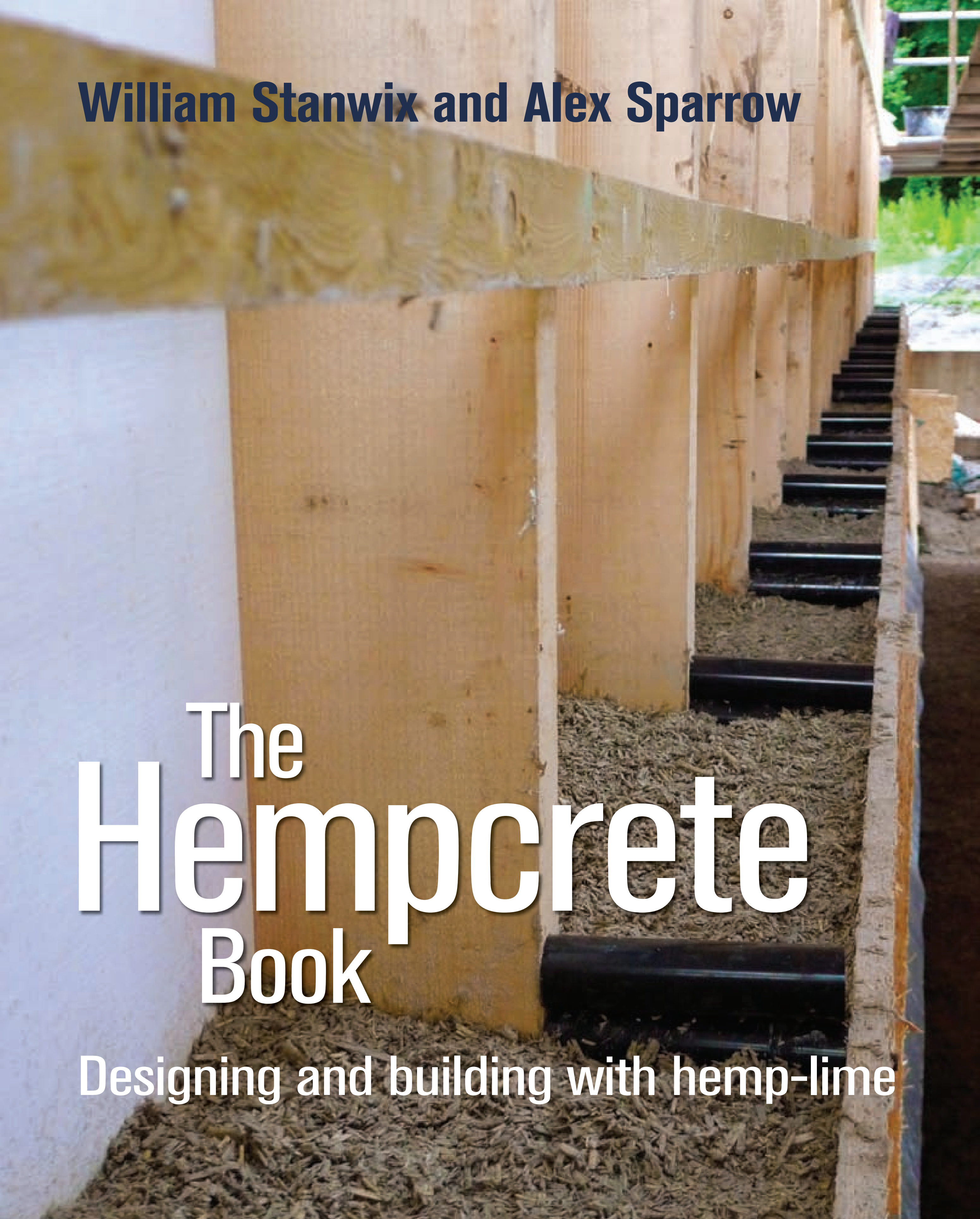

William Stanwix and Alex Sparrow

The Hempcrete Book

Designing and building with hemp-lime

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Contents

This book is for
Jacob John Renbourn

Not only a talented builder but also a true
hemp devotee. He is greatly missed.

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Massive thanks to www.radiomeuh.com for the background noise.

Foreword

When Rachel Bevan and I did the research that led to the publication of *Hemp Lime Construction* in 2006-7, we had a fairly good idea of the location of every building containing hempcrete in the UK and Ireland. Seven years or so later, it is impossible to keep track of the use of this remarkable composite building material, as happily its use has become almost commonplace in the UK – evidence of the widespread acceptance of this excellent sustainable way of building. However, whenever such an innovative form of construction quickly gains popularity there is a risk, if it is used by people who expect it to behave like 'conventional' materials, of careless and poorly supervised construction, detailing and specification. For this reason *The Hempcrete Book* is most welcome, as it brings up to date the knowledge and experience gained in recent years and provides clear guidance to those who want to apply hemp materials correctly in a range of applications.

As pressure builds to meet increasingly strenuous energy-efficiency targets, many weird and wonderful building techniques and materials have appeared on the market. These are often embraced with remarkable haste, even if barely tried and tested, particularly when backed by glossy brochures and exaggerated performance claims. Most of these systems involve plastic and petrochemical-based substances which can sometimes present fire hazards, emit toxic chemicals and pollute the planet when disposed of in landfill. They use fossil-fuel resources and produce significant carbon dioxide emissions, although ironically their use is intended to reduce such emissions! Many so-called low-energy or zero-energy buildings have been shown to consume more energy in their materials and construction ('embodied energy') than is saved in the lifetime of the building.

Hempcrete, on the other hand, not only has low embodied energy but also locks up CO_2 in the building fabric. It is fireproof, healthy, breathable, regulates humidity levels and is much more thermally efficient than comparable materials. All of this is explained in detail in this excellent book. Once you become aware of hempcrete's advantages it is hard to find another way of building that can meet the demands of sustainable, healthy and energy-efficient construction so successfully. Furthermore, since the hemp plant can be grown in so many parts of the world, it can be used to insulate buildings in poorer developing regions as easily as in Western countries. Hemp also provides food, oil, clothing, paper and many other products in addition to construction materials.

