Client Report :

Final Report on the Construction of the Hemp Houses at Haverhill, Suffolk

Client report number 209-717 Rev.1

Prepared for :

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Executive Summary

The development at Haverhill was to some degree an experimental project from the outset and intended to allow comparison to be made between “hemp” houses and those of traditional construction.

With the growing interest in innovation and need for sustainable construction a number of parties showed interest or provided support for this study including Suffolk Housing Society , St Edmundsbury Borough Council, The Housing Corporation, HAPM, Chenevotte Habitat (French hemp producer), and HL2 (the only UK producer of hydraulic lime). The research into the two building methods has been conducted by the Building Research establishment (BRE) paid for in part by a £60,000 Innovation and Good Practice grant from the Housing Corporation.

The houses were built for Suffolk Housing Society as part of a social housing development. The development is located within the Borough of St Edmundsbury.

The scheme involved the construction of eighteen dwellings 16 of which were built using conventional construction methods and materials but two of which were of a form of construction referred to as Hemp.

During the project BRE studied the two systems for:

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

The main findings were:

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.

Construction costs: It is estimated that the true cost of hemp construction was £526 per square metre compared to £478 for traditional construction.

A copy of this report can be found on BRE's web site at www.bre.co.uk/pdf/hemphomes.pdf. Suffolk Housing Society has published a summary of the findings that is available in hard copy or from its web site www.suffolkhousing.org.

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The trade name for the hemp product is Isochanvre.

The two Hemp Houses are founded on a limecrete foundation and brick plinth. The walls are of timber “balloon” type structural frame and these were shuttered and cast using a hemp/sand/lime matrix (in small lifts). The ground floor is a hemp / lime / sand slab topped with a sand / lime screed. The upper floor is of tongued and grooved boarding on timber joists . The roof is of trussed rafters and is covered with concrete tiles. Heating pipes and conduits for the electrical services are cast into the wall matrix.

The site consists mainly of two storey houses arranged in terraces and the two hemp houses form the end of a terrace of five houses. The two houses immediately adjacent to the “hemp houses” although traditionally built, are in many respects (e.g. size, layout, number of stories) almost identical and have therefore been used as “benchmarks” in some of the BRE studies.

The plan form of the houses is typically simple although there are steps and staggers on plan which have taxed the building team but at the same time helped to assess how buildablity the system is.

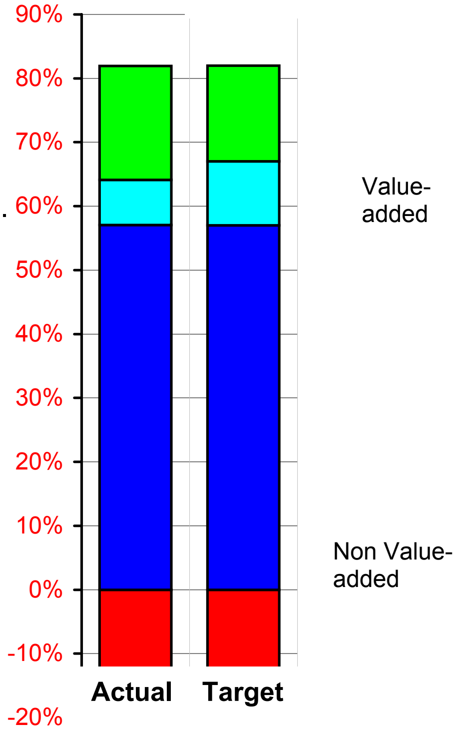
The Hemp Houses were regarded as a research project and although it was important to demonstrate that they could comply with the Building Regulations the Local Authority were not involved in checking the construction on site. Ralph Carpenter of Modece Architects, the project architects acting for Suffolk Housing Society, however, ensured that the Local Building Inspectors were in agreement with the general approach and they took part in various demonstrations to enable them to understand this novel form of construction. All parties were keen that “on paper” the houses should perform adequately and whilst it was accepted that the ‘Hemp houses’ would not meet all current requirements it was agreed that the final approval would be dependent upon the outcome of the research programme. The principal areas of interest were structural, acoustic and thermal performance.

BRE Studies of the hemp houses at Haverhill

Calibre – Performance Measuring Toolkit

Introduction

The Centre for Construction Consultancy (CC) prepared this Final Report on a study into the construction of the dwellings at Haverhill.



CALIBRE, a PERFORMANCE MEASURING TOOLKIT was used to observe the construction process for two pairs of terraced houses, the first, a pair of traditional two-storey, brick and block cavity walls, the second pair, the Hemp Homes, built of a hemp (trade name Isochanvre) and lime matrix round a timber frame on a limecrete foundation / plinth. The team recorded the man-hours consumed during works and the waste generated during the construction of each house. The activities were monitored in real time on site and photographic records were kept using digital cameras. The team also monitored four adjacent bungalows and four houses. In a CALIBRE study of this kind, the emphasis is on the buildability and not the efficiency of the processes. None of the construction team had built this way before so there were no benchmarks to improve on,
At each stage of the programme a learning process is involved, so the digital photographic records were an important part of development and improvement.
It was clearly understood that the innovation involved in the construction of the hemp houses would result in at least a doubling of the construction time, and possibly even a trebling.

Since its start in November, the project has suffered many delays, caused by extremely wet weather, flooding, snow and frost. The choice of lime over cement for environmental reasons meant that the Hemp Homes required temperatures of 5°C and rising whereas the traditional houses could continue to be built at 2°C with a rising temperature. The heavy clay soil had exacerbated the problem and ground conditions had been bad, even though DCH had put in place some remedial measures. The sequence of construction and the increase number of man hours required for the hemp houses meant that the traditional houses were roofed in and being fitted out while the first hemp house was being finished off and the shuttering to the second hemp house was nearing complete.

This report includes data on the two hemp homes and two control houses up until 21st August 2001. The total recorded man-hours consumed on the 2 hemp homes was 2742 man-hours, over 428 man-days, this averages out at 6.41 man-hours per day (not quite double the man hours expended on the control houses and therefore well within the expected target. For the 2 control houses the total recorded man-hours was 1578 over 378 man-days, this averages out at 4.17 man-hours per day. The histogram above compares the overall performance for the four houses monitored against the target (the industry norm).

It is worth noting that on other sites significant savings in labour have been achieved and overall rates per m² of external wall are down to around 5 man hours including all placing of shuttering, casting and removal of shuttering.

The foundations to the hemp houses demonstrated a saving in soil disposal accounting for about half of the material (by volume) of the traditional houses as their excavations were both narrower and shallower. Remedial measures to remove a waterlogged top layer of clay, led to the need for several extra courses of brick in order to bring the plinth up to ground floor level. The use of the lime/hemp mix involved two mixing processes and it took time for this to become an organised and routine activity. The short 'shelf life' of the mix and the need for cumbersome protective clothing took some getting used to. The introduction of a special mixer helped the mortar mixing gang keep up with the bricklayers building the plinth.

The timber (balloon) frames for the Hemp Homes were constructed on site and stored in a compound until the scaffolding was erected. Prior to their assembly, the frames were stacked adjacent to the building plots and a crane was then used to lift the frames and roof trusses into position. The panels were positioned and fixed by the 'hemp team'. The need for greater accuracy in the construction of the brick plinth at the base of the walls was soon understood and the timber frames had to be packed up to ensure a level wall plate. Accuracy was doubly important because the slope on one side of the roof was to be continuous along a terrace of houses that was stepped, staggered and skewed on plan. Alignment was achieved after a little 'head scratching', the roofs were made watertight and the roof tiling to the first hemp house was laid.

The electrical conduits and back boxes were easy to install although the subsequent packing of the hemp around them and at awkward corners needed some care. The shuttering and casting of the hemp walling went well although it was slower than anticipated. At one stage, the special mixer had to be repaired. The supply of hydraulic lime ran out and more had to be imported from a new source in France. This occurred once the pipe-work and wiring were in place, floorboards were down and the lime skim coat was being applied in the first hemp house.

The CALIBRE Productivity Toolkit

As a direct result of the Building Research Establishment's privatisation in July 1997, ten new research centres were established. They were set up to focus on specific aspects of the construction industry. One centre was Centre for Process Improvement in Construction (CPIC) (now called Construction Consultancy) whose main task was to develop and use “real time” performance monitoring tools to measure on-site construction efficiency and objectively assess actual construction productivity and performance.

These assessments enable ‘inefficiency’ to be identified, actual progress to be compared with planned progress, benchmarks to be established and targeted, and used to set targets with the aim of improving competitiveness and performance.

The measurement tool used is named CALIBRE and was developed by CPIC from extensive experience gained by the BRE over twenty years for the measurement and productivity assessment of housing and school designs. The CALIBRE monitoring process is simple in use and is undertaken without interfering with the task being undertaken. The process has four main elements namely:

- Mapping the construction process
- Identifying and coding the packages and tasks
- Monitoring the site and factory construction process
- Analysis reporting and feedback

A CPIC team is usually on the construction site from day one of the project where it follows the entire construction process through to completion. Typically the monitoring and feedback is undertaken continuously from the moment the first operatives set foot on site to the last operative leaving site. Comprehensive training is provided to bring each observer up to the same high level of understanding, with a full time back up being provided by the Process Managers back at CC.

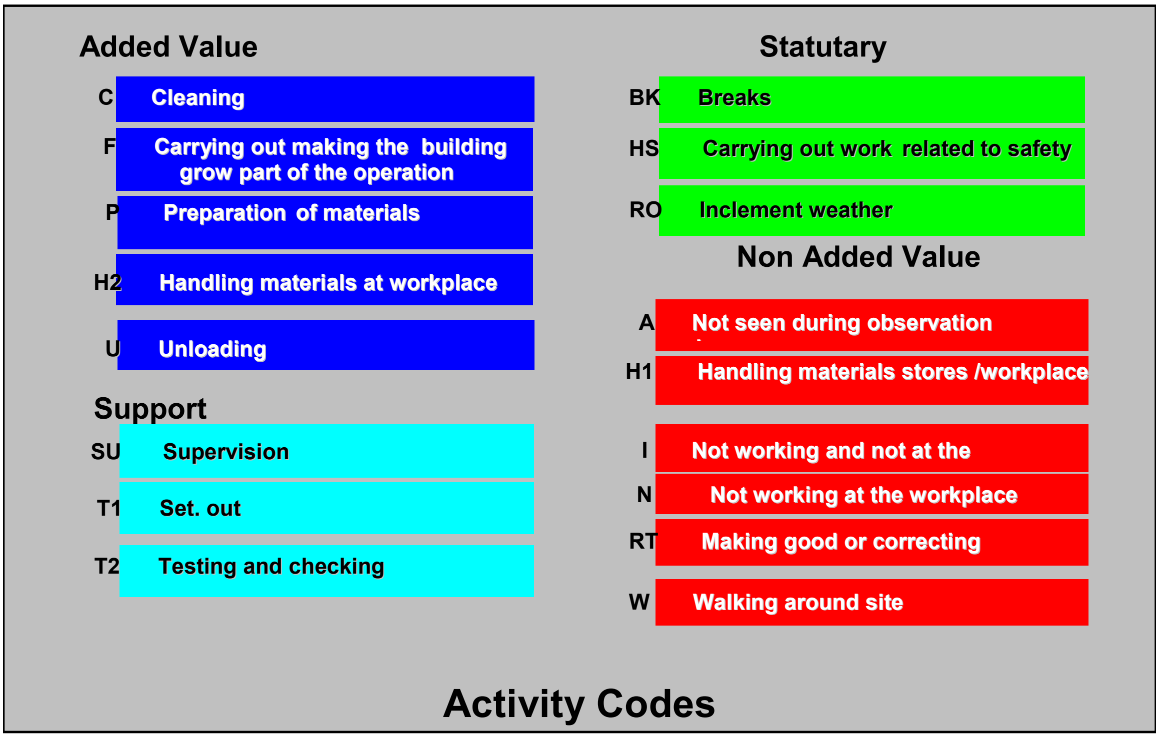
All software and hardware essential for the monitoring process is provided along with technical support from the BRE’S Information Technology department.

