Building with Hemp and Lime

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This lecture investigates hemp and lime as a building material, in use, and covers the properties of lime, characteristics of hemp and lime construction, thermal performance, costs, and quantities, building issues, and then finally hempcrete specifically: CO2 emissions and potential market.

In the book you will find the ‘sister piece’, ‘Hemp (Cannabis Sativa L.)’, which should be read in order to understand the historical, agricultural, environmental and economic background issues.

Lime

Lime has many environmental problems associated with it.

- It is mined on a large scale.
- It has a moderately high embodied energy (800kg / tonne).
- It is a finite resource.
- It is processed centrally away from the mining operations, necessitating the high haulage costs of a heavy material (heavy loads cause more CO_2 emissions and pollution)(WWF 1994).
- Lime Kilns use fossil fuels.
- It is associated with biodiversity loss due its mining operations and its contribution to global warming.

Despite this are many benefits to using lime. The following are the advantages of using lime as a plaster, render, and mortar in buildings;

1. It is “breathable” (high porosity, high water vapour permeability): breathable walls control internal humidity, reducing condensation and preventing mould growth. This improves the indoor air quality and the health of a building’s occupants.
2. Low thermal conductivity - ~1 W/(m K) - and a moderately high specific heat allow the plaster to act effectively as a thermally massive heat store, contributing to the thermal comfort of the internal environment.
3. Lime is a long lasting material. (For example the Pantheon in Rome).
4. Lime is easily recyclable (re-burnt to form hydrated lime or used as aggregate) or is naturally absorbed into the land without causing toxicity.
5. Autogenous Healing: as lime buildings move small cracks can appear. Water penetrates into the cracks and dissolves any free lime. This brings it to the surface where the lime carbonates and heals the crack automatically.

6. Protection: lime acts as a very good 'sacrificial' external surface, protecting the essential structural elements of building from the weather, fire and vermin, although it must be maintained.
7. Lime mortars protect stone work and bricks, enabling them to be easily recycled, reduce material usage over time and lessen the need for major building repairs (Holmes and Wingate (2002), p..62).
8. Lime mixtures have good workability and are well suited for plastering.
9. Lime is alkaline, preventing mould growth and making it undesirable to small animals.
10. Lime washes are breathable and aesthetically appealing.
11. Lime allows for relatively easy building maintenance; regular lime washes or re-pointing prolong the longevity of a building.

    Sources: May (1998), Holmes and Wingate (2002), Building with lime forums (2005), BRE (2001).

Lime is reasonably difficult to use in comparison cement and is more labour intensive. It requires patience to work with and careful site management to ensure the material sets properly. Lime requires several coats over several days, has to be cherished (kept moist) and protected from the weather for up to a week for successful application. It takes time for lime renders and plasters to fully set (several months) and it can be damaged by frost before becoming fully set (Holmes and Wingate (2002), p. 126) meaning that construction is weather dependent and external work is not recommended in the winter months. All of these considerations mean that lime has become unpopular in modern, fast, economically driven building sites where time is money (May 1998).

To minimize the environmental impact of lime, the smallest amount of lime possible should be used that maintains the benefits of using it outlined above. The carbon dioxide emissions, pollution, waste, haulage requirements and landscape disruption from mining would be vastly reduced if limestone could be mined and burnt locally in efficient kilns using biomass as fuel, as was traditionally the case in the UK (May 1998). Its CO_2 emissions per tonne can possibly be reduced from 880kg to 330kg. Overall it seems reasonable to advocate lime as a building material, from an environmental perspective, for all of the benefits outlined above. Further reasons are that it increases the longevity of buildings, improves the internal air quality and doesn't require landfill and, if only lime was produced from limestone and not cement, it can be made using biomass.

Although burning biomass is CO2 neutral it is still a finite resource as it needs available land to be grown. The dangers of the over production of lime from biomass are intensive monoculture farming and displacement of food crops. Emphasizing again that using as little lime as possible to do the job required is desirable.

Hemp and Lime Construction

Hemp hurds can be combined with lime to form the concrete like substance termed “Hempcrete”. This has been used in France since the early 1990’s to construct non-weight bearing insulating infill walls supported by a timber frame: see Figure **2.** The walls are internally plastered and externally rendered with lime and finished with lime washes. The walls are also breathable, which controls moisture and condensation and improves internal air quality. The hempcrete is also used for floor slabs, ceiling insulation and as an internal coating for renovating old stone walls.

