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Author(s): Busbridge, Ruth; Rhydwen, Ranyl

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AN INVESTIGATION OF THE THERMAL PROPERTIES OF HEMP AND CLAY MONOLITHIC WALLS

RUTH BUSBRIDGE AND RANYL RHYDWEN

*Graduate School for the Environment, Centre for Alternative Technology
& School of Computing and Technology, University of East London*
ruth.busbridge@gmail.com ; ranyl.rhydwen@cat.org.uk

Abstract: The monolithic walls of hemp-lime construction enclose and protect a structural timber frame to provide a healthy, breathable building fabric that meets current UK building regulations. It has been proposed that by using hemp as a building material it is possible to actually remove carbon from the atmosphere. Whether or not ‘hemp-crete’ can be considered carbon sequestering, or even neutral, depends largely on the binder. All the lime based binders have high embodied energy, meaning they limit this possibility. Earth construction uses clay as the binder. Could clay substitute for lime in hemp-crete? This experimental research focuses mainly on the thermal properties of stabilised and unstabilised hemp-clay blocks which are tested using a transient heat-transfer probe to measure thermal conductivity, volumetric heat capacity, and derive thermal diffusivity and effusivity. Results are compared with industry-published data for hemp-lime (eg Lhoist, 2009) and found to be similar. The results of the experiments and the literature review indicate that the use of clay as an alternative binder has potential to reduce the environmental impact of the hemp-binder method and facilitate the move towards developing a building material that can be used for new build or renovation works, that removes carbon from the atmosphere at this time of need.

1. Background

Construction materials are responsible for 10-20% global CO₂ emissions and many now feel that to avoid seriously dangerous climate change carbon dioxide needs to be urgently removed from the atmosphere (Rockström et al, 2009). Modern buildings generally rely on highly insulated non-breathable air-tight construction methods to achieve high thermal efficiencies. To prevent intra-wall and internal moisture problems, complicated multi-layered wall constructions lined with fabricated vapour barriers and actively controlled ventilation are required. These high-tech and expensive solutions come with high embodied energy (and carbon) and environmental costs.

1.1. Hemp-Binder

Hemp-Binder construction simplifies the building process. It is a basic timber frame encased in a monolithic insulating matrix of hemp and binder that has been shown to have thermal advantages in terms of good air-tightness and reduced thermal bridging, creating a warm, breathable building fabric with U-values at 350mm thickness that meet current building regulations. As well as having good insulative properties it also has a moderate thermal inertia, meaning it provides an effective heat store that improves its overall thermal efficiency (Everard 2005-6). Due to its high porosity, vapour permeability and hygroscopic nature, it should handle moisture vapour well and buffer relative humidity variances.

This high hygric activity of the material, such as the exchange of water vapour

between the wall and the air, dynamically changes the thermal properties of the walls and may contribute further to improved thermal performance through latent heat exchanges, although this needs definitive clarification. The absence of toxic or synthetic materials ensures a healthy living environment. The ecological credentials of organically grown hemp and its ability to sequester carbon are convincing (Rhydwen, 2006). However, if lime (or cement) is used as the primary binder, the high embodied energy (CO₂ emissions) and other environmental impacts associated with lime-based binders limit the potential for carbon sequestration. This scenario leads to the conclusion reached by Rhydwen (2006, 69) that using the least possible amount of these (or removing them entirely) and investigating the possibilities of clay or earth as an alternative is desirable under an environmental ethos.

1.2. Light Earth

Light-earth construction has proved successful in other countries. Germany has building standards for light-earth (Dachverband Lehm e.V., 2009) as does New-Mexico (State of New Mexico, 2008). The construction method is very similar to hemp-binder but uses woodchip or straw bound with clay-rich earth.

Earth building has been proven throughout the world for millennia and clay is the binding component of earth in construction. This paper investigates whether clay could replace lime in the hemp-binder method to reduce its environmental impact.