For each observation the observer records five attributes

- What each operative is doing to.
- Which element or work package.
- Where each task is being carried out.
- Who each operative is and
- When the observer undertook the observation round

The packages of work and task codes are allocated according to a CC developed National Work Breakdown Structure, these codes take into account the nature of the construction works, the levels of observed and mapped detail that are achievable and the need for code consistency between different projects. The coding system is sufficiently flexible for additional codes to be added when unforeseen tasks are observed as construction proceeds. The work monitored is categorised as Added Value Time, Support Time, Statutory Time or Non Added Value Time.

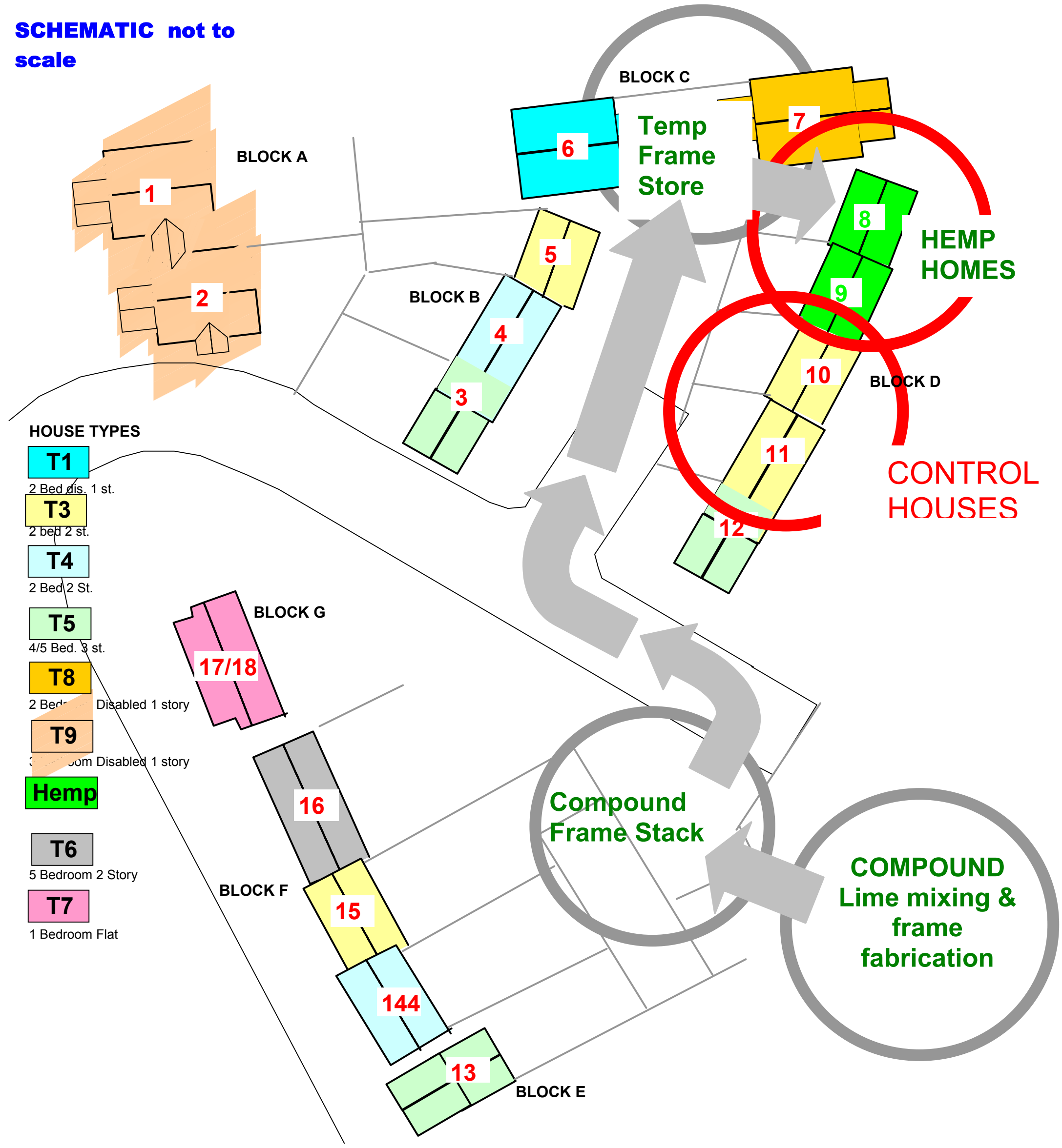
- Added Value Time is expended by operatives or plant on those activities that directly add value to the construction being undertaken.
- Support Time is spent on activities which directly support Added Value activities.
- Statutory Time is time expended by operatives that support legislation or regulations.
- Non Added Value Time is time expended which adds no value to the project.



Monitoring at Haverhill

This site consisted of 16 terraced houses and 4 bungalows. Most of the houses are of a traditional design and construction. The clients are Suffolk Housing Society and the main contractors are D C H. Two of the houses are being constructed in a novel way using a hemp and lime mix. BRE were monitoring these houses over a selected four month period and part of their brief was to study two control houses for comparison. The weather had been a huge problem during the early stages of construction and initially heavy rain and flooding made the ground conditions extremely difficult. Later, frost and low temperatures delayed work on the hemp homes, which have a 5ºC temperature limit unlike the control houses which have a limit of 2ºC. As a result, the monitoring has over-run to eight months, this report covers all stages up to first fixings for the control houses and the first of the Hemp Homes. It also includes the preparation work on the timber and the site assembly of the frames in the compound for the hemp houses.

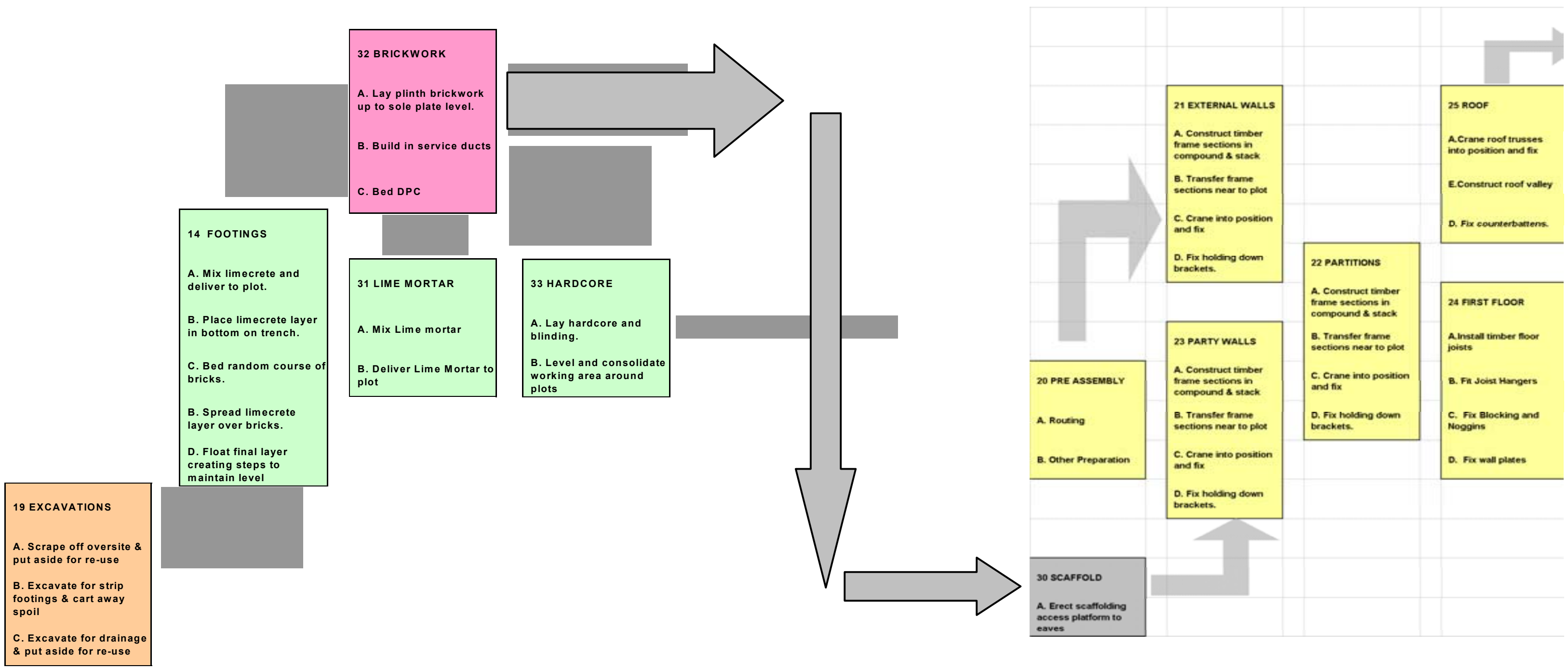
The schematic layout below illustrates the work areas for the on site fabrication of the Hemp Homes frames.