Hempcrete has a λ value (conductivity which the rate of the passage of heat through the material) of ~0.076 - 0.11 W/(m.K) when mixed with a mild to moderate hydraulic lime consisting of ~85% hydrated lime and ~15% clay or pozzolans. For floor slabs, a more hydraulic lime is used and sand is added to improve strength and water resistance λ value ~ 0.13 W/(m.K). For the ceiling insulation and the internally insulating stone wall coating, a pure hydrated lime is used and a higher percentage of hemp to provide a more insulating and lighter mixture λ ~0.08 W/(m.K).

There are several construction firms in France using the technique (e.g. Artcan, Camonose) and approximately 200-300 homes have been built. As lime has an embodied energy of ~20-50% lower than concrete and hemp is deemed environmental friendly with a low embodied energy, 1.4 MJ/tonne (BRE 2001, Pervaiz 2003), the main target is the environmental building sector.

This sector has grown in France and currently 20% of all the hemp hurds produced in France (~6000 tonnes a year) are utilised in the industry, an increase from only 5% in 1999 (IENICA 2003, IENICA 1999).

Two houses were built in the UK as part of the Haverhill housing project sponsored by Suffolk Housing Society in collaboration with BRE, who performed a full assessment of the building technique and the suitability of the material. The research was intended to investigate the use of the material covering several areas of concern:

- Relative structural, thermal, acoustic, permeability and durability qualities;
- Reduction in waste generated on site;
- Environmental impact;
- Construction costs (BRE 2001).

Hempcrete was used for the external (200mm, U-value ~ 0.58 W m^{-2} K^{-1} (Ralph Carpenter Arch. Personal communication) and internal walls and to make a ground floor slab as detailed in the report. The reports main findings were that;

- *Structure & durability:* The qualities of hemp homes were found to be at least equal to those of traditional construction.

- *Thermal comparisons:* Heating fuel consumed by the hemp homes is no greater than that used in the traditionally constructed houses.
- *Acoustics test:* Hemp homes did not perform as well as the traditional houses but they did meet the sound resistance requirement.
- *Permeability:* Both forms of construction appear to give complete protection against water penetration. However, the hemp homes generate less condensation.
- *Waste minimisation:* There appears to be little difference in the amount of waste produced by each method. Although the waste is of a different nature in each case, both are likely to have an environmental impact (BRE 2001).

Thermal Performance

The thermal performance of the hemp homes was interesting as despite having higher U-values (Hemp homes 0.58 w/m2.K Control Homes 0.35 w/m2/k) (U-values reflect how fast heat passes or is lost through a wall. The higher the value the faster heat is lost) they performed as well as the standard construction that met Part L 2002 UK regulations when the homes were occupied or unoccupied. The actual temperature maintained in the hemp homes tended to be 2^{o}C higher than the standard homes in winter despite having virtually the same heating fuel consumption for the period (BRE 2001).

It was also found in a follow-up report using thermographic cameras that the external temperature of the hemp homes' walls was lower (~5^{o}C) than for the standard construction homes despite the internal temperature being maintained at 20^{o}C in both (BRE 2003). This second finding could imply that heat is flowing more readily through the standard wall construction despite its lower U-value, this be could failure of the standard homes walls insulation (poor construction or becoming wet). The hemp homes also used less fuel to heat during the winter of 2002-3 (BRE 2003).

Another factor in the thermal performance of hempcrete walls is their thermal mass. Thermal mass will tend to absorb heat during hotter periods and release it again during colder periods. Thermal mass is not accounted for in U-values. Therefore the unexpected thermal performance seen in the hemp homes could in part be explained by the inherent thermal mass of the hemp walls acting as a heat capacitor. When DEFRA reported on hempcrete construction it recommended that the technique be taken up more widely, to provide buildings with thermal mass but low embodied energy (DEFRA 2005c).

Regarding concrete, it has been found that its thermal properties are dependent on the materials added, their proportions in the mixture, the amount of water used, the degree of porosity (air holes) and the final density (Bouguerra 1998, Kahn 2002, Demirbogia 2005, Mendes 2001). Figure 1 demonstrates the difference porosity and therefore density can make on conductivity. As concrete is 60% lime it seems reasonable to presume that the differing mixture parameters of hempcrete will have a similar affect on thermal properties.

