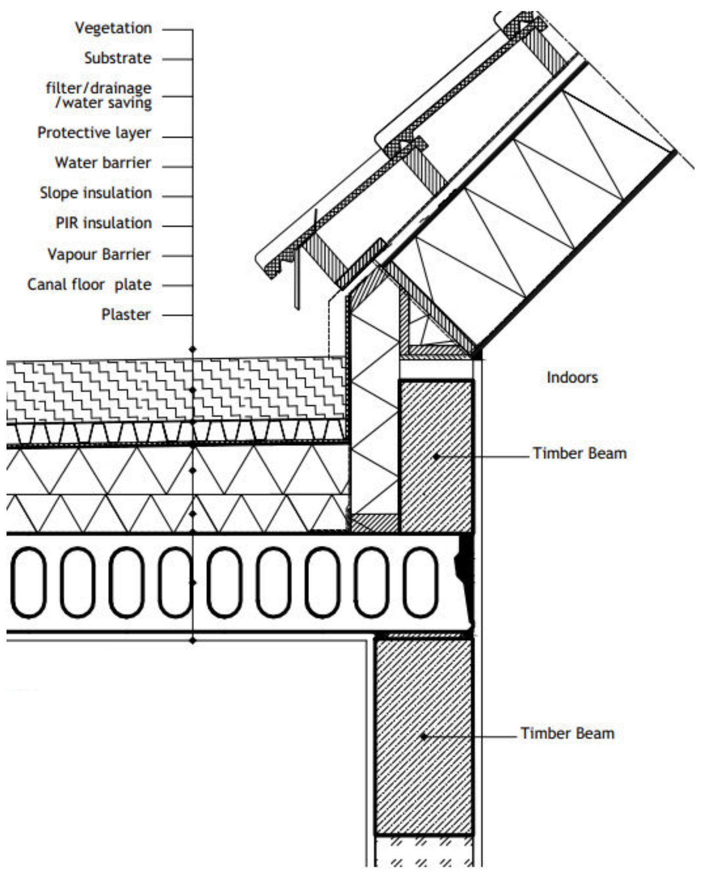

Figure 7: Hempcrete block application - Roof detail.

Comparison between different hempcrete options

The 2D Wufi Simulations

Alexandra made use of WUFI 2D to assess dynamically some important aspects in building applications for monitored indoor conditions of a bathroom and a bedroom in different sections and a typical Dutch year.

The assessed aspects were:

- The surface condensation (NEN-EN ISO13788:2013) (Fig.8)
- The interstitial condensation (Fig.8)
- The mold growth risk of the encased timber for the case of the hempcrete design. (Fig.8 and Fig.10)
- The water content in driving rain facades (Fig. 9)

For the case of condensation, the last year of decade was assessed. For the rest, the whole decade was considered.

The condensation

The assessed hempcrete options were characterized by thermal conductivity values that belong to the range of λ = 0,073 – 0,115 W/(mK). The results showed that the hempcrete options were not associated with condensation issues.

For surface condensation, when the different hempcrete options were compared, the number of condensation hours remained limited and no winter or consecutive condensation hours occured. Even for the case of hempcrete walls with a thermal conductivity of 0,115 W/(mK).

The amount of interstitial condensation in the 32 cm monolithic hempcrete wall sections remained zero for all hempcretes under scrutiny. Hempcretes with higher sorption curves were proven beneficial for the reduction of interstitial condensation in sections with encased timber.

Mold growth risk in timber

No particular risk of mold growth on the surface of timber towards the exterior was detected in the relevant analysis. Nevertheless, the results showed that the risk is influenced by the water absorption capacity of hempcrete. A milder relation between the reduction of the risk and the thermal conductivity of the hempcrete was also observed.

The aforementioned two observations were taken into account in the optimized case (Fig. 10). No risk of mold growth is detected since the graph decreases rapidly after the influence of the high initial condition of the simulation is passed (yellow colour). As the simulation time passes (until 10^{th} year) the risk decreases even more (black colour).

The driving rain facade

The results of the relevant analysis showed that rainwater accumulation may occur in hempcrete driving rain facades.