SCHEMATIC not to scale
BLOCK A
BLOCK B
BLOCK C
BLOCK D
BLOCK E
BLOCK F
BLOCK G
Temp Frame Store
HEMP HOMES
CONTROL HOUSES
Compound Frame Stack
COMPOUND Lime mixing & frame fabrication
HOUSE TYPES
T1
2 Bed dis. 1 st.
T3
2 bed 2 st.
T4
2 Bed 2 St.
T5
4/5 Bed. 3 st.
T8
Disabled 1 story
T9
Disabled 1 story
Hemp
T6
5 Bedroom 2 Story
T7
1 Bedroom Flat
1
2
3
4
5
6
7
8
9
10
11
12
13
144
15
16
17/18

The Hemp Homes Processes

The Process Map below illustrates packages and tasks that were monitored

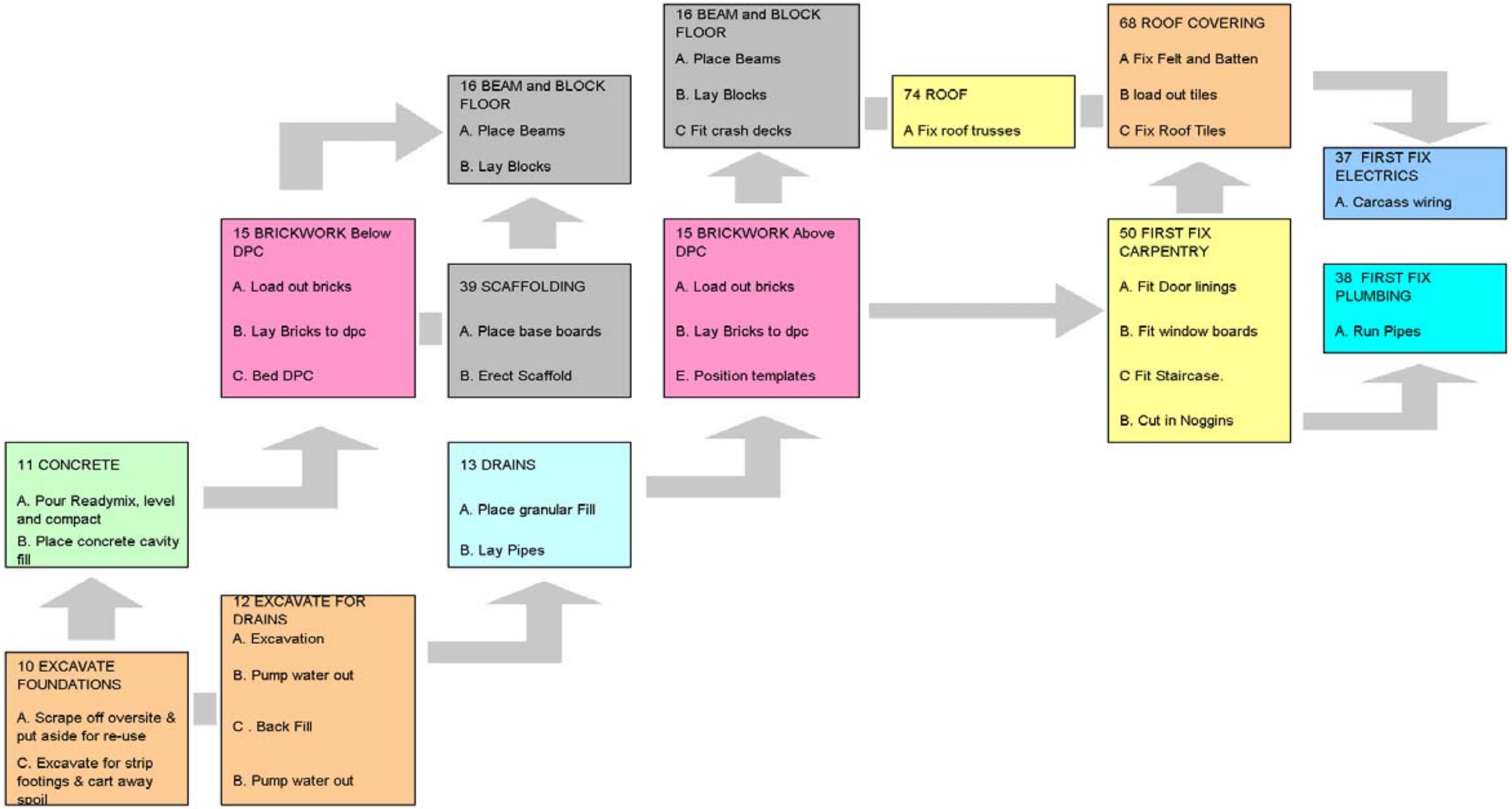
This diagram is the process map up to the completion of the timber frames for the Hemp Homes. Each box represents a package and contains the task level breakdown monitored on site.



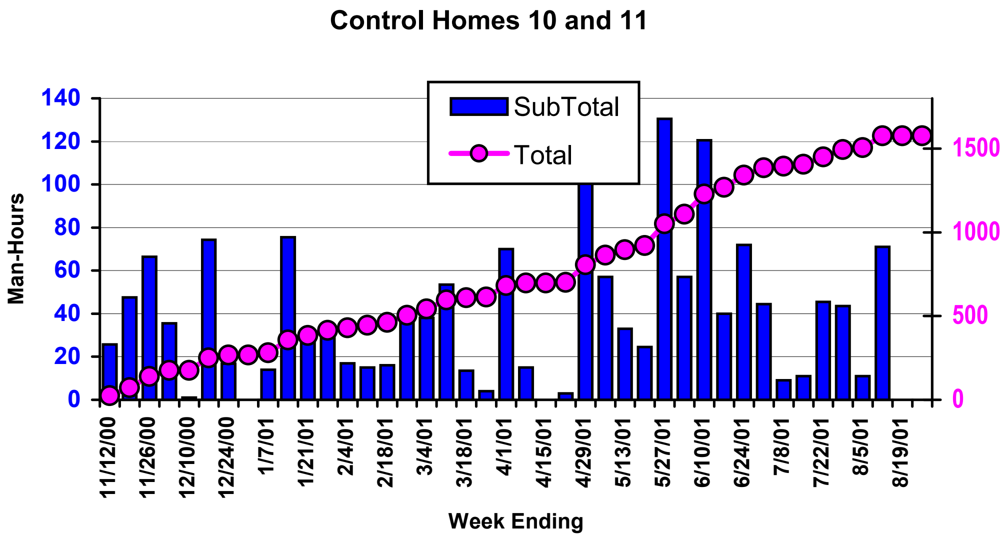
The Control Homes Processes

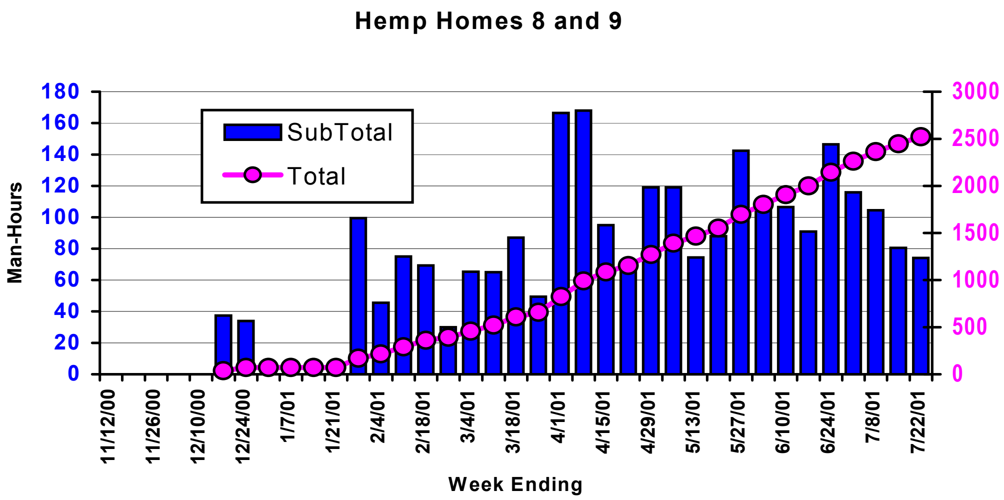
The Process Map below illustrates packages and tasks that were monitored

This diagram maps the processes up to the fitting out stage of the control houses, each box represents a package and contains the task level breakdown monitored on site.