The construction and use of buildings are responsible for at least 50 per cent of the CO_2 emissions from human activity. Therefore using materials with a much lower environmental impact is crucial to reducing environmental damage and resource consumption. Designing and building with hempcrete is a real demonstration of a total commitment to 'saving the planet' and protecting the health and well-being of a building's occupants. It's an easy commitment to make, because hempcrete is affordable, great fun to build with and is truly sustainable. Thanks to this book, it will now be even easier to use.

Tom Woolley
County Down, April 2014

Introduction

This is a book about 'natural building'. An increasing number of people across the UK, and the world, are consciously deciding to use natural materials when constructing new buildings or restoring old ones. People usually choose natural materials because they want a building that is sustainable or 'low impact' in terms of eliminating or minimizing any lasting negative effect on the world in which we live. In practice this means reducing as far as possible the 'embodied energy' associated with the materials and methods used in the construction of the building; minimizing the amount of fossil fuels needed by the occupants to power, heat and cool the building through its lifetime; and minimizing toxic emissions and any other harm to human society or the natural world.

People also choose natural materials because they are increasingly aware of how such materials can not only maintain the structural fabric of the building well but also help to keep humans in good health. In contrast to many synthetic materials, natural materials contain no harmful chemicals. They are also vapour permeable (they allow moisture to pass through), which has significant implications for the health of both the building and its occupants.

There are many natural materials available for use in construction: timber, stone, earth, animal hair, straw, hemp, lime, reed and fired clay, to name just some. Many of these materials can be used in more than one way. They have a long pedigree of use over centuries, or even millennia, by humans (and other animals!) to provide warmth and shelter. Today, with our growing awareness of the threats associated with over-dependence on fossil fuels, and our increasing understanding of the negative side-effects of synthetic building materials mass-produced by highly industrialized processes, has come a resurgence of interest in older and more natural materials and methods for construction.

While many techniques from our construction history are suitable for use today, others are less applicable in the current context and probably have limited use in the new buildings of the future. However, one positive effect of this resurgence of interest is that a number of new natural materials and techniques, based on old technologies but tailored to meet our future construction needs, are beginning to emerge. Hempcrete (a hemp–lime composite construction material) is one such new material. Comprising the chopped stalk of the industrial hemp plant mixed with a lime-based binder, hempcrete provides a natural, healthy, sustainable, local, low-embodied-energy building material that can truly claim to be *better than zero carbon*. Carbon dioxide taken up by the plant when it was growing is locked up in its woody fibres, and at the end of the building's life the hempcrete can be left to compost and be used as a soil additive rather than going into landfill. As a highly insulating material with significant thermal mass, hempcrete has excellent thermal performance within the structure of a building, and there is increasing evidence that it actually performs much better in real-life situations than is suggested by steady-state modelling.

Previous: Hempcrete and lime plasters in a listed building.

Our company, Hemp-LimeConstruct, was set up when we decided to focus on furthering the use of this exciting new material in building projects across the UK. We have been building with hempcrete since 2008, on projects ranging from 'future-proof' houses to large community buildings and complete restorations of listed buildings, and provide a bespoke design-to-build service, consultancy and training. At the same time, other contractors across the UK have been using hempcrete on a much larger scale, in the construction of housing estates and commercial and industrial developments. As the profile of hempcrete within the public continues to grow, there is an increasing demand for these services. And as research into hempcrete builds, our understanding of this remarkable material is constantly developing. From the interest we at Hemp-LimeConstruct get at exhibitions and the frequency of enquiries we receive, it looks as though hempcrete has caught the nation's imagination and is here to stay.

When we first sat down to write this book, we intended to write a practical 'how-to' manual to introduce people to the method of building with hempcrete. The reason for this was that we would have found such a book very useful when we first started working with the material, and it didn't exist. We hope that others wanting to build with hempcrete will benefit from our six years of experimentation and refining of techniques; learning from *our* mistakes rather than their own.

Freshly mixed hempcrete.

As the book took shape, we realized the importance of including discussion of some key topics and concepts that underpin the successful use of hempcrete, and we hope readers will find this background interesting and useful. Many people will want to flick straight to the practical details contained in Part Two, but we'd urge all our readers to take the time to ensure they understand the contextual information and important underlying concepts discussed in Part One. A firm understanding of these is essential for anyone wishing to become a successful hempcrete builder.

Hempcrete is especially attractive to self-builders and community groups, because of the relatively low-tech nature of the construction method. Also, owing to the fact that it's a relatively labour-intensive construction method, big savings can be made by providing your own labour. However, as our company and others have proved over recent years, hempcrete is also commercially viable as a construction material in a wide range of applications. Its cost is comparable to that of conventional construction methods, but if you factor in the true cost of the embodied carbon of conventional building materials, in terms of environmental damage, and consider the financial benefits of the energy savings that hempcrete delivers through the lifetime of the building, you could argue that it's actually a lot cheaper!

We hope that readers will be inspired and encouraged by this book to develop their own hempcrete projects – but first, an important caveat. It is beyond the scope of this book to show every possible way of using hempcrete, and in any case the industry as a whole is still exploring this. Also, it is important to remember that while the

Hempcrete housing at The Triangle in Swindon.

principles and information outlined in these pages are sound, the physical properties of hempcrete change slightly depending on which binder you are using. As will become clear, it is also a material (like many others) that has the potential for problems associated with a lack of understanding or poor workmanship on the part of the builder. For these reasons, it is important to remember that on any build it is the responsibility of the building designer to specify the exact materials and design construction details, and the responsibility of the builder to ensure a high standard of knowledge and skill in those who are working with the material on-site.

There is a great pleasure to be found in building with hempcrete, which comes not only from the extraordinary thermal performance achieved but also from the simplicity: both of the material itself and of the elements within a typical hempcrete construction. Hempcrete's low-tech nature means that, with relative ease, highly energy-efficient buildings can be constructed that contain virtually no synthetic, highly processed or high-embodied-carbon materials. With a good understanding of the material, and a little practice, hempcrete is a hugely rewarding material to work with, and can produce beautiful, healthy, 'future-proof' buildings.