"Because of the growth of interest in the use of hemp with lime……… A particular challenge to be addressed for wall systems relates to the increasing requirements of UK Building Regulations for thermal insulation. Although fibres in blocks or lime increase the insulation value, this is not going to be sufficient for the new 'U' values without very thick walls, and these are not likely to be acceptable. There is therefore a need to establish an effective solution to this challenge" (DEFRA 2005c).

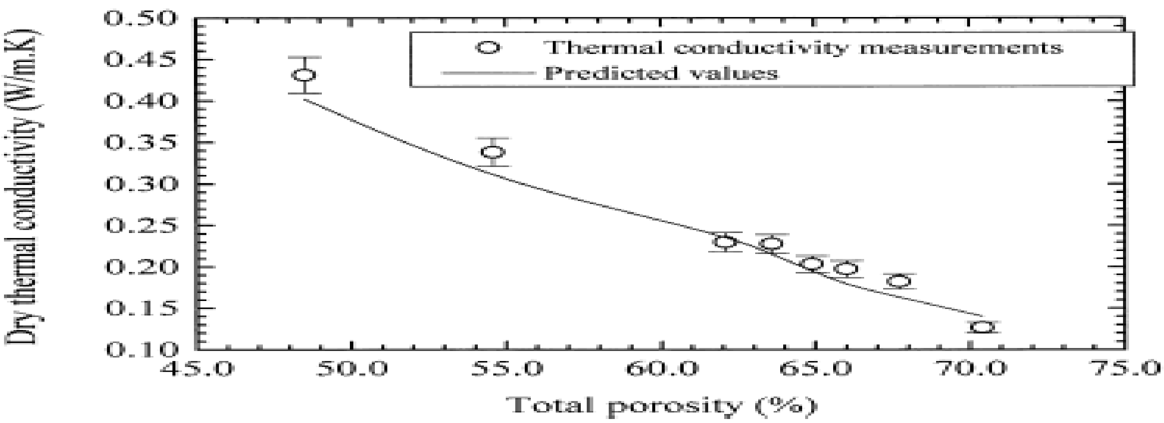

Figure 1: The effect of porosity. Source: Bouguerra (1998).

Apart from the inherent thermal properties of the hempcrete, other factors are likely to have helped to maintain the higher temperatures. Thermal bridging across a building's framework can result in substantial heat losses. These are not a factor in hempcrete construction as the wooden frame is completely isolated by the mixture, meaning there is no thermal bridging. Hempcrete can also be easily formed up to window and door frames, creating air-tight seals preventing unwanted drafts and areas of heat loss. This is demonstrated in the thermal images made by BRE of the hemp homes where there are no heat losses seen around the windows and doors (BRE 2003). This also tends to suggest that the new building regulation requirements for air tightness are likely to be able to be achieved using hempcrete.