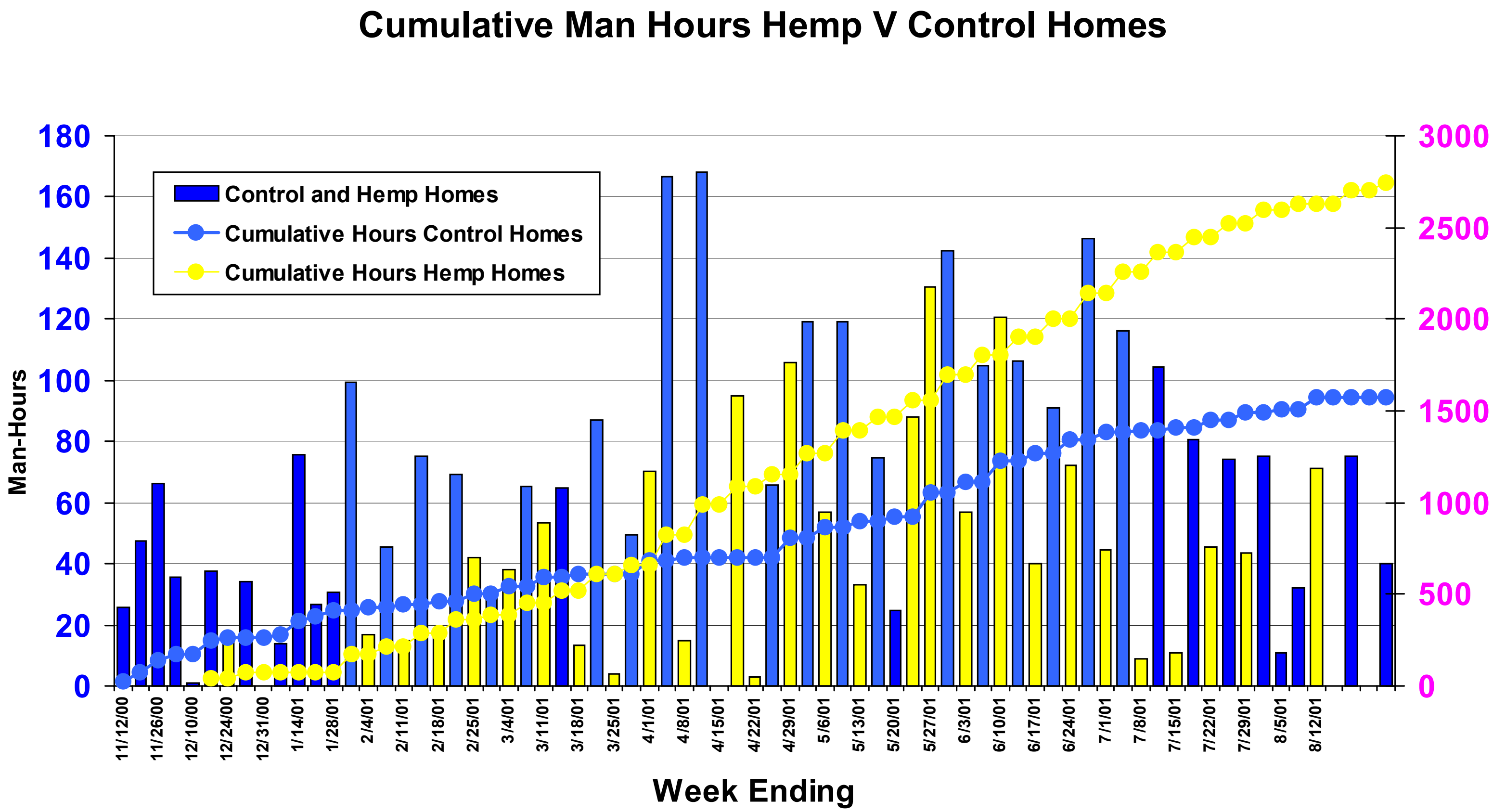


Total Man Hours Input to Hemp and Control Homes





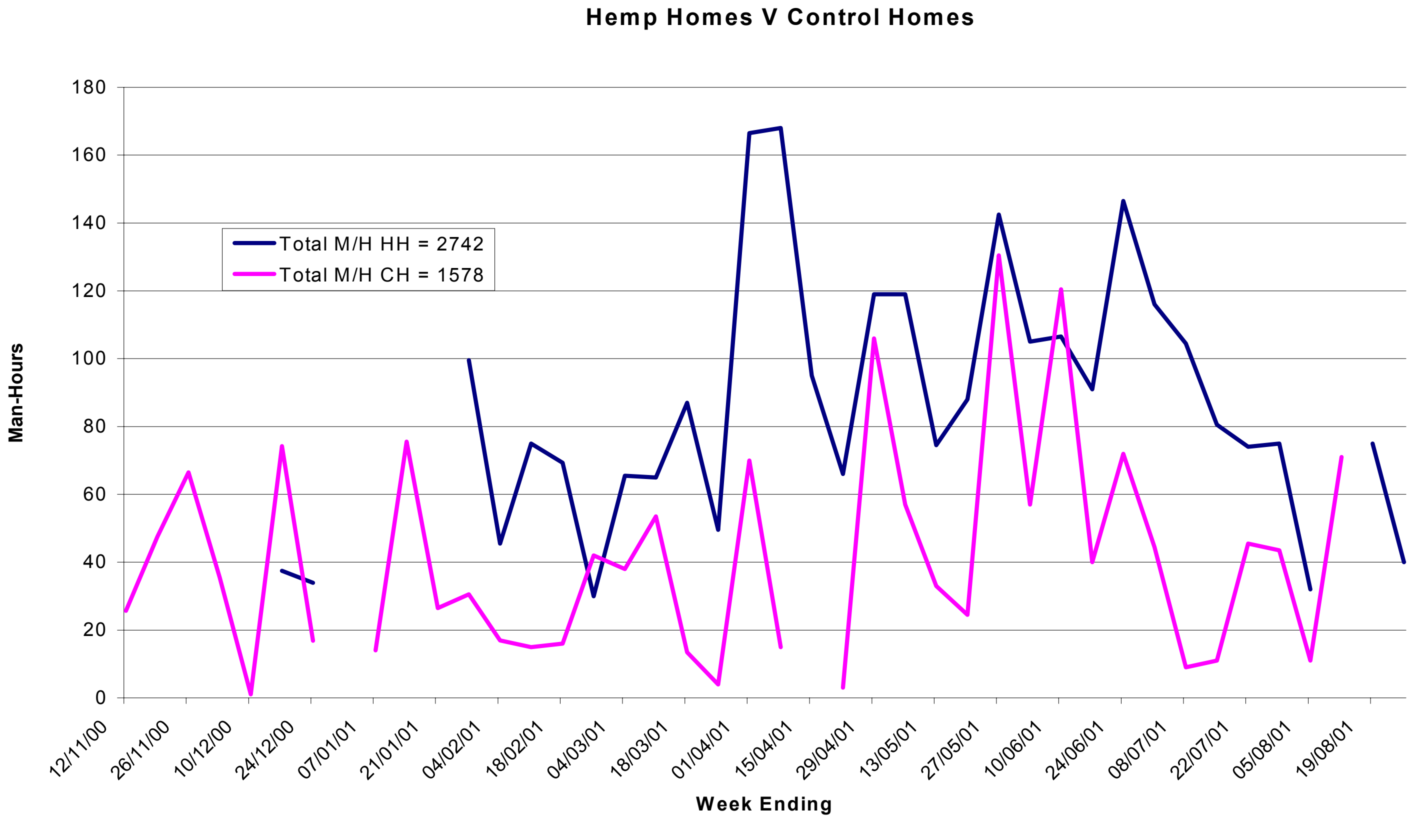
These Histograms present the weekly recorded data for the two Hemp Homes and two Control Homes. From week-ending 12/11/00 to week-ending 26/08/01.



Comparison of Man-hours (Hemp V Controls)

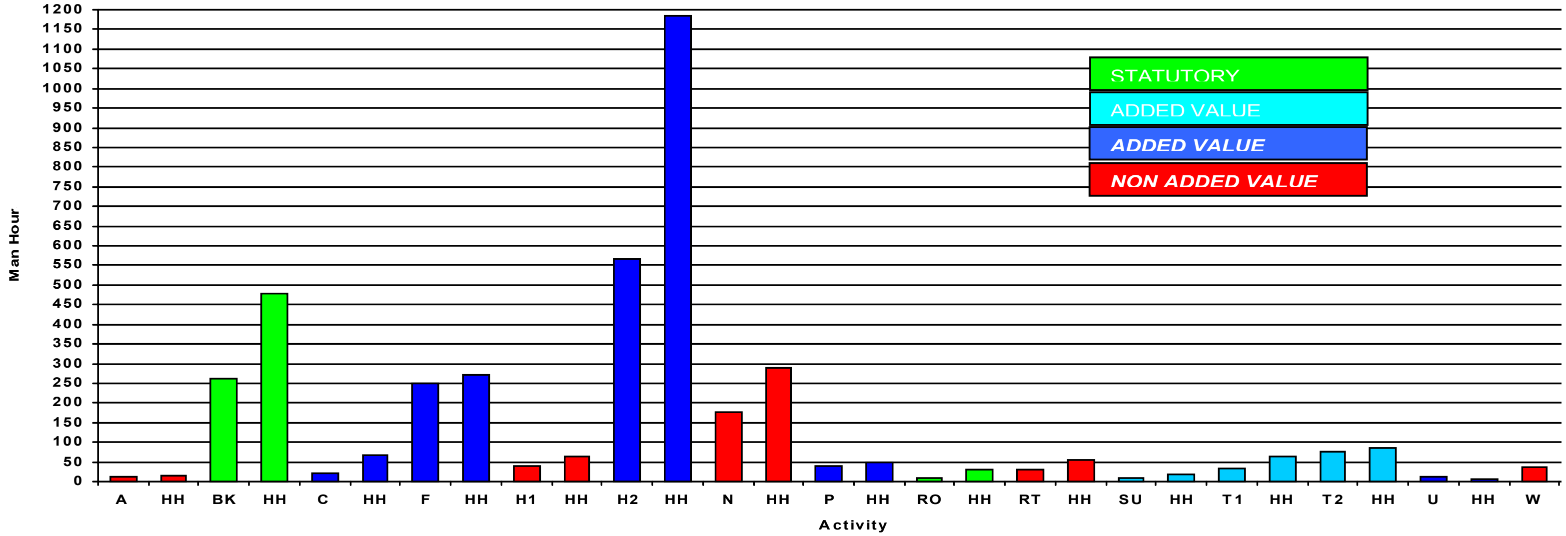
The Histograms present the week-ending records of manhours up to the week-ending 26/08/01. The blue bars represent two hemp homes and the yellow bars represent the two control homes for that period monitored.

Note: These hours do not include extra hours in different location on site which might be related to these houses.



The line graph above shows the weekly man-hours spend on these specific houses (two Hemp and two Control).

Total Activity Breakdown (Man-hours) Hemp and Control Homes



This histogram shows the number of man-hours monitored for the whole site in each of the activity categories. The columns are arranged in pairs with the left hand column of each pair representing the two control houses and the right hand column of each pair representing the two hemp houses. The right hand column of each pair is identified (HH). The left hand column of each pair is identified by the activity code which applies to both columns within the pair. These codes can be identified from the lists given earlier in The Calibre Productivity Toolkit.

The biggest work packages monitored were those of the bricklayers and they have helped to bring the non value-added percentage down from 21% to just 20%. Some notable results are 1751 Man-hours for (H2) handling at the work place, whilst 103 man-hours (H1) were recorded double handling, 90 man-hours (P) spent preparing, 262 man-hours (T1 & T2) measuring and checking, 20 man-hours (U) unloading and in the non added-value categories we also have 465 man-hours (N) not working at the work place and 85 man-hours (RT) re-work. The overall breakdowns here to the right show the actual percentages to compare with the target norms for the industry.

Hemp and Control Homes Pictures – during construction

Figure 1 The timber frame during erection.

Figure 2 Tamping the hemp/lime into the shuttering

Hemp and Control Homes Pictures – interiors

Figure 3 Ground floor interior near the completion of the 'shell'

Figure 4 Wiring and construction of interior partitions

Hemp and Control Homes Pictures – nearing completion

Figure 5. Hemp Homes on 12.06.01

Figure 6. Traditional houses nearing completion

The Site Story

Substructure.

Setting out

The JCB wheeled digger was used to reduce levels, scraping off an area of wet clay to enable the engineer to set out the excavations

The excavated soil was put to one side or loaded into the dumper, then tipped onto the spoil heap, and later carted to a landfill site. At regular intervals the trenches were checked.

Footings

The operatives shovelled limecrete into place, bedded bricks in it, and then spread more limecrete which was then given a floated finish. Stepped brick courses were then built off of the limecrete strip to economise on the material content of the construction.

The foundations were then covered to protect then from rain, frost and snow .

The mortar for the brick plinth involved a lime based mortar (Hydrated Hydraulic Lime) instead of cement. It was mixed using a special Creteangle mixer.

Building brick plinth

The footings were cleaned off . The layout involved steps & staggers. Frost resistant bricks were used below ground level and facings above

Frame

- Fabricating the frames
Only the internal wall sections of the timber frame needed routing out to improve the bond with the hemp mixture.
Platforms were constructed from which to assemble the studs.
After fabrication the frames were stored in the compound prior to erection .
- Pre-assembly stage
Once braced, the frames were moved from the compound by a fork lift with a crane jib attachment.
Scaffolding platforms were put in place
- Assembling frames
A crane was used to lift the frames over the top of the scaffolding into temporary positions.
The frames were then repositioned and fixed with holding-down straps.
- Constructing roof
The roof trusses were delivered to site and at a later stage lifted by crane onto the scaffolding round the Hemp Houses. They were then manually handled into position.