PART ONE

Principles of building with hempcrete

CHAPTER ONE

History and uses of hemp

The hemp plant, thanks to its many uses and in particular its most famous one, as a widely popular recreational drug, is one of the most instantly recognizable plants in the world. A great deal has been written about hemp's many uses throughout human history and about the politics of its prohibition during the twentieth century, and there is no need for us to reproduce it all here. In the interests of context, however, in this chapter we provide a brief description of the hemp plant, its history and the resurgence in its use today.

Hemp is the English name (from the old English *haenep*) for the cannabis plant. The words *haenep* and cannabis are both thought to derive from the Ancient Greek *kánnabis*, which in turn evolved from an older word in an ancient Iranian language from around 2,500 years ago.

Three varieties of the cannabis plant exist: *Cannabis sativa*, *Cannabis indica* and *Cannabis ruderalis*. *Cannabis sativa* and *C. indica* are seen as the more closely related species. *Cannabis ruderalis* differs from them in that its flowering happens after a predetermined number of days, rather than being dependent on the seasons, and it contains very little tetrahydrocannabinol (THC), the psychoactive substance that gives the drug cannabis its active ingredient.

Hemp is a fast-growing erect annual plant which produces only a few branches, usually at the top of the plant, and grows to a height of between 1.5m and 4m. Its stem is thin and hollow, with a diameter of 4mm to 20mm, depending on the conditions and the specific variety grown. The 'bast' fibres of the hemp plant, which are contained in the bark of the woody stem, range from about 1.2m to 2.1m in length and are extremely strong. Their quality varies depending on the timing of harvesting, and the fibres are graded in terms of their fineness, length, colour, uniformity and strength.

The inner woody stem, the 'shiv' (or 'shive', or 'hurds'), historically has not been used intensively,

Previous page: Industrial hemp growing in Yorkshire. This plant is ready for harvesting.

but this is changing rapidly in the modern world, with new uses being developed all the time: packaging filler and animal bedding, for example. It is hemp shiv that is used in the production of hempcrete.

The seeds of the hemp plant are used as a food source, and ground to produce oils for a wide range of purposes, including technical and industrial applications. The hemp plant in its whole state can be used as a biofuel, and even the cell fluid of the hemp plant is now used in the manufacture of abrasive fluids.[1]

A history of hemp

The common hemp plant, *Cannabis sativa*, is one of the earliest recorded domestically grown plants, with evidence of its cultivation by humans since Neolithic times. Hemp is found across the world, and has a long history of widespread use for a range of important products: hemp seeds for oils and resin, food, fuel, medicines and cosmetics; hemp fibre for hard-wearing clothing, rope and tough fabrics such as sailcloth (the word canvas derives from cannabis: literally – originally – 'a fabric made from hemp'), and as a pulp from which to make paper.

It is thought that the plant originated in China, and that its cultivation gradually spread westwards through India and into the Middle East, Africa and the Mediterranean, where it formed an essential part of the livelihood and culture of each people who grew it. Surviving writings from the Egyptian, Greek and Roman records show how important the hemp plant was to the lifestyle, trade and expansion of these great civilizations.

The cultivation of hemp in Europe continued throughout modern history, with evidence that its use in Britain, introduced by the Romans, continued thereafter, with the Saxons incorporating it into their medical treatments. Later kings of England promoted the cultivation of hemp, not only for its everyday uses for linen and rope but also for the vital part it played in the military supremacy of Britain as an island nation: Henry VIII passed a law making it compulsory for farmers to grow hemp, such was its importance to the defence of the realm through its use for sailcloth and rigging. Later still, the hemp plant played a not-insignificant part in Napoleon Bonaparte's downfall, since his ill-fated incursion into Russia had as its aim the destruction of Russian hemp plantations. Russia had been supplying the English with hemp, and thus equipping the navy of Napoleon's enemy.[2]

The importance of hemp in British and Irish society throughout the ages is reflected in place names across the land – for example, Hemel Hempstead in the south of England (meaning literally 'place of hemp' or 'hemp pasture'), and Cwm Cywarch in Snowdonia (which translates as 'the steep-walled mountain basin in which hemp is grown'). Street names such as Hemp Mill Walk in Loggerheads in Staffordshire speak for themselves, and Hemp Street in Belfast is at the centre of the area which, until the beginning of the twentieth century, housed the thriving industry around the manufacture of hemp rope and sailcloth for the city's important shipbuilding trade.

The long tradition of hemp growing and processing in Britain can still be seen in the surviving architecture of the hemp and flax industries. Up until the arrival of cheap imported cotton, sisal and jute, towards the end of the nineteenth century, hemp and flax were still widely used for clothing, other textile products, rope and netting. In fact, these two plants are the *only* fibre crops that are commercially viable in our temperate maritime climate. Many towns in the UK have surviving buildings that were originally a part of

The Ropewalk, Nottingham. Signs of the hemp industry of earlier centuries remain in its surviving architecture across the UK.

these important and widespread industries. The most visible of these are often the 'rope walks' of Victorian, or earlier, times: long buildings where the hemp and flax fibres were stretched out and spun into twine and rope.

For those interested in the history of hemp cultivation in the UK, a good place to start is the quiet coastal towns of Bridport and West Bay in Dorset. The rolling hills of west Dorset and south Somerset, with their well-drained, fertile soil and warm climatic conditions, provide the perfect conditions for cultivating hemp, and the town of Bridport already boasted a thriving hemp- and flax-processing industry by the thirteenth century. The earliest recorded evidence of this is a "payment for a large quantity of sails and cordage in 1211", which was followed by "an order from King John for Bridport rope and cloth to supply the navy in 1213."[3] Although the industry suffered during the sixteenth and seventeenth centuries, owing to competition from other shipyards and local depopulation as a result of plagues, there was a dramatic revival of the town's hemp and flax production during the period from the late eighteenth to late nineteenth centuries. This, combined with the relatively slow growth and development of the town since the beginning of the twentieth century, means that the history of the British hemp industry is preserved in the buildings of Bridport and West Bay today.