2. Methodology

Following an extensive literature review (Busbridge, 2009, Ch2), experimental research in this study focused on the thermal

properties of stabilised (using lime) and unstabilised hemp-clay blocks. These blocks were made using hemp hurds bound by clay slip (plastic clay in water) with varying proportions of quick-lime. The quick-lime was trialled in small quantities, as it prevents shrinkage in clay plasters (Lawley, 2008).

The same volume of hemp was used in every block and constant viscosity was maintained in the slip. The blocks were dried for 2-3months and then a transient ISOMET heat-transfer probe (Figure 1) was used to measure thermal conductivity λ , volumetric heat capacity c_v (the product of density ρ and specific heat capacity c_p) and to derive thermal diffusivity ($\alpha = \lambda/(\rho \cdot c_p)$) and effusivity ($e = \sqrt{\lambda \rho c_p}$).

At the same time the moisture content was measured as percentage wood moisture equivalent (%WME) using a Protimeter moisture probe (Figure 2). PH measurements of the binder and rudimentary compressive strength tests on the blocks were also conducted.



Figure 1: Testing thermal properties of blocks with an ISOMET transient heat-transfer probe.

3. Results and Discussion

All the blocks contained about the same volume of hemp but their densities ranged from 320 to 730 kg/m³, depending on the proportions of the clay, quick-lime and water. Adding quick-lime to the clay-slip significantly increased its viscosity due to the exothermic chemical reaction, therefore more water (up to twice as much) had to be

added to facilitate mixing. This resulted in a smaller clay volume per block, thereby allowing the manufacture of lighter blocks.



Figure 2: Measuring moisture content with a Protimeter moisture probe.

When lime was added to the slip in proportions greater than around 5% of the weight of clay, the clay no longer reacted, presumably resulting in ‘free’ lime which could carbonate in time. However, Volhard (1995, 48) advises against the use of lime with clay because it weakens the binding ability of the clay. Minke (2006, 84) also suggests that less dense light-earth walls are more likely to rot and recommends a density greater than 600kg/m³ in walls thicker than 25cm. As density increases so does the conductivity, and the insulative value of the wall correspondingly falls. To maintain adequate insulation thicker walls are therefore required and any rotting is likely to be due to delayed drying times. Thicker walls may possibly require active drying. Thermal conductivity and volumetric heat capacity were related to moisture content (Figure 3) and to density (Figure 4). Figure 3 shows the thermal conductivity and moisture readings for the 15 batches of blocks (three blocks in each batch: a, b & c). Each block had one moisture reading and two conductivity readings, one from each end. Series 2 measurements (‘a’ blocks

only) were approx 1 month later than series 1. In most cases thermal conductivity fell as blocks dried. There were a couple of exceptions to this in the drier blocks. The explanation for this might be that these blocks were essentially dry and were responding to changes in ambient relative humidity.

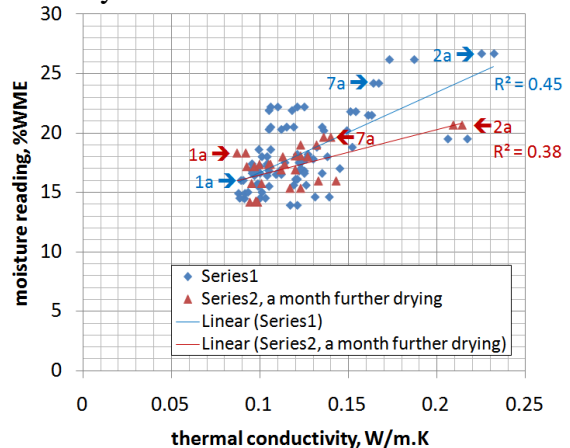


Figure 3: Thermal conductivity against moisture content.

Results for the thermal properties were compared with published values for light-earth (Volhard, 1995, 146 and Gaia, 2003, 41) (see Figure 4) and for hemp-lime (LHoist, 2009) (see Figure 5), and found to be similar. For a given density, Thermal conductivity is similar or slightly lower than published figures for light-earth.