Causes of Inefficiency - Hemp Homes

- Design issues

Plan form (steps and staggers) and associated construction difficulties.

The assembly team had great difficulty in predicting the eaves detailing.

- Site Management issues:

Accuracy in setting out the foundations.
Training.
Material shortages.
Double handling.
Slow program.

- Foundations setting out.

Repeat work.
Better planning.
One digger was taking out the pegs for the other digger.
Ground conditions were bad.
Need for supervision.

- Accuracy;

Errors in layout and level..
Difficult layout.
Ground conditions.
Use of unfamiliar materials.
Steps in the foundations.
Simpler plan form

- Training.

Learning curves too shallow.
Insufficient training prior to project.
Changes in assembly team.
Each stage was a new experience.

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- Material shortages;

Ran out of hydraulic lime - difficult to measure exactly its rate of use and the need for a better appreciation of the circumstances affecting its procurement.

- Double handling;

Double or possibly multiple handling of frames eg frames fabricated in a compound then moved to a storage area, then moved again to a temporary stack and only then lifted into place before adjustment and fixing.

- *Slow program;*

Work was constantly behind program (even adjusted) owing to bad weather. Very bad ground conditions, no incentive to maintain momentum of the work and no benchmark to provide a target to work to.

- *Method of work issues :*

Accuracy;
Multi-skilling.
Need for pre site training..

Figure 7. Methods of work

Materials Waste Study

BRE was asked to audit the material waste quantities and the causes of the waste during the construction of two hemp houses (Plots 8 & 9) and two traditional control houses (Plots 10 & 11). BRE used their SMARTWaste tool to undertake this audit using an on-site observer. The observer was supported by a BRE Environmental Manager.

Unfortunately, the financial resources available for this study only allowed effective monitoring of materials waste for 20 weeks of the construction project which lasted approximately 40 weeks. The project had been planned to last 14 weeks.

Bad weather, associated problems and delays extended the period of construction and therefore the period of monitoring necessary for a comprehensive study to be completed. This, coupled with the shared use of an observer between studies (ie CALIBRE and the Material Waste Study), a fixed budget and the availability of suitable observers for the extended period prevented the collection of a comprehensive or conclusive set of data.

The construction work performed at the end of this study (referred to as a waste audit) had only progressed to the stage where the walls of the first hemp house had been filled with hemp mix and the first fix electrical and plumbing work was complete. We cannot be certain about the extent of progress on the control houses at the time that the study stopped but from waste reports it appears to have reached the stage where roof tiling had just commenced.

The reported waste generated up to the point when the Waste Study stopped was 22.1m^3 for the hemp houses and 31.8m^3 for the controls. These figures include all the top soil removed from the plots prior to construction, whereas the actual material waste generated by the actual construction process during the period of study was approximately 4.5m^3 and 4.2m^3 respectively. However, without knowing whether the control houses were at exactly the same stage of construction the figures are of little value. Furthermore, the use of hemp-based materials in the hemp houses (eg the internal linings to walls and hemp to the floors) is known to have continued beyond the period of this waste study.

The SMARTWaste report produced at the end of the 14 week monitoring period indicates that :

- The mass of waste identified up to the time of reporting had been inert excavation material, but that it also included minor amounts of packaging, ceramics (brick, tile, etc, timber and plaster & cement products.
- The main cause of waste had been excavation (87% of the waste), along with a lesser amount of recyclable or re-useable materials. The latter of these are typically bricks, blocks, timber studwork, sawdust, empty lime/cement bags, copper pipes, plastic conduits, plywood, mortar and pallets.
- Excavated material from the hemp house/houses was considerably less than that from the traditional house.
- Other than excavated material, waste from the hemp house was mainly related work, packaging, and off cuts. Reasonable quantities of waste resulted from brickwork and carpentry eg timber shuttering.
- Other than excavated material, waste from the traditional houses tended to involved off cuts, damage and packaging, particularly off cuts of brick and block.
- The types of waste listed might be expected given the stages of construction covered by the period of waste monitoring.

Although no real conclusions can be reached from this study, one point worthy of note is that unused lime can be “knocked up” again and reused, timber is untreated and can be burned and the packaging is mainly paper which can be recycled.

Material tests

Compressive strength tests were carried out on the hemp matrix material. The test material was not collected from that produced on site but mixed separately at BRE at a later date.

The original intention was to test the hemp matrix to BS 4551 in accordance with the normal procedures employed for mortars.

However, the early tests showed that this was not always appropriate for the specimens because, in one direction of loading, they were highly compressible and demonstrated a high degree of recovery.

Consequently, Materials Laboratory Services at BRE considered that compressive testing based on BS ISO 844: 1998 for cellular plastics could be applied to the supplied specimens of this material whichever orientation was presented for loading.

It specifies a rate of deformation rather than a rate of load increase, and provides for a stated "test result" determined by the nature of the specimen's response.

Thus, a conventional rise of sustained load to a definite maximum, followed by a "failure" indicated by collapse or continual decrease of sustained load, would be reported in the conventional manner of Compressive Strength, ie maximum load divided by specimen area subjected to this load.

This would be expected from specimens loaded perpendicular to the main direction of hemp compaction during casting. That is allowing any "layering" resulting from the compaction process to burst apart by separation of the "layers" in response to test load applied to the "ends" of the layers (at a fixed rate of specimen deformation).

However, an apparently endless deformation continuing beyond 10% of the original specimen thickness, with no maximum value of load as described above, gives rise to a stated result of "Compressive Stress at 10% relative deformation" by quoting the load reached at that deformation divided by original specimen cross-sectional area. In such a case, the load considered for an originally 100mm thick specimen would be that sustained when it has deformed to a thickness of 90mm.

This would be expected from specimens loaded in the same direction as that in which the compaction process was applied, the predominant orientation of the "layers" resisting lateral bursting during load application, yet allowing continual "squashing" of the material.

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.

However, it should be noted that the orientation of the hemp fibre was not reliably identified in relation to the direction of the loading. All of the testing was performed on dry samples.

Water Spray Tests

Introduction

BRE Scotland was asked to carry out some water penetration determination tests on walls constructed from a mixture of hemp and lime mortar. The test walls were made by a member of staff from BRE Centre for Whole Life Construction and Conservation and the render and limewash coatings applied by BRE Scotland staff.

Test Samples

The test samples were made using a mixture of hemp and lime mortar placed in moulds to form small test walls of dimensions 500x500x200mm. Four walls were made for testing and left for a period of several months before a 10mm coating of lime mortar render was applied. The render, when dry, was noted to have cracking which was repaired by filling the cracks with lime paste. After the paste had fully dried and cured, over a period of several weeks, the render was given a brush applied limewash coating. The test samples were then placed in position on a water spray rig (Figure 1) to test the resistance of the material to water penetration from simulated wind driven rain.

The tests

The water spray test was originally designed by BRE to supplement results gained from testing water repellents by methods specified in BS 6477:1992 - Water repellents for masonry surfaces. The spray test itself is not part of any British Standard test method.

The rotary spray apparatus constructed at BRE Scotland sprays a ring of test walls built on a 3.6m diameter circular brick base. The test walls are placed 0.7m from the water spray nozzles and the rotating action produces water droplets that hit the test wall surfaces with a force similar to that of wind-driven rain (driving rain). Wind pressure differential between the front and rear surfaces of a masonry wall is not simulated in this test.

The spray apparatus was developed to test, in simulated conditions of severe driving rain, both the effectiveness of water repellents on building materials and the leakage through the mortar joints of masonry walls

Spraying was set for each 4 day test period at a flow-rate of 210 litres/hr. Water from the 4 day period, collected at a test wall surface via driving rain plate gauges, was equivalent to 3670 mm (3670 kg/m^2) of wind-driven rain. Annual figures for on-site measurement of wind-driven rain from the south-west quarter have been recorded as 2100 mm (2100 kg/m^2) for an open moorland site 330 m above mean sea-level and 700 mm (700 kg/m^2) in a semi-urban location 174 m above mean sea level. Both locations are in, or near to, East Kilbride (near Glasgow) and have the prevailing wind from the south west.

Therefore, over the spray period of 96 hours the test walls were sprayed with a minimum of one year's wind-driven rain similar to that at a severely exposed location, or 5 years at a less exposed site.

Test results

On completion of the 96 hour water spray test there was no evidence of water penetration through the complete thickness of any of the four test walls. Interim observations during the test period demonstrated the following:

- After 2 hours water spray no water absorption (visible dampness) was observed within the hemp walls (behind the rendered face) for each of the four test walls.
- After 24 hours water absorption (visible dampness) was observed within the hemp walls to an average depth of 20 – 40mm behind the rendered face of each test wall (see Figure 2).
- Beyond the first 24 hour water spray period the depth of water absorption for each subsequent 24 hour period further increased by approximately 10 – 15mm.
- After 96 hours, at the end of the water spray test, water absorption was observed within the hemp walls to an average depth of 50 – 70mm behind the rendered face of each test wall (see Figure 3).

The results indicate that provided the render coating remains well adhered and crack free it is unlikely that rain penetration will transverse the complete thickness (200mm) of the hemp/lime mortar wall.

Figure 8. Hemp walls (foreground) positioned on water spray rig

Figure 9. Water absorption depth after 24 hour water spray

Figure 10. Water absorption depth after 96 hour water spray

Acoustic performance tests

The BRE Acoustics Centre carried out measurements on 29 November 2001 after completion of the houses and prior to occupation.

The BRE Acoustics Centre holds UKAS accreditation for the measurement of sound insulation in the field. The measurements were conducted using the procedures accredited by UKAS.

The measurements of airborne sound insulation were made in accordance with BS EN ISO 140: Part 4 (1998). The single number quantities for sound insulation were calculated in accordance with BS EN ISO 717: Part 1 (1997)

Sound insulation measurements were undertaken between four pairs of horizontally adjacent rooms. Two between one pair of brick built homes with a large step and stagger and two between one pair of homes built using the hemp wall construction also with a large step and stagger.

The construction tested was as follows:

- The partitions between Plot 10 and Plot 11 were of traditional masonry construction with a large step and stagger and comprised cavity blockwork party walls. External walls were of brick outer with rockwool linings and concrete block inner leaf.

- The partitions between Plot 9 and Plot 8 were of hemp construction also with a large step and stagger. These partition were built using 100mm x 50mm timber frames at 600mm centres and constructed on site using plywood shuttering to form the Isochanvre (hemp/hydraulic lime plus water)/lime mix in two 150mm thick leaves either side of a 75mm cavity. The finished density of the mix is 550 kg/m3. The shuttering was moved up as the build progressed.
- The interior walls in Plot 8 were covered with a lime plaster finish while those in Plot 9 were left in an unfinished state exposing the open hemp construction. As a consequence an improvement in absorption within the rooms of Plot 9 was noted. External walls are of 200mm solid hemp construction with a 10mm hydraulic lime render.