Another of the main uses of the plant throughout history has been in religious ceremonies, and more recently as a recreational drug, due to its relaxing and mildly psychoactive effect. This use of cannabis, or marijuana, as a narcotic eventually led to the growing and possession of the hemp plant being outlawed in most Western countries in the early decades of the twentieth century. The prohibition of cannabis remains in force widely today, in the West at least, with some notable exceptions, such as the Netherlands, which was the first Western country to introduce an official policy of tolerating the possession of small amounts of the drug without prosecution. Other countries, including Spain, Portugal, the Czech Republic and Switzerland, have followed its example in recent years by decriminalizing the possession and use of small amounts of the drug. In November 2012 the US states of Washington and Colorado voted to legalize cannabis, although it is still unclear how this will work in practice, since the drug continues to be illegal under US Federal law, which of course has jurisdiction in both of these states.

Rediscovering hemp

The unfortunate side-effect of the prohibition of the drug cannabis has of course been the blanket banning of cultivation of all forms of the hemp plant, and its consequent unavailability to Western societies for its many non-drug-related uses. The cultivation of hemp in the UK was outlawed in 1928. Since the 1930s, much effort has gone into developing cultivars of the plant which contain very little THC. The success of this endeavour means that, for some decades now, an industrial hemp plant with little or no THC content has been widely available.

The term 'industrial hemp' refers to cultivars of *Cannabis sativa* which have been bred to have a THC content of 0.2 per cent or less. These cultivars have been legal to grow in the UK since 1993, and in Canada since 1995. The THC content in a drug-producing plant would be 10-15 per cent or higher, depending on the strain and method of cultivation. Because the industrial hemp plant looks identical to the drug-producing strains, however, the growing of industrial hemp in the UK requires a special licence from the government.

Since the early 1990s, more and more individuals and organizations throughout the Western world are starting to re-embrace the hemp plant, exploring its potential as a natural and sustainable source of materials with great commercial, industrial, agricultural and environmental potential. The table opposite[4] shows some examples of its many uses.

While the hemp plant is not, as is sometimes claimed, a 'miracle plant' that can solve all of the problems of the Western world, it seems that the resurgence in its use will be invaluable in a future where it is essential that we wean ourselves off our dependence on fossil fuels. At the time of writing, hemp has been grown legally again in the UK for 20 years, and the number of farmers cultivating it is steadily increasing, as local and international demand for the crop expands.

In the United States, the commercial growing of hemp has been made legal under State law in the states of Colorado and Washington, although confusingly it remains illegal under Federal law. In late April 2013, Colorado farmer Ryan Loflin

Hemp cosmetics are now a familiar sight on the high street.

Commercial uses of the hemp plant today

Part of plant		Use
Whole plant		Fuel for boilers Feedstock for biomass pyrolysis
Stem	Shiv (core)	Paper Cardboard Packaging filler Construction (hempcrete, plasters & renders) Animal bedding Mulch Mushroom compost
	Bast fibre (contained within bark)	Quality hard-wearing clothing Bags Shoes Twine Rope Netting Canvas tarpaulins Carpets Geotextiles Fibre-reinforced plastics Construction (quilt insulation, plasters & renders) Brake & clutch linings Caulking
Leaves		Animal bedding Mulch Mushroom compost
Seeds	Whole/ground	Food, including protein-rich flour Birdseed Animal feed (pressed into seed cake)
	Extracted oil	Food (salad oil, margarine & food supplements) Oil paints Solvents Varnishes Chainsaw lubricants Inks Putty Biodiesel
Cell fluid		Abrasive fluids

planted the first major hemp crop in the USA in more than 60 years. This landmark planting, five months after it was made legal in Colorado, is the result of a huge groundswell of opinion in the USA, which has been pushing for the US government to fall into line with the rest of the world in its attitude to the hemp plant.[5]

Hemp farming in the UK today

Hemp grows easily in a range of soils and climates, providing the soil pH is 6.5 or above (neutral-to-alkaline). The hemp plant is not especially nutrient hungry, although for maximum commercial yields a fertilizer is needed. It's also a deep-rooting plant, helping to break up the soil to some depth, which is beneficial for soil health and condition.

The plant is an effective weed suppressant because it grows very quickly and is very 'competitive', winning out over other plants for growing space and light. For this reason it requires no chemical weedkillers, and in fact hemp is sometimes grown specifically to clear land of chemical-resistant weeds. Another useful property of the plant is its pest resistance – there are virtually no pests or diseases that attack hemp – so there is no need to use pesticides or fungicides during its cultivation.

The speed of growth, together with its natural weed and pest resistance, makes hemp a profitable 'break crop' for UK farmers, providing a useful barrier to pests and diseases in the soil between the sowing of other crops, such as cereals, as part of a crop rotation.

The gradual depletion of nutrients in the UK's soil through the last 60 years or so of ever-more intensive and industrialized farming, and the 'replacement' of these nutrients with increasing applications of chemical fertilizers, has resulted in a very poor soil quality across much of the UK's farming land. Poor soil produces weak plants that are more susceptible to pests and disease, which in turn are targeted with increased levels of chemical pesticides and fungicides. These also indiscriminately kill beneficial insects – both soil-dwellers and airborne pollinators, which are vital for the success of our food crops. Even if the continued use of such chemical fertilizers and pesticides were the best way forward (which it isn't), the fact that many of these products are

Hemp grown in the UK is ready for cutting in August.

derived from fossil fuels means that they are a non-sustainable resource.