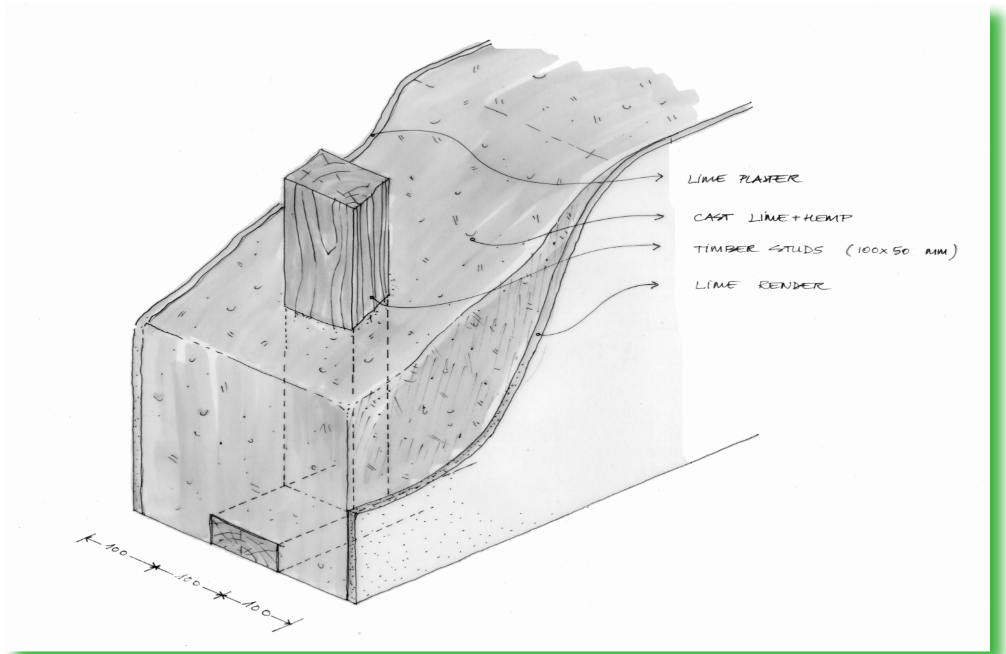

Figure 2: Hempcrete Wall. Source: Ian Pritchett (CAT 2006).

Construction Costs and Considerations

For Haverhill it was estimated that the true cost of building with hemp was £526 per square metre of floor and only £478 for a traditional style construction (BRE 2001). Labour costs to build the outside shell of the first hemp home consisted of 62% of the overall costs: this was reduced to 47% for the second home. For standard construction 57% of the cost is labour (BRE 2001). The two hemp houses were constructed without any prior training and the time of construction of the first house (~1100hrs) was considerably longer than for the second (~400hrs) (Construction time for the standard homes was ~400hrs).

The main reason cited for the reduction in construction time between the 2 hemp homes was that the builders had learnt how to use the material. It was also felt that the time taken for construction would fall further as experience grew (BRE 2001). It is clear that the time of construction can be reduced dramatically and the technique is considered to be relatively “easy” (Henry D O’Thompson Old Builder’s, Eire. CAT 2006). The material costs for the shell of the hemp homes were also 2 to 3 times more expensive than the standard build. However, at the time of writing the report, it was estimated that £1500 could be saved on the price of the lime (BRE 2001) and hemp can now be obtained more cheaply in the UK.

The price of the hemp walls in the Haverhill project was £194 per m2. At the recent hemp conference at CAT in March 2006, Limetec’s Ian Pritchett estimated that currently a 300mm wall including render and plaster could be made for between £90-120 per m^2, which compares well to the standard construction costs of £140 per m^2, as in Haverhill. At the current cost of a bag of lime ~£7 and hemp at £7-8 per 200l bale, (2009) the cost of a m2 of 300mm is ~300l of hemp and 3bags of lime;

~£33, labour costs on top are variable from very low (D.I.Y + volunteers) to very high (e.g. Industrial Contractor).

Amount of Materials

Presuming a thickness of 400mm (to achieve a U-value <0.35 W m^{-2} K^{-1} and a wall area of 90 m^2 (the Haverhill homes were 86 m^2 and 106 m^2) the volume of hemp required to construct the walls of the house would be 36000 litres or 7200 kg as hemp weighs ~20kg per 100 litres. Presuming the floor area to be ~40 m^2 at 100 mm depth this will require another 4 m^3, 4000 litres or 800 kg of hemp. The average yield of hemp straw in the UK is approximately 5500 kg per hectare of which ~70% or 3850 kg are hurds. Thus it will take 8000 kg of hurds or ~2 hectares of hemp to supply enough hemp hurds for a 2 bed terrace with 400 mm walls. The depth of wall makes a substantial difference to the amount of hemp required see **Figure 3.** Using as little lime as possible is also desirable from an environmental perspective, meaning wall thickness need to as low as possible to maintain performance.

