CONSTRUCTING A LOW ENERGY HOUSE FROM HEMPCRETE AND OTHER NATURAL MATERIALS

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Abstract: In this paper we discuss the experience of the construction of an 80 square metre single storey eco house in County Down, Northern Ireland. The house is constructed from a timber post and beam frame with hemp and lime walls. Sheep’s wool insulation in the roof and other natural or second hand materials have been used, including a grass roof. The house was begun in the summer of 2008 and largely complete in August 2009. We discuss how the design was developed and the buildability and detailing issues that were discovered during construction. Test results on the thermal performance of the house will be available in 2010 as we hope that independent monitoring will be carried out by University of Ulster. The authors of the paper have also written a book about hemp lime construction and the paper will examine what has been learned from putting ideas into practice.

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1. Searching for low carbon building

It has long been recognised that buildings and their use contribute significantly to CO₂ emissions, perhaps more than 50% of total emissions. Finding ways of meeting our housing and building needs while having a low impact on the planet has been the aim of many self-builders, architects and environmentalists. However there are two main differences in approach. There are those who have focused on getting the main stream construction industry to make buildings more energy efficient, even though they rely on high embodied energy petrochemical based insulations, cement, bricks and concrete. Others have tried to search for lower impact alternatives that also are healthier and less polluting. There is now a range of building methods and materials derived from natural low impact sources (Woolley 2006) such as earth, (Morton 2008) straw, recycled materials and so on.

We first learned about hemp and lime construction from pioneering Suffolk architect, Ralph Carpenter (Carpenter 2009) and soon realised that this was a form of eco-construction that could achieve low energy buildings using low impact materials. While it was a natural alternative material, it appeared to have great potential in mainstream construction.
Hemp-lime construction is a composite construction material and building method that combines fast growing renewable and carbon sequestering plant-based aggregates (hemp shiv) with a lime-based binder to form a lightweight material that is suited to solid walls, roof insulation and under-floor insulation and as part of timber-framed building. It also offers good thermal and acoustic performance and the ability to regulate internal relative humidity through hygroscopic material behaviour, contributing to healthier building spaces and providing effective thermal mass. It is formed by mixing together hemp shiv and a lime-based binder. The lime binds the hemp aggregates together, giving the material modest structural strength and stiffness. Lime also protects the shiv from biological decay, mainly through its ability to wick water away from the hemp shiv and its high alkalinity, as well as providing essential fire resistance. Hemp lime can be used to form solid non-load-bearing panels or blocks, typically as part of timber or other framed buildings. By varying the mix design, hemp lime materials may also be used in denser or lighter composites for floor insulation and roof insulation. (Woolley and Bevan 2007)

Hemp lime has been under development since the early 1990s, mainly through work in France and Belgium, but also including research work in the UK, funded by the Department of Food and Rural Affairs (DEFRA 2009) through the National Non Food Crops Centre (NNFCC 2009). There are many hemp lime building projects in the UK, including houses and even large industrial buildings. All have attracted considerable attention from professionals and the media. A particular benefit of hemp lime construction is its capacity to sequester CO₂ into the building fabric. As government policy becomes increasingly concerned with reducing carbon emissions and finding more efficient ways of meeting current targets, it seems possible that hemp lime can make a major contribution to this offering a genuinely zero-carbon solution to sustainable construction. We were funded by the NNFCC to produce a report about hemp lime construction and this has led to a book published by BRE Press. (Bevan and Woolley 2008)

2. Casting Hempcrete
Mixing hemp shiv and lime with water creates a lightweight lime and hemp mixture that is sometimes referred to by the generic term hempcrete. The proportions of the hemp lime can be varied according to the density and characteristics required. We decided to use proprietary hemp and lime materials from **Tradical Hemcrete ®** (Lime Technology 2009) rather than producing our own mix. There were a number of reasons for this. We were keen to support the work done by the companies involved with Tradical in terms of making hemp and lime available to mainstream industry. The construction system was about to receive Local Authority building control approval for the whole of the UK (LABC 2008) and we were also happy with the results we had seen elsewhere. Making up our own mix would have had the risk of uneven results.

Once the material is mixed with a small amount of water it resembles a sticky porridge that can be cast into walls, roofs or floors to produce a solid insulating mass using shuttering or by spraying. We decided to cast the material in shuttering rather than spraying, as it would not have been cost effective to bring a spraying team to Northern Ireland for such a small building. We found that casting the material, while quite labour intensive, was easy to do and various volunteers and helpers were able to work along side our builders casting the hemp lime.
Shuttering was made from plywood on site and this slowed down the progress, as the shuttering had to be taken off and put in place each day for the next day. A proprietary plastic shuttering system is now available which could speed up the process. Scaffolding was required as the walls got higher and we fund that lifting up the mix in small buckets was the most effective way to place it.

The hempcrete mass is solid enough to hold together quite quickly but then takes a while to dry out and cure. Drying and curing time will vary according to the mix, climatic conditions and so on, but is normally about four weeks. This may seem like a disadvantage when so many building methods offer quick-fix solutions. However, the hemp lime mix is solid almost as soon as it is cast and shuttering can be removed immediately or after 24 hours.