There is a 450mm vertical step and a 833mm horizontal offset between each of the houses. There is thus a reduction in common area between the party walls.

In summary, the results of the tests indicated good airborne sound insulation performance for the separating walls between the traditionally built homes. The performance for the separating walls between the hemp built homes was some 6dB less on average but still well in excess of the standard normally considered “reasonable” within the Building Regulations 1991 (Part E Schedule1).

However, it should be noted that the vertical and horizontal offset (step and stagger) within the design of the building (ie a terrace of houses) resulted in an extremely reduced common partition area. This is likely to have had a favourable influence on the measured sound insulation performance which may thus be reduced for different design layouts.
Given the technical nature of acoustic results, the following information is provided to assist the understanding of the reader.

The sound insulation performance of a floor or wall will vary with the frequency of the noise. In order to simplify such effects the performance is normally expressed in terms of a single number quantity that takes into account the range of frequency variations compared to a standard frequency performance known as a weightings curve.

For walls the sound insulation can be expressed as the airborne performance in terms of DnT,w, a single-number quantity which characterises the sound insulation between rooms as a weighted level difference.

The performance of a partition can be compared with the recommendations contained within the Building Regulations 1991 (Part E Schedule 1) however it should be remembered that these recommendations do not give a numerical performance value for the post construction sound insulation testing. The stated requirement is that a separating wall should resist the transmission of airborne sound.

To enable the acceptance of new and innovative constructions the Approved Document provides a test method and performance criteria for new properties (Section 3). These criteria are sometimes taken to indicate “reasonable” sound insulation.

For the insulation of walls against airborne sound Section 3 (new build) of Approved Document E requires tests in upto 4 pairs of rooms. As they were two different types of construction, strictly speaking the test looked at 2 pairs of rooms for each. However, this does not change the conclusion.

The requirement is that the mean sound insulation should not be less than 53 dB with no example less than 49dB DnT,w,. The Table below demonstrates that the sound reduction at ground and first floor levels for both types of construction exceed this performance criteria with a mean of 57.5 dB DnT,w, for the hemp construction and 63.5 dB DnT,w, for the traditional construction.

It should be noted that where less than 4 pairs of rooms are tested, the values must meet the mean values quoted above.

It must be stressed that the numerical results obtained during this visit are not in themselves evidence of compliance or non-compliance with Building Regulations.

Test No	*Source Room*	Receiver Room	$D_{nT,w}$ (C ; C_{tr}) (dB)
	Traditional Construction		
01_0070	Lounge, Plot 10, Park Road	Kitchen, Plot 11, Park Road	**63(-1 ; -5)**
01_0071	Bedroom, Plot 11, Park Road	Bedroom, Plot 10, Park Road	**64(-1 ; -5)**
	Hemp Construction		
01_0072	Lounge, Plot 8, Park Road	Kitchen, Plot 9, Park Road	**58(-1 ; -5)**
01_0073	Bedroom, Plot 9, Park Road	Bedroom, Plot 8, Park Road	**57(-2 ; -6)**

Table of results for the Acoustic tests.

Monitoring of internal conditions

The temperature and humidity were monitored in all four houses – two traditional and the two hemp houses - during a four month period from December 2001 to April 2002. This period included three months during which one hemp house and one brick house remained unoccupied.

Looking at the data collected using thermal and humidity loggers we find that the temperatures maintained in the hemp houses have been consistently one or two degrees higher than in the brick houses for the same amount of heat input.

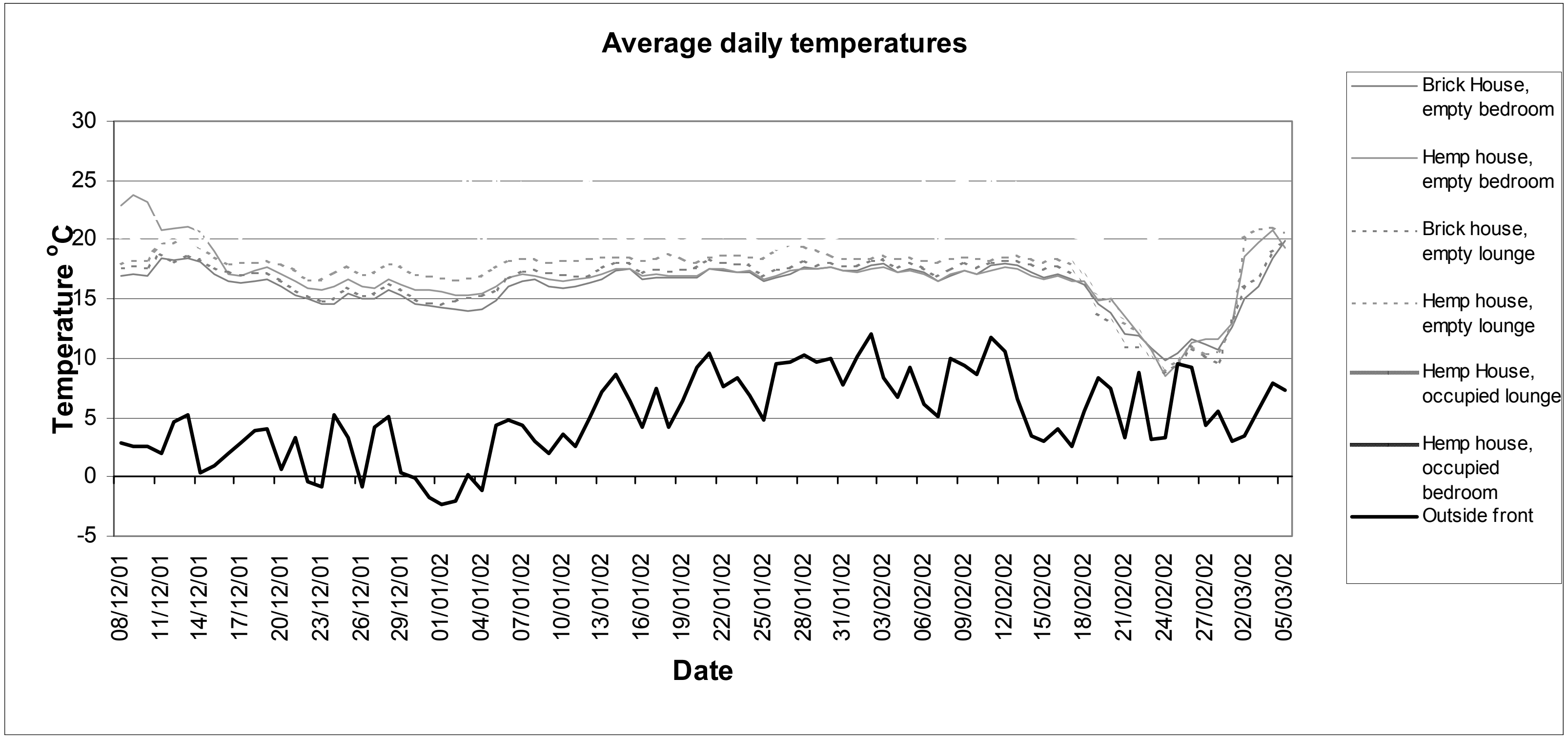
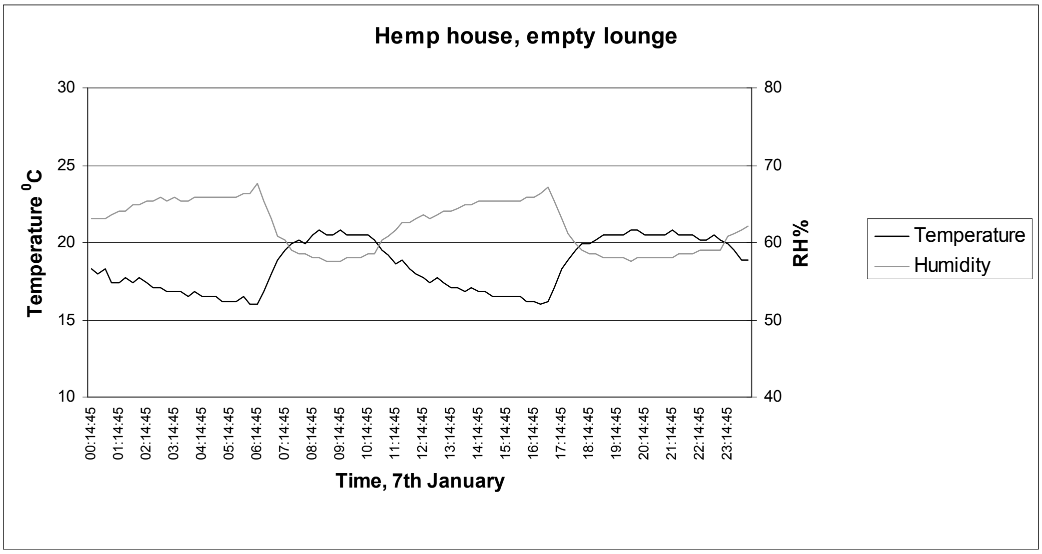


Figure 11. Graphical summary of the temperature readings at Haverhill



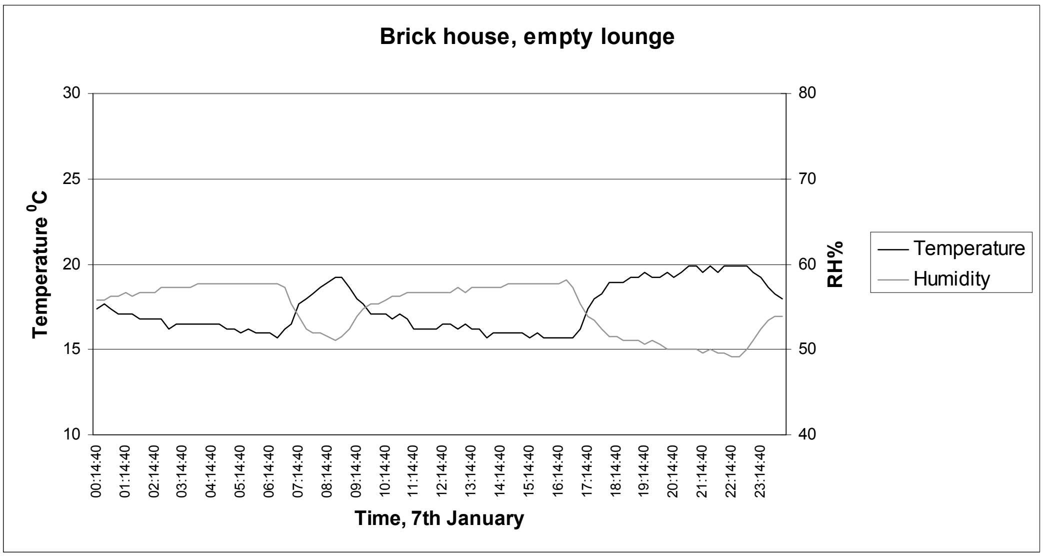


Figure 12. Comparison of the temperatures and humidities in the lounge of the traditional brick house and the hemp house – 7th January 2002

Understanding the use of Hemp

The aim of this section of the report is to provide a rudimentary indication on the sort of issues and parameters likely to be relevant to those considering the use of hemp as a method of house construction. The information in this section is compiled from a mixture of sources including unverified comments, opinions and experiences.