To avoid issues that can be associated with high presence of water, the use of an adequate waterproof but breathable render or cladding is advised.

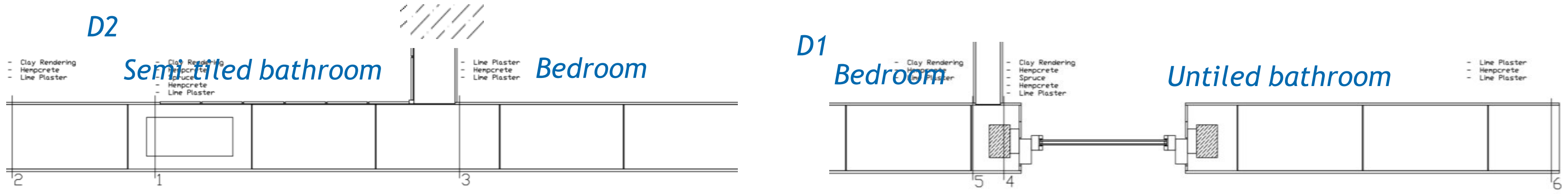

Figure 8: Horizontal details and sections in assessment. Left detail D2, right detail D1.

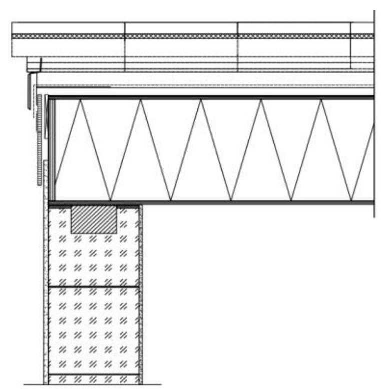

Figure 9: Driving rain façade, vertical detail in assessment.

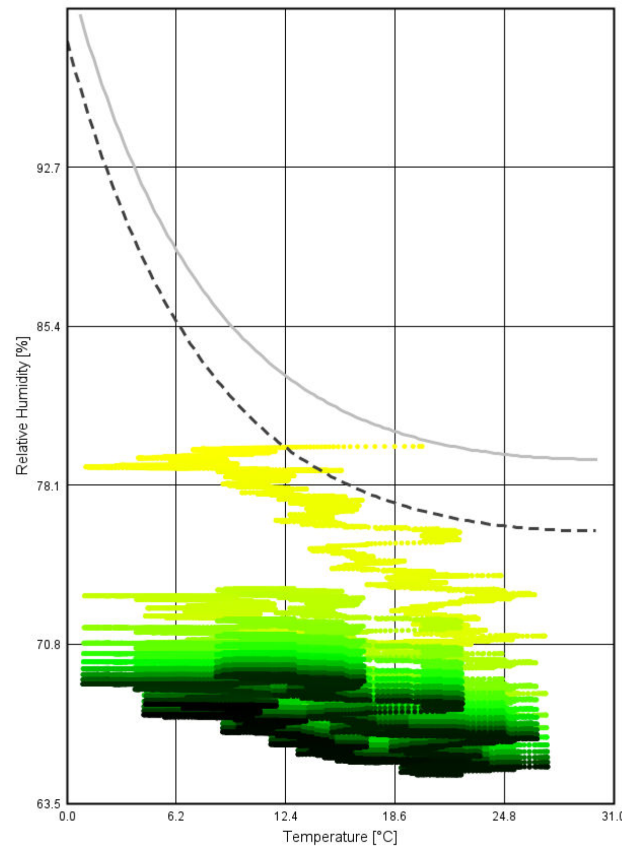

Figure 10: Isopleth for the external side of the spruce column for optimized case of hempcrete wall in detail D2 (Fig.8).