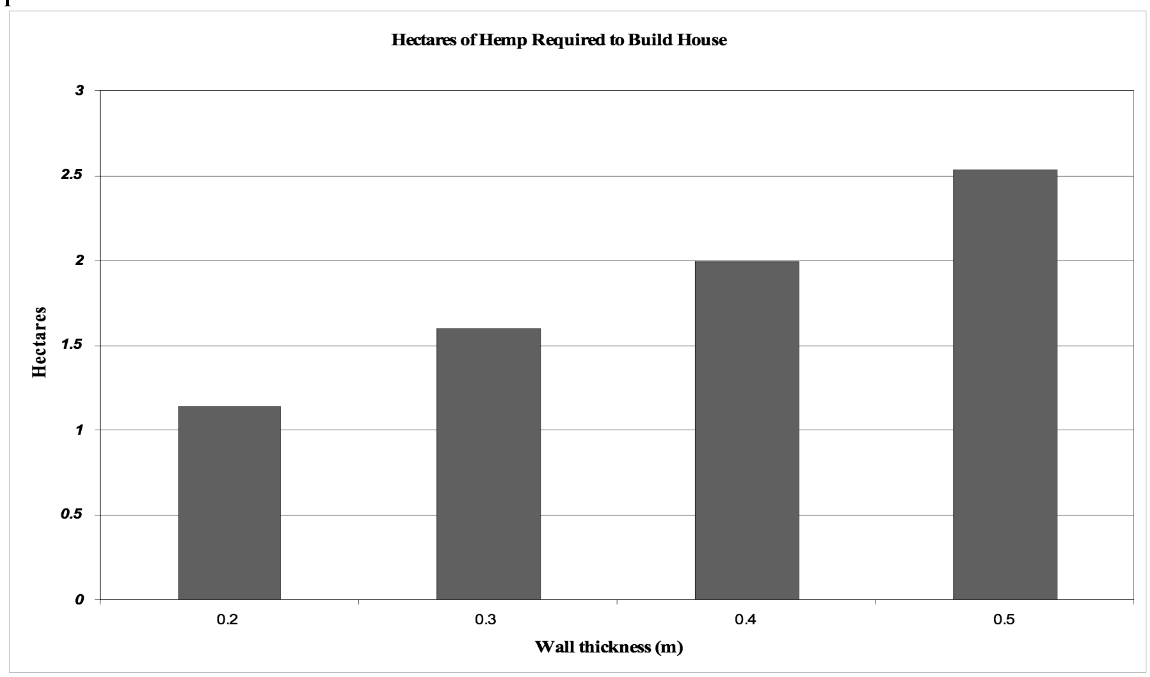

Figure 3: Area required against thickness of wall. Source: this author.

Building Issues:

The Haverhill report contains an extensive review of on-site problems encountered and basic recommendations. One of the main problems was the weather, which was mainly responsible for the build taking almost twice as long expected. Lime is sensitive to frost damage and therefore construction had to wait for the temperature to be above 5°C. It is also necessary to keep lime plastered and rendered walls moist for a short period (3-7days) after they have been applied and it takes approximately 2-3 months for the lime to completely dry.

The drying time is longer in cold and wet conditions. It was however estimated by Ian Pritchett at CAT (2006) that if the hempcrete is sprayed onto the wall (a technique already developed in France), full construction time can be as little as 2 weeks. The wet environment near the wall during the drying period can lead to mould growth on materials close to the wall (e.g. the back of picture frames) and on surface hemp which hasn't got n adequate coving of lime, but not in the actual wall, as lime's high ph prevents mould growth.

Henry O'Thompson reported incidences of mould occurring in this manner, although Ian Pritchett felt that this could be overcome by using a more hydraulic lime (Discourse CAT (2006)). Ralph Carpenter (personal communication) has noted that north and west walls seem to be more prone to this problem although once the mould is removed and the wall plastered the problems haven't reoccurred.

All these considerations led to the recommendation that the technique should only be considered between February and September in the UK (BRE 2001). This leads to a problem as hemp is harvested in September and therefore over-winter storage is necessary which increases prices and complicates logistics. It costs ~£30 a tonne to store hemp and as discussed takes up a lot of room due to its high bulk density. These issues are difficult and not being able to build all year round in the U.K. climate may be restrictive for the building industry to adopt the technique.
Lime renders need continued maintenance as they are primarily a sacrificial layer to the weather to protect the underlying wall.

"However, the maintenance burden associated with hemp is regarded as comparatively small. As an in-situ material, repairs, minor alterations or remedial works are likely to be accommodated with comparative ease. Apparently, the material has been used extensively for "plaster" mouldings in houses across France"(BRE 2001).