Why build Hemp houses ?

One of the main reasons for using hemp is that " hemp construction" is considered environmentally friendly and highly sustainable. This is in part due to the fact that Hemp can be grown in the UK in four months and Isochanvre can be produced in UK under licence from that part of the plant which is currently considered a 'waste product'. Amongst the other reasons put forward are:

- Extremely low embodied energy to the hemp (1.15 kw/m³) and significantly lower embodied energy to the lime than conventional masonry materials
- Savings can be achieved in relation to the amount of excavation required. From BRE observations, one notable advantage of this form of construction over the conventional houses was a reduced requirement to dig and a 50% saving in the amount of soil disposal resulting from the construction of the foundations.
- Although this type of construction entails differences in process, the skills required in building the hemp house are not radically different to some of the well established craft skills employed in concrete work and carpentry in the UK. The degree of accuracy required for the construction of the structural timber frame is generally achievable with on-site processes.
- The lime / hemp slab forming the ground floor is considered to be vapour permeable but water resistant and is unlikely to require the inclusion of a damp proof membrane in most circumstances.
- That the use of lime provides protection to the timber frame in terms of resistance to rot and that consequently the framing to the external walls is thought unlikely to need additional protection in the form of timber treatment
- That the lime/hemp matrix used for the walling is considered to be resistant to fire and vermin.
- That the hemp and lime walls are breathable giving the completed hemp houses a pleasant and slightly more rustic feel. They even have some exposed timbers internally.

When to build

The effect of temperature is very important both for the ‘setting’ of the hydraulic lime and for the drying out of the walls after construction. Work should be programmed so that the stages of construction that involve the mixing, placing and curing of the hemp matrix occurs in the better months of the year. The temperature needs to be above 5ºC and rising.

Where to build

There are no limits to where hemp houses can be built.

What you need to build?

- Standard or specially adapted pan mixers for mixing the hemp and lime conglomerate Creteangle Model L mixers were adapted with a single paddle in place of the standard two paddles
- Personal protective equipment to include goggles, masks and long armed gloves to protect against the corrosive effects of the lime.
- Shuttering and tamping tools
- Trestles

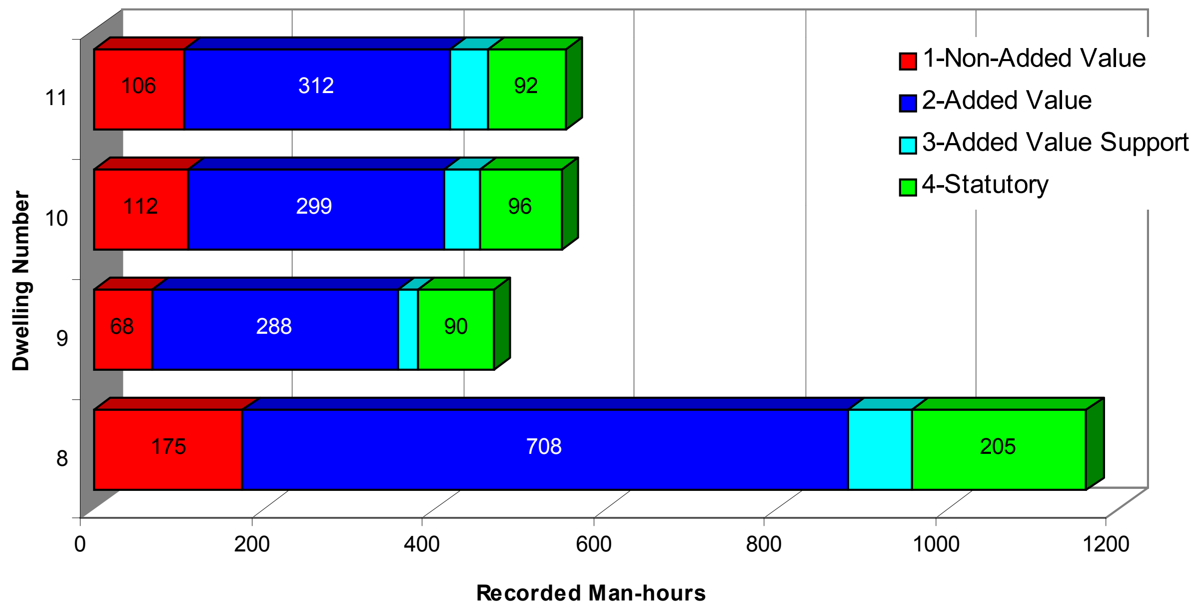
People

A key requirement is to have a building team that have been well briefed in the method of construction and use of materials in advance of the construction work.

The labour input might be expected to be in the region of 5 man hours per m² of 200mm thick solid wall construction with proportionately less for 100mm thick walls

The BRE monitoring suggests a total man-hour input of well in excess of this on the Haverhill site for the first house.

The labour input for the construction of the two types of house at Haverhill as summarised in the following diagram.



The reduction in the time taken to construct House 9 is due to two factors. The first is that House 8 has a gable end which increases the amount of construction work. The second and more important is that it is clear that the builders 'learned' on the first house and were able to put this into practice on the second one – it is reasonable to expect some further savings (in time and labour costs) if more houses had been constructed using hemp.

[Note the total for house 9 is probably underestimated by around 60 hours because the fitting out was not complete at the time the recording stopped – but this still makes the time very comparable with the 'traditional houses'.]

Health & Safety – use safe procedures

It is important that all necessary health and safety procedures are followed, in particular special attention must be paid to the use of hydraulic lime and safety sheets should be obtained from the supplier and appropriate personal protection equipment must be worn/used.

The process of building

Delivery and storage of hemp

On the project at Haverhill, the hemp arrived packed in paper sacks weighing around 10kg and containing 0.1m³ material. The sacks were of heavy weight paper and water resistant but could not be left outside unprotected because of potential / likely attack by rodents that find hemp seed nutritious and also because rain will damage the material if it is left exposed for long periods. The handling of these bulky sacks, which was all done by hand, is an issue in terms of process efficiency. The protection of the sacks during storage is an issue in terms of material waste. There is scope for improvement in both cases.

Shuttering

The shuttering used at Haverhill was cumbersome, and involved mainly half sheets of ply, with screws to fix it to the timber frame, temporary blocks, jointing battens etc. The division of labour associated with the shuttering and casting was also an issue as the carpenters were content to do their shuttering work, but were not prepared get involved in the casting of the hemp. This contributed to a lack of continuous working and men sitting idle.

Modece Architects have had numerous discussions with the shuttering manufacturers about developing a modular, plastic shuttering system which clips together and can be clipped onto the timber frame without the need for screws, cutting sheets of ply, temporary blocks and difficulties associated with joints. So far there has not been sufficient time or the resources to develop anything along these lines but the architects believe this should be a priority issue and would reduce the man hours per m² of wall construction by as much as 30%. This potentially takes the number of hours required well below those for the 'traditional' houses at Haverhill.

Mixing

The mixing process at Haverhill was carried out using a pan mixer made by Creteangle, and adapted so that the paddles would not allow the coarse particles of hemp shiv to clog up the machine. However, the mixer used at Haverhill had a relatively small capacity (about 0.06m³) which was sufficient for a 3 man gang but would not keep a larger gang working efficiently. The mixer was a model L weighing around 500kg. It was difficult to move.

The optimum would be to have a mixer of the same type but of larger capacity providing it could be operated and emptied by people without lifting gear. Anything heavier than the mixer used at Haverhill would present difficulties on wet ground etc.

Another alternative might be some kind of silo mixer where the feed and output are more constant, such as where the feed to the mixer might be via hopper and funnel and where the mix could be pumped from the mixer through a tube to be placed in the shuttering. The problem with pumping through a tube is that lime is much more sticky than cement and could very quickly block the tube and regular flushing with water would be necessary. This water could be reused in the mix as lime is capable of being knocked up again and again.

Without practical trials or further experience we cannot be conclusive. The mixer used at Haverhill seems to be an efficient mixer and appears relatively easy to operate. Its fast rotation means that it has a much shorter turn round time (around 3 minutes) than a conventional mixer which has a turn round time of about 8 minutes. However, a hopper feed might make operation easier.

Casting the hemp into the shuttering

At Haverhill, the mixed hemp was turned out of the mixer into a wheelbarrow. The mixer was easy to use and clean owing to the design of the paddles : unlike conventional Belle mixers where lime builds up and needs to be regularly scraped off the sides of the mixer.

From the barrow the mix was either tipped into the shuttering via bucket or shovel, which was quite labour intensive. If the shuttering had been constructed with the furthest sheet rising higher than the nearest, then the mix could have been discharged (from the mixer or barrow) against the higher of the two sheets. This would have eliminated waste. It can be scooped up off the floor and reused if necessary but a system to reduce spillage in the first place would appear to be more efficient. The difficulty arises at the top of the cast where it is not possible to feed the hemp mix in from above (eg internal walls) and in this case it has to be manually cast – this is possible and not particularly time consuming but a culture shock for many builders. Once the mix is in the shuttering (to a depth of no more than 600mm -arm length), it needs to be quickly and evenly spread and then lightly tamped down. This can be done with a purpose made tool of timber or metal which is sufficiently heavy for tamping without the application of unnecessary force by the user. Many builders apply too much force when tamping because they think the material needs to be firm. In fact, it should remain relatively open and not too dense, particularly in the core, as this slows the drying process.

The timber frames to the walls should be designed with long, unobstructed spaces between studs and with no horizontal obstructions (such as noggins) and floors hung inside the frame – this is something which does not come naturally to builders and requires considerable forethought. The reason for omitting all horizontal obstruction is that the mix has to be pushed in under them and this can be difficult and time consuming.

Sequence of work

It was found that it is easiest to build the timber frames on the ground and rear them up in sections – which are then easily joined together. The roof should be put on early in the job, but the timber frame needs temporary diagonal bracing to stabilise it until the hemp is cast. The roof covering can be put on to allow work to continue under cover and in the dry although the lower edge should not be fixed if casting at the top of the wall is not to be obstructed. It is then best to strike scaffolding as it is much easier to continue working without the obstruction it otherwise presents. Work that then needs to be done at first floor level can be performed more freely from movable forms of scaffolding. However, most of the subsequent work can be completed from the first floor within the building.