The situation nationally at the beginning of the twenty-first century, apart from among those farmers who are returning to smaller-scale, organic farming, is soil across the UK's farms that is almost totally devoid of those insects and other organisms which convert decaying organic matter into the nutrients that plants need to grow. These tiny creatures also provide a key source of nutrients at the bottom of the food chain, and their absence is a significant factor in the huge loss of biodiversity in the UK that has occurred over recent decades. The cultivation of a plant such as industrial hemp, which is not nutrient-greedy, can be grown using only organic fertilizers and without chemical weedkillers and pesticides, and breaks up the deep soil, has the potential to bring huge benefits in terms of soil health, food production and the UK's ecosystem as a whole.

Industrial hemp is sown in the late spring, from early May to early June, at a density of around 30-38kg of seed per hectare. The ideal conditions are a warming soil with plenty of moisture present. Prevailing conditions are more important than exact timing when sowing, since the seedlings are not frost hardy.

Seedlings emerge within five days, and grow rapidly, sometimes at a rate of 30cm a week. The crop is harvested in August, having attained a height of 2-4m. As it is cut down, the hemp plant is also cut into shorter lengths and is left on the ground for up to a month for 'retting': a biological process whereby the hemp straw becomes more workable and the bast fibres begin to separate from the shiv. When the retting process is complete, and the sun has dried the hemp, it is baled and stored under cover. The raw hemp straw is then processed to separate it into saleable parts. The different markets for each part are shown in the table below (see also table on page 19).

Hemp can be grown for the straw alone, or allowed to grow on for a seed crop. It is possible to grow a 'dual' crop, for fibre and seed, although this is much less common because the flowering of the plant does lead to some reduction in the overall quality of the stem, from which the bast and shiv fibres are obtained.

Various models of hemp processing have emerged in the UK in recent years, ranging from the super-high-tech, such as the multi-million-pound processing plant in Suffolk built by Hemp Technology Ltd (formerly Hemcore), to small-scale and (relatively) low-tech solutions such as those employed by K J Voase and Son in Yorkshire, who process all of their own hemp using machinery they have built or adapted themselves, on the farm where it is grown.

Current UK markets for hemp straw

Part of straw	Proportion of crop (approx.)	Market
Shiv (stem core)	60%	Construction industry, horticulture & animal husbandry
Bast fibre (strong fibres in which the stem is wrapped)	30%	Textile industry, construction industry, scientific & technical industries, automotive industry
Fines (small pieces of bast fibre)	7%	Consumer goods (e.g. mattresses)
Dust	3%	Fishing (e.g. ingredient in fishing bait)

CHAPTER TWO

Hemp in construction

Hemp for use in construction forms a relatively small, but growing, proportion of the output from hemp farming in the UK. The main ways in which hemp is used in construction are to make hempcrete and to provide fibres for quilt insulation.

'Hempcrete' is the popular term for a hemp–lime composite building material. It is created by wet-mixing the chopped woody stem of the hemp plant (hemp shiv) with a lime-based binder to create a material that can be cast into moulds. This forms a non-load-bearing, sustainable, 'breathable' (vapour permeable) and insulating material that can be used to form walls, floor slabs, ceilings and roof insulation, in both new build and restoration projects.

Hempcrete was developed in France in the mid-1980s, when people were experimenting to find an appropriate replacement for deteriorated wattle and daub in medieval timber-frame buildings. Across Europe, awareness was growing about the extensive damage that had been done to such buildings in the post-war period through ill-advised repairs using ordinary Portland cement. Using this material to replace the vapour-permeable earth-and-lime mortars and natural cements in historic buildings prevented the buildings' fabric from 'breathing' (see Chapter 4, page 58). This in turn led to the retention of moisture within the fabric, which damaged the timber frames.

A replacement was sought that would not only preserve the vapour-permeable nature of a building's fabric, thereby keeping it in good health, but also provide insulation. It was discovered that the stem of the hemp plant, highly durable and comprised of strong cellulose (capable of going from wet to dry and vice versa almost indefinitely without degrading), was the ideal aggregate to add to lime mortars to achieve this effect. Thanks to the cell structure of the hemp stalk and the matrix structure created by the individual pieces of hemp inside the wall, together with the properties of the lime binder itself, a hempcrete wall has a good ability to absorb and release

Previous: Hemp–lime composite – hempcrete – being cast around a structural timber frame.


Hempcrete used as a replacement for wattle and daub.

moisture (see pages 41 and 56). Also, since a great deal of air is trapped inside a hempcrete wall (both within the hemp itself and within the matrix of the hemp shiv in the cast material), it is a surprisingly good insulating material, and the density which the lime binder adds gives the finished material a good amount of thermal mass. Almost as soon as this technique was developed for the repair of historic buildings, people started experimenting with its use in sustainable new build – and found that it was equally suitable for this application.

More detailed information on the way hempcrete works within a building's fabric can be found in Chapters 4 and 7.

Is building with hemp a new phenomenon? It hardly seems likely that human civilizations would have cultivated the plant for millennia for such a wide range of uses *without* using it in their buildings. It is unlikely, however, that physical evidence of any such use in ancient times would survive, since plant-based building materials will of course eventually decay, returning to the soil from whence they came. After all, that is one aspect of the very reason that we are interested in them today: a low-impact building material will allow us to house ourselves 'lightly', without leaving a legacy of adverse effects on the environment behind us.

There is some evidence, however, that building with hemp did not start in the twentieth century and, further, that properly maintained hemp buildings can last for centuries. A historic hemp house in Miasa village, in the Nagano prefecture of Japan, now recognized as a Japanese national heritage site, was built in 1698 and survives in good condition to this day.

At the time of writing, hempcrete has been used in building for around 30 years – since its ‘invention’ in the 1980s. The use of hempcrete has gradually spread, first across Europe and more recently around the world, and the number of people using it, both in new build and in the repair of older buildings, continues to grow.

In the UK a great many buildings, both commercial and residential, have now been built with hempcrete. A notable upsurge in the commercial use of hempcrete came with the Renewable House Programme, funded by the UK government between 2007 and 2010. Under this scheme, a range of developers received varying levels of public funding to build social housing using natural renewable materials, resulting in the construction of around 200 homes. Of the twelve projects funded, seven used hempcrete as an insulation material.