dGmR

Comparison between hempcrete and the conventional options

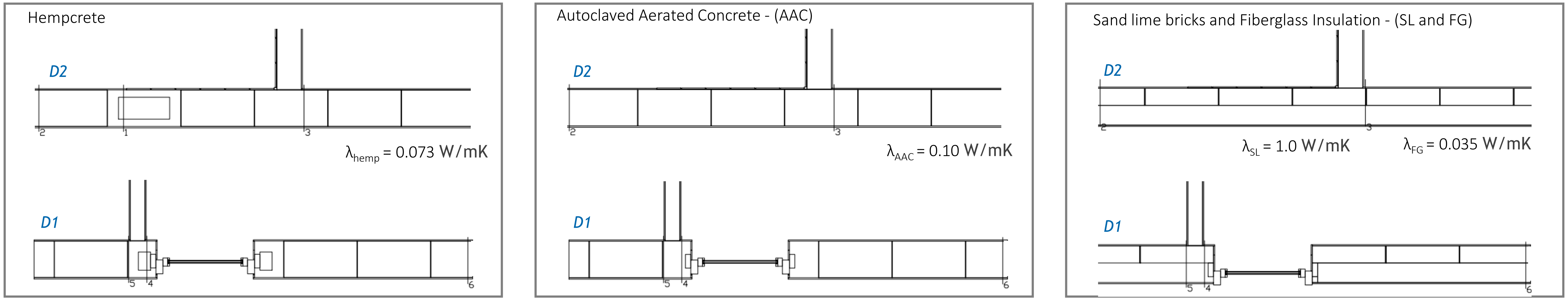

Figure 11: Horizontal details and sections in assessment. Upper detail D2, below detail D1.

2D Wufi Simulations

The difference in terms of interstitial and surface condensation between hempcrete and the conventional materials of Autoclaved Aerated concrete and Sand lime bricks with fiberglass insulation was also assessed (Fig.11).

According to the results, hempcrete outperforms AAC in the semi-tiled bathroom section even for the case of walls with the same thermal resistance, where AAC exhibits surface condensation during winter and interstitial condensation.

In comparison to the SL design, hempcrete walls even with lower thermal resistance ($Rc_{hemp.}$= 4,18 m² K/W, $Rc_{sl.}$=4,80 m² K/W) exhibit same or better performances (D1, section 4 corner) in terms of surface condensation.

In terms of interstitial condensation, equal performances with zero condensation were detected for both monolithic hempcrete sections and SL designed sections.

WUFI Plus energy simulation

The differences between the performance of hempcrete and the two conventional design options were assessed in a case study of a detached house located in the Netherlands.

The thermal resistance of the façade was equal for all the three design options (Rc= 4,8 m² K/W).

The energy consumption, the indoor relative humidity and indoor temperature fluctuations were derived for two bedrooms and the living room of the case study. The results indicated that:

- Hempcrete performs better in the Relative Humidity threshold and the regulation of indoor humidity levels. (Fig.13)
- The higher volumetric heat capacity of the conventional designs, due to higher material use (AAC) or high density (1900 Kg/m³-SL) was beneficial for the decrease of the energy consumption (Fig.14).
- The high volumetric heat capacity of the SL design leads to slightly better performances in the temperature threshold mainly in the summer (Fig. 13 - Dark green operative temperature).