In the case of our project we did not begin the casting until the end of October and we were lucky to get mild weather for most of the time. It is not a good idea to cast hemcrete when there is a heavy frost. We provided frost protection using hessian at night. As the weather got colder and damper it was clear that the hemcrete walls would not easily dry out and we remained a little concerned about moisture levels for the next two months or so. Despite the slowness to dry out this did not appear to create any serious problems other than to delay progress.

When the material has dried out it becomes a strong and solid composite which creates a weatherproof mass providing thermal insulation, thermal storage and a substrate, which can take a variety of finishes.

3. Timber Frame construction

Normal practice is to construct a simple timber frame or sub-frame which provides the principal structure of the building supporting any floors and roofs, the hemp lime is then sprayed or cast around the timber frame to provide solid walls, and possibly floors and roof.

In our case we built a post and beam structure using locally sourced Douglas Fir and constructed the roof structure using composite I-beams. The intention was to cover the roof and provide weather protection whilst casting the walls. Due to appalling wet weather over the summer, the roof construction was slow and we realised that we could only cover it with a temporary cover. This was to provide access to completing an air-tight detail at the heads of the walls. While this form of construction has created a very strong and attractive building, cost savings could have been made by using a simpler frame that could have been pre-fabricated. At the time we could not find a timber frame company to do this but we are now working with one to develop an efficient pre-fabricated system. Most timber frame construction systems in the market place stick ignore the potential of natural and sustainable materials. (Woolley 2008)

One reason for choosing hempcrete is that is that it simplifies construction. Most timber frame systems have quite complex build ups and often have difficulty in achieving target air tightness standards. This should not be a problem with hempcrete as it is a very simple building method that can be grasped by ordinary builders within a few hours instruction. This was confirmed by our experience and while the joiners overcomplicated the shuttering initially they soon realised that because of the lightweight nature of hempcrete, it is not the
same as concrete. We did not have to worry about breather membranes and taping joints in the walls as the homogeneous nature of the material fills all voids. We used a “Heraklith” board as permanent shuttering around window openings as this provided a good key for the hempcrete to bond to.

Another way we could have simplified construction would have been to use a permanent shuttering board on the inside of the walls but we chose to shutter both sides. The walls were finished with a hydraulic lime plaster internally and externally. We had to wait for a while after the walls were cast so that this could be done in a frost-free period and this allowed the walls ample time to dry out. The plasterers were concerned about the hemp walls sucking moisture from the plaster but this did not seem to be too much of a problem.

4. Insulation Properties

We decided to build hemcrete walls that were 300mm thick. Very successful hemcrete buildings have been constructed with walls of only 200mm but others have used walls that are up to 500mm thick. There is sufficient evidence to show that 500mm thick walls will create a zero energy building but we wanted to test the effectiveness of thinner walls. We were concerned that a further substantial amount of material for such a small building might not be cost effective.

From a wide range of literature the general consensus from various scientists and also the manufacturers of hemp and lime products used to be that hemp and lime composites have a thermal conductivity (lambda) value of around 0.09w/mK. This is a conservative figure, which is being superseded as more scientific tests are carried out. For instance subsequent tests at the National Physical Laboratory indicate an improved figure of 0.07W/m.K. (Bevan and Woolley 2008)

Tests of the thermal conductivity of walls at Ralph Carpenter’s house in Suffolk by Plymouth University led to an agreed reading of 0.08 w/mK. These were taken on a wall which was 200 mm thick and had been constructed a number of years ago so the walls could be assumed to have fully dried out and the lime carbonated. Based on this we calculated the “R” value (thermal resistance) to be 2.75 with plaster and surface resistances taken into account. The team at Plymouth University agreed that a “U” value derived from this would be in the region of 0.36-0.37 W/m²K. This empirical work confirmed a lambda value of 0.08-0.09 for hemp and lime and as this conservative figure has been repeated by so many authorities that it seems reasonable to accept this when making building regulation applications. (Bevan and Woolley 2008)

If a wall of 300mm were constructed using these figures, this would have a “u” value of approximately 0.26W/m²K to 0.28W/m²K. This would be quite adequate to meet the new building regulations thermal standards. However experience has taught us that the actual thermal performance of hemp and lime buildings is much better than might be predicted by crude “u” values. More recent work suggests that a 300mm wall could have a “u” value of 0.23 or even better by reducing the density of the walls with less lime based binder.

The insulation performance is also related to density and thus the placement of the material by spraying or tamping can affect the thermal performance. If too dense a mix is used or the material is too heavily tamped in shuttering then the insulation value may not be as good. Spraying the material onto permanent shuttering should generally give a lower
density and thus better thermal performance. The mix proportions of hemp and lime can also be varied so that by reducing the amount of lime a less dense mix will be achieved. This is normally done where hemp is used in roofs, so that it is both lighter and a better insulator. On the other hand a denser mix will be preferred in floors for greater mechanical strength.