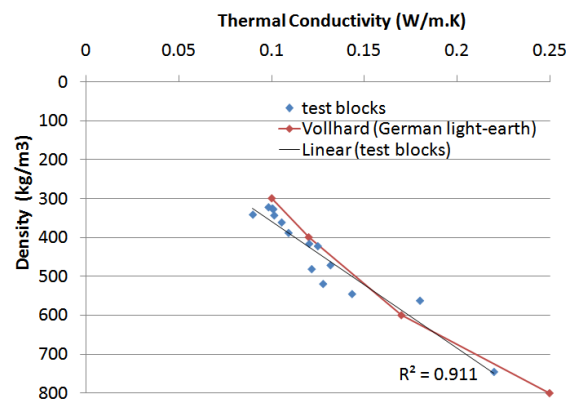


Figure 4: Thermal conductivity against density for hemp-clay and light-earth

In Figure 5, the density, volumetric heat capacity, thermal effusivity, diffusivity and conductivity of hemp-clay are compared to figures recently published for the various hemp-lime mixes produced commercially by LHoist under the trade name Tradical[®] Hemcrete[®] (LHoist, 2009, and Evrard, DeHerde & Minet (2006).

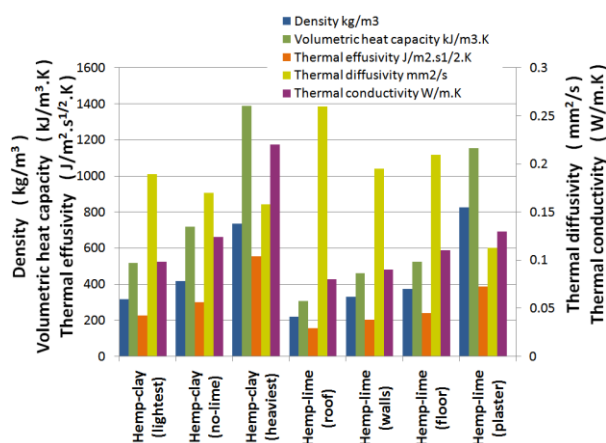


Figure 5: Comparison of figures for hemp-clay and Tradical Hemcrete.

The hot-box methodology they used requires dried samples, unlike those used here. Thus if similar hot-box conductivity tests were to be conducted on dried hemp-clay then lower thermal conductivity values would be inevitable, bringing the values closer to those for hemp-lime (since conductivity increases with moisture content).

All types of occupied buildings operate in the real dynamic world, not in the steady state world of conductivity measurements. Heat not only travels through walls, it can also be stored in them. The walls can have thermal inertia commonly referred to as thermal mass. The wall's density and specific heat capacity determine the size of this thermal inertia and predict how much heat the wall can store for dynamic exchanges through its external surfaces. The rate at which heat spreads through a wall is

indicated by its thermal diffusivity (its conductivity divided by the product of density and specific heat capacity). A low thermal diffusivity is indicative of a material through which heat passes slowly.

Hemp-binder has a desirable combination of low conductivity and reasonable thermal inertia (low thermal diffusivity) meaning that in buildings exposed to cyclic thermal and hygric variations, its thermal performance is likely to be better than indicated by static U-values alone. Evrard & De Herde (2005, 29) have reported how a 250mm hemp-binder (lime and cement combination) wall almost completely dampens a (24 hour period) continuous sine wave external temperature variation. This combination of thermal properties also gives a low thermal effusivity meaning the walls are warm to touch and contribute to thermal comfort by lowering radiative heat loss which can contribute to ~50% of the sensation of heat loss.

Although the exact mechanism of the impressive reported thermal performance of these monolithic walls (BRE, 2002) stills needs clarification and is being intensively studied by the Hemp and Binder research group of the Graduate School Environment of the Environment CAT. The results published here suggest that clay based hemp walls have similar thermal properties to other hemp-binder walls. This means that in terms of thermal performance clay could be an effective binder for hemp monolithic walls and insulating renders.