Since the UK construction industry is notoriously slow to adopt new practices, and has been largely sceptical of the need for (or even the possibility of) using natural materials, State-funded and -driven programmes such as the Renewable House Programme are invaluable in facilitating investigation into issues relating to the large-scale adoption of natural materials within the construction sector. The programme certainly had its challenges, and many of the projects undertaken suffered to some extent from the effects of contractors being given novel materials to work with. However, the overall results were encouraging, and no problems were encountered to suggest that hempcrete, along with other natural materials, would not be suitable for adoption on an increasing scale within the mainstream construction industry.

There are also some other uses of the hemp plant in construction, primarily of the bast fibres in the manufacture of fibre quilt insulation materials, and both shiv and bast fibre as an addition to lime plasters, providing additional strength and some insulation to the plaster. While these materials are not the main focus of this book, they are occasionally referred to throughout, so a brief overview of them is included later in this chapter. First, however, we look at the different ways in which hempcrete can be used.

Hemp shiv for building

Currently in the UK there are no agreed standards for the characteristics of hemp shiv for the construction industry, nor for its production or processing. In France, where the hemp building industry is more established, there are strict guidelines for hemp farmers that govern the quality and colour of hemp shiv to be used in construction, and it is hoped that, in time, similar standards for the nature and quality of the product can be agreed for the UK industry.

The processing of hemp shiv for use as a building aggregate (once all the leaves, seeds and bast fibres have been removed) involves breaking it up into small pieces and removing any remaining fibre

Loose hemp shiv against a new hempcrete wall.

and dust. Hemp shiv for building should be as dry and clean as possible, with a minimum of fines (small pieces of bast fibre) and dust present.

The length of the pieces should be between about 10mm and 25mm, but this is not absolutely critical: successful walls have been made with shiv that contains shorter pieces (especially when spray-applying, see page 29), but it is generally acknowledged that pieces of this length produce a good matrix structure within the wall, which is beneficial for its thermal performance (a material's 'success' in conserving heat and power in a building) and vapour permeability (the degree to which a material allows water vapour through it). Walls are also regularly built with hemp shiv that contains a certain amount of fines, although the proportion must be low, otherwise the fines can soak up too much water and potentially affect the setting of the binder. The absence of dust from the shiv is far more important, since excessive dust can have an even more significant impact on the structural integrity of the wall – in extreme cases leading to collapse (see Chapter 5, page 76). This is because the dust soaks up a very high proportion of the water added at the mixing stage, causing the binder to fail. The only way to avoid this is to compensate by adding a lot more water, but this will significantly extend the drying time of the hempcrete. The presence of excessive amounts of dust in hemp shiv for building is to be avoided at all costs.

Hemp should be stored dry, although it comes in plastic-wrapped bales, so there is a certain tolerance of these being left outside on-site in the short term if suitable storage is not available. The shiv should go in the mixer as dry as possible, to avoid excess water entering the mix, but if some areas of a bale do get wet it will not affect the quality of the finished hempcrete. However, if the shiv has been subject to prolonged exposure to moisture and starts to show signs of rotting (the colour changing to black), all black areas should be scraped out and removed from the bale before adding it to the mix.

There is no need for any treatment of hemp shiv with fire retardants or preservatives as long as it is being used with a lime-based binder for hempcrete. Once cast as hempcrete, the lime in the binder acts to effectively inhibit insect attack and protect from dampness and fire.

Sources of hemp for building

Until recently, the majority of UK hemp farmers supplied their raw hemp under exclusive supply contract to a company called Hemp Technology Ltd (previously 'Hemcore'), which invested in a large hemp-processing plant in Halesworth in Suffolk and supplied hemp products to a range of markets, including the construction industry.

Hemp shiv for building comes from the woody stem of the plant.

Hemp Technology went into administration on 28 October 2013. They appear to be seeking investors, but at the time of writing it seems unlikely that the company will be revived in its current form.

The shiv that Hemp Technology Ltd processed for use in construction was sold on to the market exclusively by the parent company, Lime Technology Ltd, as Tradical® HF and was marketed as part of the Tradical® Hemcrete® system together with Tradical® HB, the hempcrete binder made by industrial lime producer Lhoist, which Lime Technology has the exclusive rights to supply within the UK. To date it has not been possible to purchase Tradical® HF without the equivalent binder, or vice versa, in the UK, and so this has artificially restricted the supply of hemp shiv on to the UK market. However, this may soon change in the light of the current situation at Hemp Technology.

Those wishing to source UK-grown hemp from other suppliers have been restricted to a small number of independent farmers who had not signed exclusive supply contracts with Hemp Technology, and who process their own hemp.

There is nothing to stop builders making links with farmers and sourcing their own shiv for building, but if the farmer is not used to supplying to the construction industry it is important that the essential qualities of hemp shiv for construction are understood by both parties. There needs to be clear agreement in advance about the qualities of the product required (as described earlier) and the cost, including that of transportation to site. Some natural building suppliers supply hemp shiv from independent UK farmers, although this is far from commonplace at the time of writing.

In early 2013 the French company Chanvrière de l'Aube commenced talks with several natural building suppliers in the UK about supplying its hemp shiv through these outlets. Samples shown to the authors were encouraging in terms of the shiv having a very good standard of dryness, a very low dust and fines content, and a consistent colour. However, broad discussions around price suggested that it might be more expensive than shiv currently on the UK market.

It remains to be seen whether importing French hemp shiv into the UK is a commercially viable enterprise. Such imports do not help the development of the (less well-established) hemp-processing sector in the UK, and the use of foreign shiv would make hempcrete less sustainable, since locally grown UK hemp (with, therefore, lower embodied energy – the energy used in sourcing, manufacture and transport of a material) is available for UK builders to use. On the other hand, the presence on the market of French shiv, subject as it is to the more stringent standards imposed by the French authorities, may prove competitive to UK shiv producers in terms of quality, if not price, and may provide the required impetus for the UK industry to develop its own quality standards for construction hemp shiv.