The strength of the mixture was tested and "*the results of this test were a mean compressive failure strength of 0.458 MPa for the 'wall' mix and a compressive stress at 10% relative to deformation of 0.836MPa for the 'floor' mix. This suggests that the walling material will continue to deform as the load is applied but the flooring material is more rigid as a result of the sand/aggregate"* (BRE 2001).
Although the waste produced for the hemp homes was reported to be the same as for standard construction, the waste was all fully recyclable. Furthermore, due to the weight of the walls, the hemp homes only required half the foundations and the material dug out for the foundations comprised 87% of the waste burden for building in general.

The hemp floor slab and walls were considered relatively impermeable to water which was confirmed by BRE in an extensive water saturation test which meant that the hemp homes didn't require any damp- proof course (BRE 2001). It was also considered that the hemp homes had less condensation, as would be expected with walls that are breathable. The homes also met the acoustic requirements of buildings regulations (BRE 2001) and although its use in passive solar design has not been investigated Prof. T. Woolley felt that it was well suited for passive solar applications (Discussion forum; CAT (2006)

Hempcrete and Carbon Dioxide

The reduction of waste, the low embodied energy of the materials, the thermal performance and air-tight construction will all reduce the construction and running CO_2 debts of a house built using hempcrete for its walls.

There is also carbon sequestered from CO_2 in the atmosphere as hemp grows. For every tonne of hemp grown ~500kg of carbon is sequestered or ~1,800 kg of CO_2 (Pervais 2003). The embodied energy of hemp is 1.4 MJ tonne (BRE 2001, Cherrett 2005) which equates to ~0.112 kg of CO_2 per tonne (Calculated using CO_2 conversion factors quoted by Cherrett 2005 for UK farming = 0.0008 tonnes per MJ) meaning that approximately 1.8t of CO_2 is sequestered for every tonne of hemp hurds used. It is important to realize that this will be an overestimation as the calculations only involve the actual amount of carbon in hemp by weight and the embodied energy which appears very low. However it does not include the environmental costs of growing the hemp in monoculture, the NO2 released from the land that is fertilized or the wider consequences of any herbicides if used. As NO2 is a potent greenhouse gas therefore in terms of CO2 equivalent CO2e, the actual CO2 saving in real terms will be much less for monoculture cultivation.

The recent French LCA uses French energy mix (~90% Nuclear) as well and although it accounts for the energy of manufacture of fertilizer doesn't include the emissions as above and fertilizer accounts of the ~60% energy used in farming (Boutin 2005), also note that all the figures for the binder in this LCA are from L'hoist provided data and presume high re-carbonation rates. Re-carbonation of lime is a difficult thing to assess accurately and is dependent on the lime binder being exposed to moisture and CO2.

It is estimated that on average approximately 20-25% (Anon 2005) of the carbon dioxide is reabsorbed overtime. Opinion on this varies however and some say that 100% can be re-absorbed, due to impurities, lack of CO2 and moisture 20-25% is generally realistic however is probably conservative with hemp and lime as this material is highly porous which would allow CO2 and moisture access easily. It is also takes about 1-5years to occur, however cement re-carbonates very slowly at a rate ~2% every 100 years. Thus for the different lime based binder a range of re-carbonation amounts will be presumed with the cement element of the binder no really reabsorbing any CO2 during the 100year life of the building.

Further research is necessary in this area to accurately ascertain how much CO2 is absorbed by the lime in the walls overtime.

Therefore, recalculating:

- $1m^3$ of hempcrete uses 1000 litres of hemp hurds which weighs ~100kg, meaning that ~180kg of CO_2 dioxide will be locked up per 1 m^3 of wall in the hemp shiv.
- Lime used however has a wide range of embodied energy figures, from the ICE database 0.2 to 9MJ/kg, however the mean is 5.3MJ/kg and meaningful range is 4-9MJ/kg.

When calculating the total CO2 emissions range from the CO2 burnt from lime must be included as well as the CO2 from embodied energy, all lime releases about 0.48kgCO2 /kg when burnt from the limestone.

For 5.3MJ/Kg ICE gives 0.74kgCO2/Kg overall and this includes 0.48kgCO2/kg from the limestone and thus 0.26KgCO2/Kg from the 5.3MJ of energy used in the production process. Given the range of Embodied Energies for lime is 4-9MJ/kg, this gives a range of CO2 emissions of 0.196 – 0.45 KgCO2/kg for the embodied energy and thus overall a range of 0.676-0.93KgCO2/kg before any re-carbonation has occurred. This means that anywhere between 676 kg - 930kg (mean ~740 kg) of CO_2 are released per tonne of lime produced (personal calc using Bath (2008)). Limetec's product contains ~15-20% cement which from the ICE database has an average of 0.83KgCO2 per tonne and is thus reasonable equivalent to the lime in current production methods. Of note however cement embodied energy is hard to reduce further whereas lime can be produced from biomass kilns.