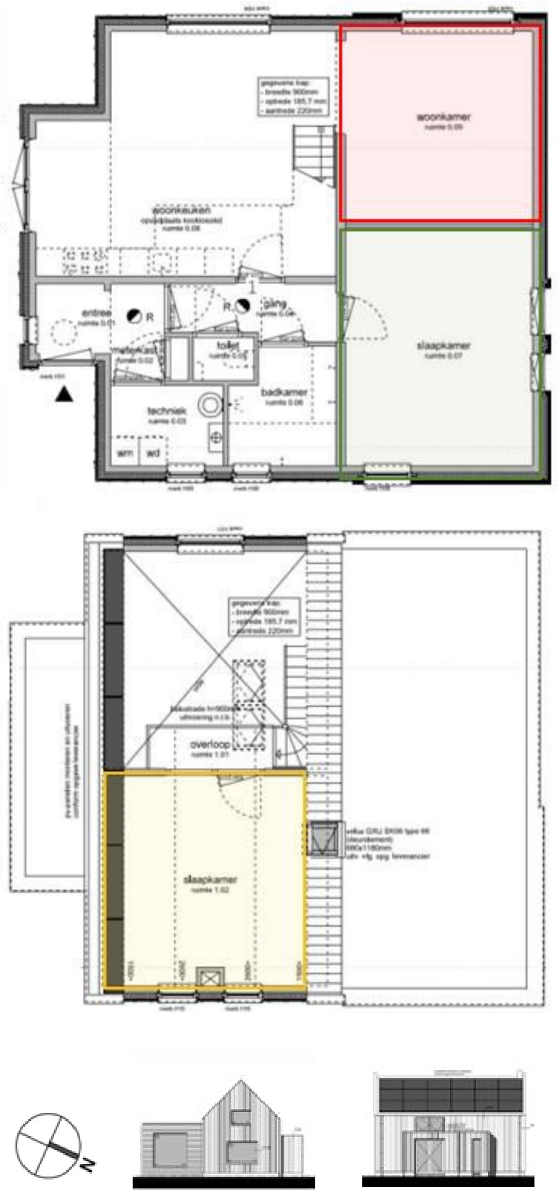

Figure 12: The case study and the assessed rooms

The Energy simulation

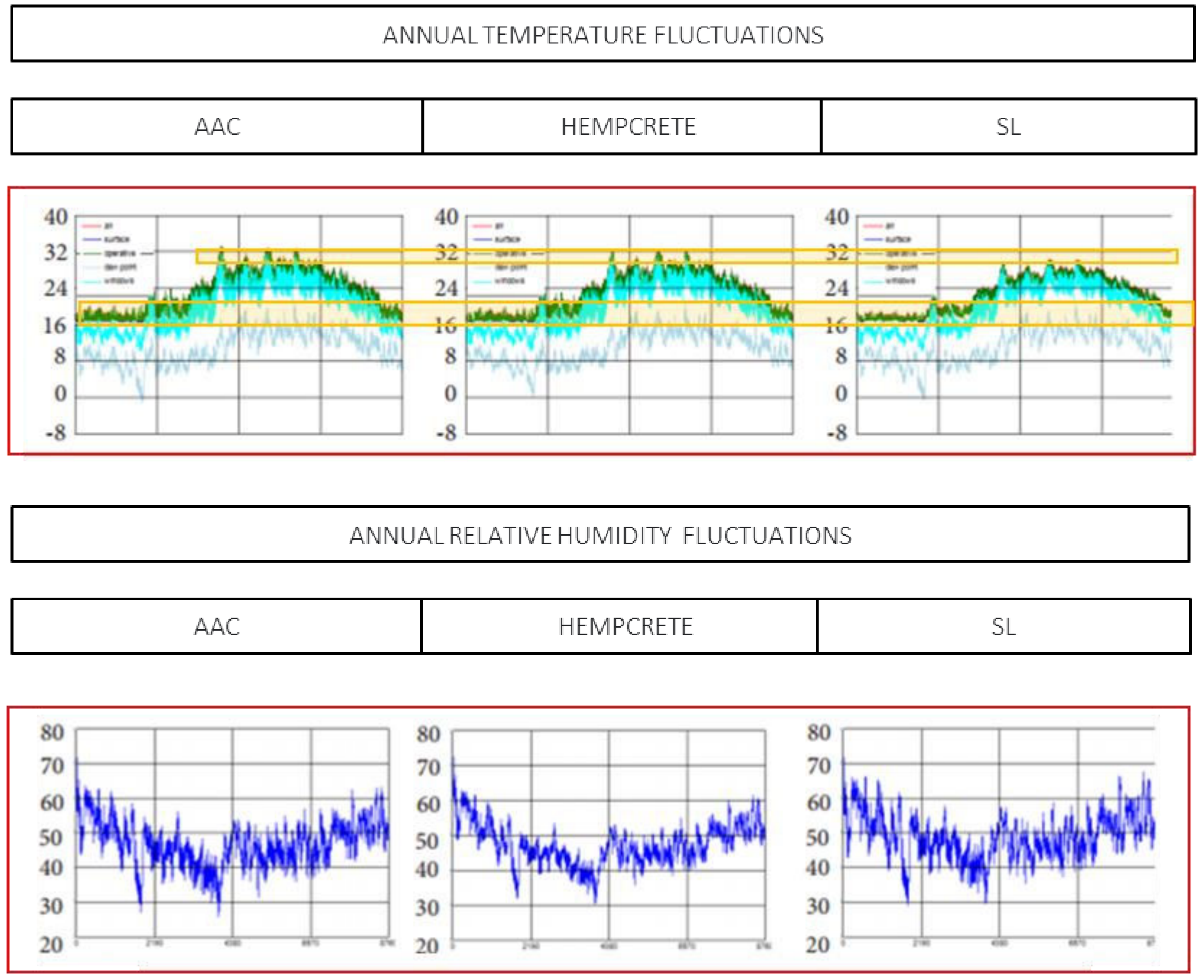

Figure 13: The annual fluctuations in the living room.