It is not possible to draw any conclusions on the hygric properties of hemp and clay, although figures from May (2005, 10&13) (figure 6) and unpublished work by Simon Wilkinson for the Hemp and Binder research team at CAT indicate that the hygroscopic and vapour handling properties of hemp-clay are also at least as good as hemp-lime.

Material	Hygroscopicity (% increase in mass) (Speed of response)	Hygroscopic capacity (Kg/m ³)	Vapour Permeability (GN.s/kg.m)	Capillarity (kg/m ² h ^{1/2})
Lime	1.75% Slow	28	75	1
Clay	3% Very fast	52	40	2

Figure 6: Moisture handling properties of lime, and clay [adapted from May, 2005,10&13]

4. Other findings

Rudimentary strength tests were inconclusive but they did suggest that hemp-clay may be comparable with hemp-lime. The compressive strength of one of the pure clay blocks was at least 40% of that of a hemp-lime block of the same density, as tested by BRE (2002, 22). Further, more controlled tests on strength and shrinkage parameters are required to determine the benefits or disadvantages of adding quick-lime to the clay.

Blocks were dried in a wet summer in mini greenhouses. This was not ideal as humidity was high. Moulds grew on exposed surfaces (Figure 7), particularly on blocks with a smaller clay proportion and on blocks with higher moisture content, but did not penetrate deeper than 1 cm.



a)



b)

Figure 7: a) Blocks drying in the mini-greenhouse, b) mould growing on the hemp-clay-lime blocks

Despite the high alkalinity (pH12.8), mould unexpectedly grew only on blocks containing lime. Although this could have been due to various factors and no conclusions can be drawn, it may indicate that the combination of quick-lime and clay produces conditions more conducive with mould proliferation.

	Binder EE (MJ/m ³)	Aggregate/ Hemp EE (MJ/m ³)	TOTAL EE (MJ/m ³)	Binder EC (kgCO ₂ /m ³)	Aggregate/Hemp EC (kgCO ₂ /m ³)	TOTAL EC (kgCO ₂ /m ³)
Hemp-Lime with 15% OPC in binder: 330kg/m ³	1142 (151+991)	0.15	1142	165 (27+138)	-198	-33
Hemp-Lime without OPC: 330kg/m ³	1166	0.15	1166	163	-198	-35
Concrete 15% OPC, 85% aggregate: 2200kg/m ³	1518	33	1551	274	9	283
Concrete 7% OPC, 93% aggregate: 2200kg/m ³	708	15	724	128	10	138
Lightweight concrete 15% OPC, 85% aggregate: 600kg/m ³	414	9	423	75	3	77
Hemp-Clay: 110kg hemp, 490kg clay 600kg/m ³	49	0.3	49	2.45	-198	-196

Figure 8: Comparison of the embodied energy and carbon of concrete, hemp-lime and hemp-clay

The net embodied energy (EE) and embodied carbon (EC) for various composite materials were calculated using figures from the ICE database (ICE, 2008), taking into account raw materials only (ie

excluding energy for aerating lightweight concrete blocks). For hemp-clay EE is very low and the EC is convincingly below zero (see figure 8).

5. Conclusions

Clay is globally abundant and widely locally available. Hemp-clay is relatively lightweight, completely safe to handle, is reusable, and fully biodegradable. Initial investigations of the basic thermal parameters of hemp and clay monolithic walls show that these are similar to their hemp-lime equivalent. Hemp-clay therefore has the potential to further reduce the environmental impact of the hemp-binder method and means that an effective, easy to use building material that actually removes carbon dioxide from the atmosphere is close at hand at a time of need.

6. Future work

A series of questions remains to be answered, such as the following. Is there any benefit in adding lime? Does it address the slight shrinkage issue and increase compressive strength or does it weaken the binding ability of the clay. What is the optimum clay proportion and optimum density?

Mould growth needs to be addressed. For this, water must be reduced to minimum. The drying time is also critical.

Empirical research is needed and is on-going already into hygroscopicity, capillarity and vapour permeability of the composite hemp-clay material.

Physical strength (compressive and tensile strength, and shear resistance) needs to be fully investigated.

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