- ~200 kg of lime will be used in 1m3 of hempcrete
- Meaning a range of ~135 kg -186 kg of CO_2 will be released into the atmosphere from the lime used to make a m3 hempcrete (mean 148kg CO_2).
- Every kg of the lime will then re-absorb a certain (~25-75%) amount of CO2 over time of the 0.48kgCO2/kg burnt of during burning. This equates to a range of 0.12kgCO2/kg to 0.36KgCO2/kg. Therefore for a m3 of hempcrete (200kg of lime) this gives a range of CO2 re-absorption 24-72KgCO2/kg over time. For the Limetec binder this will be less by 15-20% due to the cement content.
- Therefore overall the CO2 emissions from the lime in a m3 of hempcrete could be anywhere from 63kg (135-72kg) to 162kg (186-24kg).
- This then means that anywhere from 117kg to 18kg of CO2 are sequestered into a m3 of hempcrete depending on the embodied energy of the binder and the re-carbonation of the lime. These again are likely to be overestimates unless the hemp is grown organically.
- In a standard wall there is also the plaster and render to consider. Lime has a density of ~1500kg / m3 therefore a m2 of 20mm of lime plaster weighs ~30kg which adds another ~9.5-24kgCO2 of emissions per m2 of wall if lime is used.
- Therefore, overall, for a standard 300 mm hempcrete wall every metre square (0.3m3 of hempcrete) potentially locks up ~(117kg x0.3)-9.5kg= 107.5 kg of CO_2 or emits ~ ((-18kgx0.3)+24kg) = 18.6kg of CO_2, depending on the lime figures used.
- standard cavity wall constructions emit 100-220 kg of CO_2 per m^2 (Ian Pritchett CAT (2006), personal calc using Bath (2006)).

This emphasizes the crucial aspect of reducing the embodied energy of the lime to a minimum or using another binder with a lower embodied energy (**e.g. Clay**) to remove CO2 from the atmosphere. These calculations don't take into account the CO_2 emissions from construction.

There are however potential CO_2 savings in running hempcrete homes, due to its good thermal performance, which significantly reduced the heating requirements of a home in Haverhill. The type of binder will influence the thermal performance of the walls and this influence is under further investigation.

Due to the farming aspects mentioned above and the uncertainties in the embodied energies further research is necessary in this area to ascertain a true picture of how CO2 or CO2e is locked up by using hempcrete, although if the hemp is grown organically and the binder is changed to clay this could potentially be ~180kg per m3 used. This could a reasonably large sequestration of carbon especially if hemp and binder insulating plasters are utilized for renovations works.

Potential Market for Hempcrete

Although there is currently no market for hempcrete in the UK, interest is growing (Ansells Breweries have commissioned and had built a hempcrete building) and the French market has grown by 400% in the last 10 years. The costs of construction are low and there is proven example of performance in the Haverhill project which was acceptable to the local planning office in keeping with 2002 building regulations. The WISE building at CAT is being built using Hemcrete as an external skin (CAT (2006) Pat Borer 2007).

The size of the market is uncertain and could range from just a few environmental builders to larger developments, especially as it has a possible short construction time, it reduces waste and there is both increasing demand and legislation for environmental buildings. Add in the health benefits of breathable walls and the fact that carbon is stored in the walls, and it seems that the potential for hempcrete used in this style of construction could be considerable. The logistics of using hempcrete and the build period (Feb-Sept) are however unattractive.

Assessing this potential with a market research tool incorporating the attitudes and perceived desirability of hempcrete to the final consumer, the contractor, the processor and the farmer is beyond the scope of this lecture although is an area of research that is necessary. The 6000 tonnes of hurds used a year in France could build ~750 Haverhill style homes. In France the number of new buildings isn't as high as a proportion of the hurds are used to insulate old stone buildings in Northern France with an internal 50mm hempcrete covering. Anecdotally this technique is very successful although I couldn't find any published data on the technique beyond advertising.

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