It should be possible to complete a lift of hemp (cast into shuttering in 600mm lifts - half a sheet of ply) to one house with a gang of 3 people in one day. The shuttering is then removed (no need to wait) and lifted up ready for the next days casting. The speed of repositioning the shuttering is critical for efficient working and this often slows the rate of work. The casting can be performed relatively quickly as long as the system is set up to achieve this and there is no reason why a whole two storey houses cannot be cast in 8 – 10 working days. Indeed it is preferable to work quickly in order to avoid over tamping and also to ensure rapid and even drying.

Conclusions

Modece architects would prefer to have a prefabricated shuttering system available for this work, a mixer which can be fed from a hopper, and possibly some form of tube and pump to get the wet mix from the mixer to the shuttering. A mechanical tamping tool might also speed things up.

The other issue that needs to be addressed is the drying out time for the houses - in warm summer weather this is around 8 weeks for a 200mm thick wall in a well ventilated environment. But in the winter it can take several months and with still winter air there can be discoloration to the surface (not a problem but unsightly) so it does appear that work should be done from February through to September and not during the winter. The manufacturers are beginning to realise that users are placing their orders in the summer for this reason, and there is relatively little activity during the winter months.

Cost to build hemp houses

The cost to build will probably depend upon a variety of factors including, for example: the type and size of dwelling, the numbers of units involved, the method of building, the costs of materials , labour, plant, management, supervision and administration and some of these may vary according to the prevailing economic/ market conditions around the time of construction and according to the location of a project.

The tender price for building each hemp house at Haverhill was around £54,000 compared to £34,000 for the two traditionally built control houses. This may not be a true reflection of the cost of construction since the contractors had no experience on which to base their calculations. The internal finish is simple and cost effective and external render is a single coat. When the efficiency of shuttering can be resolved, then costs could come down to levels comparable to masonry construction (see above).

A detailed comparison of costs for the 'shell' of t he buildings has been carried out and is summarised in the Table below.

House type	Cost of Materials	Labour	Total Cost per m^2 of completed wall
Hemp House Plot 9	£8,375	£7,450	£194.79
Hemp House Plot 10	£11,102	£18,501	£277.49
Traditional House	£4,845	£6,554	£140.42

The costs are for each of the hemp houses – Plot 10 was constructed first contains an element of learning but also an extra wall (this has been taken into account in calculating the cost of materials and the cost per m^2).

It should also be noted that the costs are also based on the following:

- The materials and labour are for the construction of the shell of the building up to roof level but excluding the roof, windows and doors as these are assumed to be the same in the two buildings.
- The material costs are apportioned on the area of wall assumed to have been build for each house (81.24m^2 for Plot 9 and 106.68 m^2 for Plot 10)
- The cost of excavations for the ‘traditional’ house foundations are included but no other preliminaries or site work.
- No internal finishing or fixing is included
- Prices for all materials except the lime and the Isochanvre are taken from UK Building Costs Blackbook 2002.

It is interesting to note that the labour charges are similar for the second hemp house and the traditional house. This suggests that with further improvements in the efficiency of mixing and placing the hemp/lime mix that this type of construction could become less time consuming that traditional construction. At present the cost of the hemp and lime far exceed the costs of traditional materials but it is already known that saving of up to £1500 could be made on the cost of the lime.

Performance of the constructed house

Structural issues

The hemp used for the walling occurs as in-fill between the studs and transomes of the timber frame and thus appears to have no obvious or primarily structural role other than a wind bracing.

The ground floor slab of the houses is cast between the external walls and therefore should not carry the direct loads of the external walls. The floors only appear to carry the loads of some lightweight partitions (timber stud), furniture and occupants.

Theoretically, the compressible nature of the material and its response to the removal of load, may cause people to questions its performance and some form of appropriate test may be necessary before any definitive conclusion can be reached. Evidence from completed buildings where a 30mm screed is laid over the hemp flooring shows that there is no movement overall and the substrate appears capable of supporting normal domestic loading.

Six months after completion, there were small cracks by the sill on the upstairs front windows of each hemp house - but these appear to be only in the render layer. There were more substantial cracks on the front and rear walls running vertically at the place where the two hemp houses meet. It seems that the two houses are moving relative to each other on their separate timber frames. Lime renders are easy to repair and generally will withstand more movement than cement renders.

Observations were also made on the floor slabs and according to the architect (Ralph Carpenter), there were no reports (up to the 6th March 2002) to suggest any cracking to the floor topping, of sand and hydraulic lime screed. Similar claims have been made for hemp houses built in France up to ten years ago.

Performance in Fire

Literature provided by the producer claims that the Isochanvre material is fire resistant when combined with the lime. An earlier review was made of these results in relation to Building Regulation 7,1d. The tests show that the hemp/lime material is non-combustible and it is likely that the French results should be acceptable in the UK as they were carried out by a very reliable research organisation to established standards that seem to be similar to the new European ones. Information from the architect indicates that the CSTB (Centre Scientifique et Technique des Batiment) in France tested the Isochanvre using tests that are broadly equivalent to those that tend to be used by the BRE although different class gradings were involved. He also stated that there was no impact on the material after 4 hours at temperatures of up to 1800^{o}C.

When the Isochanvre Isolation (that is the loose fibre) was tested by Centre Techniques du Bois et de l'Ameublement in France the result was classified as M2 which is 'low-flammability'.

Energy consumption, thermal performance and moisture control

The energy consumption figures for the hemp houses at Haverhill provided by Modece Architects are given in the following Table.

Conclusions that can be drawn from the data include:

- General patterns of consumption for heating using gas-fired central heating are almost identical for all 4 houses if the hot water use is taken out. (As a check the energy consumption of an identical 5th house (brick built) has been included – the house was excessively hot and this could account for the higher than average consumption rates).

- The SAP ratings and U value calculations suggest that the Hemp Houses (Plots 8 and 9) should be using significantly more energy than the brick houses and this is demonstrably not the case.
- The outside weather conditions were monitored during the first three months and the coldest period was clearly during December 2001, a fact which is reflected in the energy consumption figures.
- The section headed ‘Monitoring of internal conditions’ earlier in this report shows the temperatures to be very similar in both the hemp house and the traditional house although the hemp houses maintain marginally higher temperatures.

House number	Gas consumption from date of occupation on 07.12.2001 to:		
	13.01.2002	01.03.2002	04.04.2002
Plot 8 Isochanvre Occupied throughout	246 units = 2725kw	220 units = 2437kw	149 units = 1650kw
Gas used per day)	73kw Heating/ hot water	52kw Heating/hot water	48kw Heating/hot water
Plot 9 Isochanvre Unoccupied to 01.03.2002	184 units = 2038kw	139 units = 1539kw	136 units = 1506kw
Gas used per day	56kw Heating only	33kw Heating only	44kw Heating/hot water
Plot 10 Brick Unoccupied to 01.03.2002	185 units = 2049kw	141 units = 1561kw	132units = 1462kw
Gas used per day	57kw Heating only	34kw Heating only	43kw Heating/hot water
Plot 11 Brick Occupied throughout	280 units = 3103kw	230 units = 2547kw	130 units = 1440kw
Gas used per day	86kw Heating/hot water	55kwm Heating/hot water	42kw Heating/hot water
Plot 5 Identical to 4 houses above and occupied since 29.10.01 Total energy consumption over 157 days 10,225kw Average daily consumption 65kw which is around 7kw higher than plots 8 – 11 above			

An assessment of the thermal performance of the hemp houses at Haverhill provided by Modece Architects leads to the following conclusions.

Thermal performance is expressed in terms of U values. The U value is calculated as the inverse of the thickness of the material divided by its thermal conductivity (lamda) and can be expressed thus:

$$U = \frac{1}{R} \qquad R = \frac{\text{thickness (mm)}}{\text{thermal conductivity}}$$

Using this formula the U values of the different constructions have been calculated and applied to the standard method for measuring the SAP rating.

- The SAP rating for the brick houses was calculated as 87
- The SAP rating for the hemp houses was calculated as 77

(the lower the rating the less well the theoretical thermal performance of the building)

Referring now to the energy consumption data which was collected during the four month period from December 2001 to April 2002 which also includes three months during which one hemp house and one brick house remained unoccupied, it is possible to see that the energy consumption figures run virtually parallel for the entire period.

Looking at the data collected by BRE using thermal and humidity loggers we find that the temperatures maintained in the hemp houses have been consistently one or two degrees higher than in the brick houses for the same amount of heat input. At a temperature of 19ºC people can be very sensitive to even half a degree difference and once the tenants are familiar with the way their houses work it is likely that they will start to adjust their radiators to deliver comfort conditions more efficiently. This should reduce the overall energy consumption in the hemp houses.

It is anticipated that during the autumn of 2002 there will be a tenants training day designed to help them to maximise the effectiveness of their heating systems. This will focus on a combination of overall thermostatic control and thermostatic radiator valves in order to balance the heating systems. The energy consumed during the ensuing three month period will be closely monitored and lifestyle patterns will be compared in order to determine whether the hemp houses can be shown to outperform their identical brick neighbours. At worst the same scenario as was observed from December 2001 to April 2002 will continue, in which case all 4 houses will continue to perform in a similar way. In both cases it will be clear that the theoretical performance of the hemp houses does not match their performance in real life in that they are using significantly less energy than predicted.

Conclusion

The hemp houses constructed of Isochanvre and lime should be consuming more energy than the brick control houses, which are constructed with 2 leaves of masonry separated by 100mm of blown fibre rockwool cavity fill, with 50mm Styrofoam insulation to the suspended concrete floors and with 200mm rockwool insulation to the roofs. This is not the case. It is interesting to note that the brick control houses meet the revised standards in part L of the Building Regulations, introduced in April 2002. It can therefore be assumed that the hemp houses satisfy the new part L of the Building Regulations.

Maintenance and life cycle issues

The use of hemp appears to be comparatively new so, as with any material or system of building, it is difficult to be certain about its likely performance over longer periods than the experiences available to date eg that of its performance over a 10 year period in France.

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.

The fact that the wall matrix only involves the use of lime and hemp (ie no sand) colour consistency for matching in work should be good.

Other Commercial Issues

On this site, ‘Right to Buy’ and therefore ‘mortgageability’ should not become an issue because the housing association cannot sell the houses to the tenant s.

If people are going to source lime from anywhere else other than the English manufacturers they need to consult the manufacturers of the hemp who will know what works successfully with it. There can be problems if the wrong category of lime is used or lime is obtained from inappropriate or sources.

Appropriate specification and supplier selection should prevent potential problems.

Conclusions

The conclusions for each aspect of the research are given in the appropriate section. However, the **main findings were:**

- *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.
- *Construction costs:* It is estimated that the true cost of hemp construction was £526 per square metre of floor space compared to £478 for traditional construction.

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