Volumetric heat capacity, material use and energy consumption

ACC → Cp∗ρ = 850∗400 = **340 kJ/m³** ** → 22.4 KWh/m²
Hempcrete → Cp ∗ρ= 1500∗405 = **607.5 kJ/m³** → 23.3 KWh/m²
SL → Cp∗ρ= 850∗1900 = **1615 kJ/m³** → 21.8 KWh/m²

** AAC volume of material used = 76.4 m³
** Hempcrete volume of material used was calculated at 56.8 m³

Figure 14: The Volumetric heat capacity and the annual energy consumption.

Environmental analysis

For the environmental analysis Unit factors of 1 m² with equivalent performances were constructed for the cases of:

- A load bearing façade with a thermal resistance of Rc=4,80 m² K/W
- Load bearing internal walls
- Separation walls with an acoustic insulation of at least Rw= 37 dB

For the load bearing parts of the hempcrete design, solid timber was selected for the load bearing system. The final UF thicknesses for the assessed designs are presented in Fig. 15.

The main aspects of the analysis were:

- EPDs according to the new European standard *EN 15978:2021* were used.
- The conservative scenario of release of CO_2 through the decomposition of biomass after the end life of biological materials was considered.
- LCA Scenario D was taken into account.
- The end life scenarios considered were: incineration for timber, recycling for the AAC and deposition for the rest.

Thickness of walls (m) (excluding renderings)

Type of wall	Hempcrete	AAC blocks	SL bricks with FG insulation
Facade	0.35	0.48	0.15 & 0.16 (SL/FG)
Internal load bearing walls	0.075	0.165*	0.158 *
Separation walls	0.075	0.10	0.07

Figure 15: The Unit factors of the case study.

Comparison between hempcrete and the conventional options

Environmental analysis

As expected, the biobased design consisting of hempcrete and timber performed better in the environmental analysis, even though the fiberglass insulation attenuated the environmental impact of the SL design (Fig.16).

For the acquisition of a final environmental result including all the environment categories the monetary valuation method was used. The monetary values were taken from available Dutch literature (Fig. 17), according to:

- STICHTING NATIONAL ENVIRONMENTAL DATABASE, “Environmental performance assessment method for construction works, version 1.1.
- Handboek milieuprijzen 2017 methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieuimpacts.

New environmental cost indicators will be released soon. The new cost indicators are expected to further increase the difference between the environmental performance of hempcrete and the conventional designs.

Type of wall	Measurement Unit	Hempcrete Design	Sand Lime Design	AAC Design
Facade	m^3	48.8	43.2	66.9
Separation	m^3	2.3	2.3	3.0
Load bearing	m^3	5.5	6.5	6.4
Final Costs	(€)	**5.14 E+02**	7.1 E+02	1.06 E+03

Figure 16: The volumes of used materials and the environmental costs per design.

Impact category	Measurement Unit	Cost per eq. (€)	Source
GWP Fossil	Kg CO2 eq./UF	0.05	NMD
GWP Biogenic	Kg CO2 eq. /UF	0.05	NMD
GWP Luluc	Kg CO2 eq. /UF	0.05	NMD
Ozone depletion potential	Kg CFC11 eq. /UF	30.0	NMD
Acidification Potential	Mol H+ eq. /UF	4.0	Handboek 2017
Eutrophication Fresh water	Kg P eq. /UF	1.9	Handboek 2017
Eutrophication Fresh water	Kg PO4 eq. /UF	9.0	NMD
Eutrophication Sea Water	Kg N eq. /UF	3.11	Handboek 2017
Eutrophication Land	Mol N eq. /UF	0.04	Handboek 2017
Photochemical Ozone Creation	Kg NMVOCeq. /UF	2.0	NMD
Abiotic Depletion potential – Elem.	Kg Sb eq./UF	0.16	NMD
Abiotic Depletion potential - Fossils	MJ /UF	7.7 E-05	NMD
Water Depletion Potential	M3 water /UF	1 E-04	Assumption

Figure 17: The cost indicators.