We tried to take care on site to ensure that the hemcrete was not over-tamped, as this would make the walls too dense. We mixed the materials dry in a large pan-mixer, driven off the back of a tractor and tried to carefully control the amount of water that was added. There is little doubt that weather and humidity affected the moisture content and when the walls had dried out, slight differences could be seen from the colour of the walls. We assumed that as the day wore on and we became tired we might have been less careful about how much water was added! However once the walls had dried out there was good consistency in the nature of the walls.

The thermal performance of the building will be tested with air-tightness blower door test, thermal imaging and some monitoring of temperature over the next year. University of Ulster Centre for Sustainable Technology and will be assisting us with this. (CST Ulster 2009)

5. Thermal Mass and comfort

What the building regulations and conventional methods of measuring thermal performance do not do, is to take account of thermal mass and the ability of insulating materials to store heat and release it into the building. Thermal mass is a complicated issue because it operates in a number of different ways in buildings. Lightweight timber and steel frame buildings, insulated with lightweight synthetic or mineral materials, may have little thermal mass and thus the fabric cannot store heat. If the building is designed to make use of passive solar gains through south facing glazing then there needs to be enough thermal mass to absorb and store this heat. However heavy construction may retain too much heat or, when the ambient temperature is cold, take too long to heat up, to ensure good thermal comfort. It has been argued that heavyweight construction will mitigate the effects of climate change (Arup 2005) but simply including a lot of heavy concrete in walls or floors does not necessarily guarantee success.

Heavyweight materials like solid concrete are not able to absorb and emit heat quickly and cannot buffer moisture. Other heavy low impact materials, such as unfired earth cob or straw-clay can also provide better than expected thermal performance, though generally additional insulation is needed in order to comply with the building regulations. (Goodhew & Griffiths 2005)

Hemp and lime on the other hand provides a happy medium of being a lightweight material with the characteristics of a heavier material which both insulates and stores heat. This allows it to respond to ambient conditions much more effectively and it balances thermal and humidity variations as required.

Lightweight synthetic insulation materials cannot store heat at all and if subject to thermal shock (sudden changes of temperature) will allow heat to flow surprisingly quickly, however good their thermal resistance. Hygrothermal materials like hemp and lime will slow down these changes (decrement factor) and thus can maintain much more stable conditions.
Thermal comfort is a key factor in how people experience buildings and even slight changes of temperature can make people feel colder or hotter if other factors come into play. For instance, even in a warm building, cold drafts can make people feel cold. Humidity levels also have a very significant effect on people's comfort and if humidity is too high or too low, then people will also feel that the temperature is not right.

We do not have the benefit of winter performance yet but during a very hot spell in May it was noticeable how cool the building remained. The value of thermal mass in preventing overheating was noticeable.

6. Other materials used in the construction
We tried to continue an ecological theme for most of the other materials and products in the building but this was tempered by pragmatism and budget! We chose sheep's wool insulation in the roof but our plans to use a wood fibre sarking board above the sheep's wool were abandoned because of the problems of sourcing this and other ecological products in Northern Ireland. In the end we use a mineral wool dense sarking board. Composite I-beams were used for the rafters in the roof as this created a strong roof while providing depth for plenty of insulation. The hempcrete walls were taken up into the I-beam rafters and then a softwood rafter toe was fixed in place to provide a good roof overhang.

The front face of the roof is slated but the rear north-facing roof was covered with plywood decking and then an epdm membrane. This was covered with second hand carpet and then grass. This has proved to be a bit of a local tourist attraction and created a lot of interest in the building from people who have never seen a green roof before.

Originally we had considered using the post and beam frame to make the floor off the ground but ended up with a concrete slab. On top of this we have placed 250 mm of expanded polystyrene, nearly all of which was from recycled sources. We also used second hand eps for perimeter insulation around the slab. Timber windows were made by a local manufacturer from recycled pitch pine. Internal finishes are clay paints and tiles.

As the house is intended for an old person and is also fully accessible/life time homes compliant, we have included underfloor heating, though we doubt it will need to be used very often. This is heated by a small propane gas-condensing boiler. Provision has been made for the installation of warm water solar panels and a storage tank. A small wood-burning stove is included in the living room.

Rainwater will be collected in a number of rainwater butts and a bio-powered on-site sewage system has been installed.

7. Conclusions
We are generally happy with the use of hemp lime as a form of construction. It has so many advantages over other forms of timber frame construction. It needs care in use but can easily be applied by any mainstream builder and is perfectly feasible for self-builders. Detailing is relatively simple and should not present difficulties to any competent architect with an open mind.
In addition to this new build construction we are going on to use hemcrete in the renovation of an old stone building. About 75mm of hemcrete will be applied directly to old lime plastered rubble stonewalls and we believe that this will give a significant improvement in energy efficiency.

Despite our worries about dampness and drying out over the winter, the final plastered walls are in good condition. Delays to the project could have been reduced by building at a different time of the year. Prefabrication would be another option. The project has received many visitors who are intrigued at the use of solid wall construction. We have left two areas of the hemcrete walls unplasterd with an external “truth window.” A film of the construction process of the house will be available on the Down District Council “Sustain and Build” web site. (Down District Council 2009)

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