Details of hemp shiv suppliers in the UK can be found in the Resources section at the back of this book.

Cast-in-situ hempcrete

Cast-in-situ hempcrete refers to mixing hempcrete on-site and casting it into moulds constructed from shuttering, or formwork, to form the walls, floor or roof in the exact position that they will remain within a building. The shuttering may be temporary or permanent.

Because hempcrete is a non-load-bearing material, it is always cast around a structural frame, which provides the main load-bearing element of the building. This is usually, but not always, built of timber. This applies whether it is being used in a new build or a restoration context. In new builds the usual method is to construct a simple stud-work frame from softwood, and bury this within the centre of the hempcrete wall, but alterations can be made to the frame to accommodate different design details, both of the wall itself and of internal and external finishes.

Mixing the hemp shiv and binder together with water can be done with a variety of types of mechanical mixer, depending on the quantity needed, the speed at which it is required, the method of application and access to the site.

The freshly mixed hempcrete is either placed (rather than 'poured', since it isn't a liquid consistency), or sprayed into the void created by the shuttering. It is left for a short time to take an initial set (i.e. set hard enough to bear its own weight), after which the shuttering, if it is temporary, is removed and the hempcrete is allowed to dry out gradually over the next few weeks, until it is dry enough for finishes to be applied.

Hand-placing

The hand-placing of cast-in-situ hempcrete refers to the use of manual labour to place the hempcrete into the void created by the shuttering, as well as to ferry it from the mixer to the place where it is needed. The placing process needs to be carried out carefully to ensure both the quality and certain desirable characteristics of the finished material. The manual transport of the hempcrete is done using large tubs or buckets, since it is a relatively lightweight material.

The hempcrete is cast in shuttering, usually temporary, around the structural frame, which is usually placed centrally within the wall. Hand-placing is the 'standard' method of building with hempcrete, although, since it is quite a labour-intensive process, mechanical delivery systems

Mixing hempcrete for hand-placing.

Cast-in-situ hand-placed hempcrete around a soft-wood timber structural frame.

(spray-applying – see below) have been developed. These are particularly suitable for very large-scale commercial applications.

The placing of the hempcrete material by hand allows a high level of control over the quality of the finished product, although there is a need to carefully monitor consistency of workmanship if lots of people are involved in the placing. The low-tech, hands-on nature of hand-placed cast-in-situ hempcrete appeals to self-builders, whether individuals or groups, who have the time to devote their own labour to the build process in order to reduce costs.

The hand-placed cast-in-situ method of applying hempcrete is the main focus of this book.

Spray-applying

The method of spray-applying hempcrete is often used in France and has now arrived in the UK thanks to Myles and Louisa Yallop of The Limecrete Company. They have been a driving force in the increasing use of sustainable construction methods in the mainstream building industry, and have championed the use first of hand-placed and now of spray-applied hempcrete over recent years. The Limecrete Company's spraying machines, the first of their kind to be used in the UK, have been in operation since early 2012.

As with all things, spraying hempcrete has its advantages and disadvantages. The picture is developing rapidly, with new ways of using the machines, and new equipment to enhance the method, constantly being developed. The spray-applied method for cast-in-situ hempcrete follows broadly the same technique as that for hand-placed hempcrete, but with fully mechanized delivery and placing of the hempcrete, and some minor alterations to the structural frame to accommodate the way the machine works. The hemp shiv is of a finer grade than that used for hand-placed hempcrete (see Chapter 6), as shiv

Spray-applying hemp.

Sprayed hemp is projected against a permanent shuttering board.

Hemp spraying machine.

containing pieces longer than 20mm was found to block the hose on the spraying machine.

The hemp and binder slurry are mixed together at the nozzle of the sprayer. Due to the force with which it is projected out of the nozzle, spray-applied hempcrete adheres firmly to the surface on to which it is sprayed. Usually this surface is a permanent internal shuttering board, from which the hempcrete is gradually built out to the desired wall thickness in several passes. There is no need for a shuttering board on the other face of the wall – all that is required is the skill to build up a flat wall.

With spray application the structural frame is usually positioned on the inside face of the walls, where the permanent shuttering boards can be attached to it. However, since the spraying machine cannot spray around corners, to make the most of this method of application an open, easily accessible frame is required.

For self-builders wanting to carry out the work themselves, sprayed hempcrete is not really an option. The expensive machinery is not something you can hire by the week, and in any case the skill required to operate it can only be developed over time. However, spray-applying has the potential to reduce the number of people needed on-site during the placement of hempcrete, especially on large-scale builds. Against this, of course, you have to factor in the capital outlay, and time and money spent cleaning, transporting, maintaining and repairing the machine.

For builds of up to around $100m^3$ (a very large house or large community building, for example) the costs of hand-placing and spray-applying are comparable, with any variation usually depending on the frame design and site-specific issues. As you start to move up to larger builds, spray-application really comes into its own.

Pre-cast hempcrete

As an alternative to in-situ casting, hempcrete can be pre-cast into either blocks or framed panels. This usually brings distinct advantages in terms of predictability of the build process, since in most types of pre-cast hempcrete construction the drying of the hempcrete, or at least most of it, is completed off-site, so any uncertainty regarding the time needed for this is eliminated. This is a particular advantage for the schedule of works in large-scale commercial builds, and times when the construction phase must take place during winter.

However, the downside of pre-casting is that it is often a more complicated way of using hempcrete,

Hempcrete blocks waiting to be laid.

Hempcrete blocks are laid on a thin bed of lime mortar.

Hempcrete blocks in a new-build house under construction. (Note: the timber structure in the foreground is wooden scaffolding, not part of the frame!)

with a higher number of processes and materials involved. This in turn means that it may be a less sustainable construction method, although in truth, accurate comparison between cast-in-situ and pre-cast hempcrete is extremely difficult owing to variables such as the scale of the build, design details, the materials used and the distance between farm, processing plant, factory and site. The main pros and cons with pre-cast methods are outlined below.