*conversion: 1 mol N =0.014 kg N
** conversion: MJ/UF x 4.81E-04 = kg Sb-eq

Other aspects

- ### The net floor surface

An important aspect that is considered in building application is the final net surface of the building. The result of the case study showed that the thinner internal loadbearing walls were able to compensate for the thicker hempcrete façade.

Design	Measurement Unit	Net floor area
Hempcrete	m^2	99.9
SL	m^2	100.07
AAC	m^2	92.03

Figure 18: The final net surface of the designs.

- ### The material costs

Hempcrete is more expensive than the conventional materials, which is currently one of the main barriers for the propagation of its use . The estimated price of the design options per m² of gross area in the case study were:

Costs per m² of gross floor area

Hempcrete : 190 € *
AAC: 145 €
SL: 107 €

*exc. Timber

Figure 19: The material costs

dGmR

Conclusions

Conclusions

The results of the research showed that the limited propagation of hempcrete's use in the Netherlands is not associated with the performances of the material.

In the vast majority of the performed analyses, hempcrete showed similar or better performances in comparison to the conventional masonry options.

The material has been already researched to a high extend and information on its application can be found in the available literature. Nevertheless, interest parties are hesitant to use the material due to their biased idea about biobased materials and biodegradation or fire safety issues, even though such issues are not the case for hempcrete blocks. The latter in combination with the higher material costs and the current regulation which restricts international material supply and fails to incorporate the beneficial properties of hempcrete (moisture regulation and specific heat capacity) in the required calculations are currently the main barriers. The use of hempcrete adds value in buildings and offers potential in terms of environmental and financial costs. Hempcrete blocks are able to provide energy efficient and comfortable constructions. Their high hygroscopicity and high specific heat capacity can be beneficial for buildings.

In addition, hempcrete is associated with social and environmental aspects on which its industrialised competitors fall behind. Some of these aspects are not reflected in the modern building regulation and therefore are frequently forgotten. Nevertheless, they provide a considerable advantage to the option of selecting hempcrete in the case of projects which aim for high sustainability scores or for indoor environments with controlled RH fluctuations.

Recommendations

- Research on the incorporation of phase changing materials in the composition of hempcrete blocks.
- Research on the required thermal resistance and properties of hempcrete walls in order to meet the BENG regulation energy requirements by means of dynamic hygrothermal simulations. Comparison to the hygrothermal dynamic response and required thermal resistance of conventional construction materials.
- Research on the long-term influence of the rendering's properties on the performances of hempcrete facades and encased timber in the case of driving rain orientation.

The Next Step

Take it, more can be done with biobased materials like hemp-crete. But it takes some courage and research. At DGMR we can help you with distinguishing facts and figures. We help you integrating it in your next project.

DGMR

About 250 experts want to be the best in their field. We challenge ourselves every day to come with unexpected solutions. Effective for society. Innovative for clients. Crucial for the comfortable living environ-ment of today and tomorrow. DGMR is an independent company that does not walk the beaten track. We like to push the limits of possibilities. We challenge ourselves and our clients to find solutions together that are of lasting value.

Graduation at DGMR
Means setting up and developing an actual and practical research independently, with expert guidance. The informal atmosphere gives a pleasant working environment where, in addition to professional knowledge development, there is also a lot of room for self-development. We cooperate with, both Dutch and International students, from among others TU Delft.

For more information please contact:
- Bas Hasselaar, advisor building physics and sustainability (about bio-based materials)
- Gertjan Verbaan, division manager (about internship or graduation projects)

Alexandra Vontetsianou, graduated from Delft University with an 8.5!

https://dgmr.nl/en/ >>

Intern or Graduate Building Physics | DGMR >>