Blocks

Hempcrete blocks are usually laid by wetting on the surface and bedded using a thin mortar of hydraulic lime and sand. They are coursed in such a way that thermal bridging (also known as cold bridging – a 'cold bridge' is a break in an insulation layer that allows heat to bypass it) between the outer and inner wall surfaces along the mortar joints is minimized. The blocks cut easily with a hand saw, which is useful for fitting them closely around the structural frame, but to improve the speed of construction and to minimize wastage the frame should be designed around the block size, or vice versa.

A number of different companies have been producing hempcrete blocks commercially for several years, both in Europe and, to a lesser extent,

Adnams' distribution warehouse was constructed from a mixture of hempcrete blocks and cast-in-situ hempcrete. *Image: Adnams*

in the UK. At first glance blocks might seem to be the obvious way of using hempcrete, especially considering the benefits of off-site drying. However, there is a fundamental inefficiency in casting blocks which are then laid in mortar, because you need a mixer and formwork (shuttering) to make the block in the factory, and then several subsequent processes must take place before it becomes part of the finished building. Casting the wall in situ is more cost-efficient.

The main arguments against blocks are as follows:

- In order to cast blocks of sufficient structural integrity that they will stand up to handling during manufacture, warehousing and transportation, the density of the hempcrete mix must be increased (i.e. the proportion of binder must be higher) compared with cast-in-situ hempcrete. This reduces the insulation performance, although it increases the thermal mass.
- The blocks need to be laid using a bedding mortar which, although only a thin layer, can potentially create cold bridges through the wall.
- The compressive strength of hempcrete is not such that these blocks can be used structurally to support the load of the roof, as concrete blocks would be, so although strong enough to support their own weight, they still need to be laid around a structural frame.

These three factors, combined with the fact that blocks are a more expensive and (potentially) higher-embodied-energy option, mean that cast-in-situ will usually be the preferred method for building with hempcrete.

There have been attempts to cast 'structural' hempcrete blocks, with a higher compressive strength, capable of taking a level of compressive force, but these are not really practical, since the increased density of the hempcrete that is required to provide structural performance means that the insulation value is significantly reduced. Such 'structural' blocks may be most suitable for internal walls, where a higher density is desirable to provide increased thermal mass or better acoustic performance within the building.

Despite their drawbacks, there are many examples of hempcrete blocks being used within the UK to good effect. They are particularly suitable for large-scale builds, for reasons already described, and can be combined with other forms of insulation. A notable example of such a build is the Adnams brewery warehouse in Suffolk, which was built using 100,000 hempcrete blocks combined with 1,000m^3 of cast-in-situ hempcrete. Blocks may also be suitable for very small builds or builds where there is limited access, when mixing on-site may be undesirable for cost or logistical reasons.

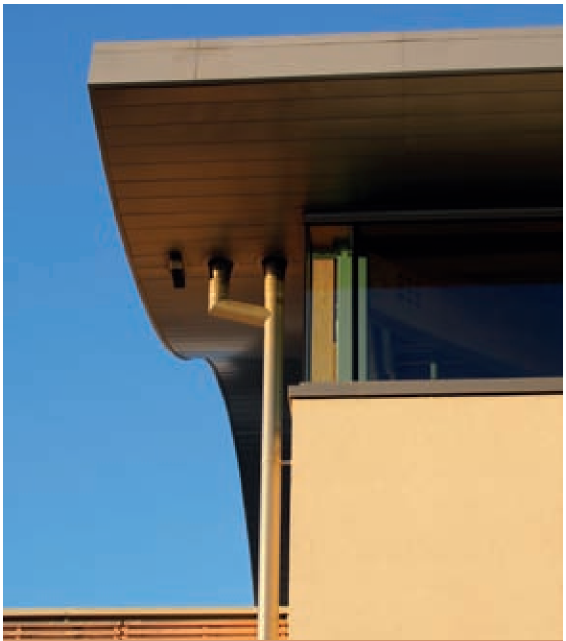
Panels

At the time of writing, Hemcrete Projects Ltd, part of the Lime Technology group, is the sole producer of pre-cast hempcrete panels in the UK. The panels, which comprise a timber frame-work, a built-in insulation layer and a 'breathable' vapour-control layer, are produced and dried off-site, then supplied and assembled on-site by Hemcrete Projects. In contrast to blocks, there is no need for mortar at the assembly stage, which means no waiting for this to set before finishes can be applied.

Two types of panels are produced, Hembuild® and Hemclad®. The insulation layer in both types is generally hemp-fibre quilt (see page 38), which gives them a lower U-value (better insulation performance) than cast hempcrete for a given wall thickness. This is a development driven by market demand for lower U-values, rather than an indication of natural-fibre quilt's superior overall thermal performance to hempcrete. See Chapter 7 for a detailed description of the thermal performance of hempcrete.

Hembuild® panels are structural, i.e. the timber-frame elements are designed such that when joined together on-site, the panels form the structure of the building, as well as the insulation and the airtight thermal 'envelope' (the surface that contains the building's internal heated volume). These panels are suitable for one- to three-storey buildings and are probably most suited to large residential buildings, schools and commercial buildings.

Hemclad® panels have an identical make-up except that the timber elements are not designed to be structural. Instead, they are joined together to act as a cladding around a separate supporting structural frame, often made from glulam (glued laminated timber), steel or concrete. These panels are primarily suitable for commercial or industrial



Hemclad® panels are used in this large commercial building.

Panels being made at the factory. *Image: Lime Technology Ltd*

developments, owing to their cost and scale, but have also been used around oak frames in residential buildings. Both types of panel can be manufactured and supplied in bespoke sizes, and are supplied in a range of U-values, depending on the requirements of the client.

The panels are air-dried at the manufacturing plant, which involves blowing air through them to achieve faster drying, and during the winter this air may be heated. Taken together with the increased use of mechanized processes and transportation, there is some doubt that pre-cast panels can claim the same level of environmental credentials as cast-in-situ hempcrete, and they are arguably less sustainable than blocks because of the additional processed materials they include. However, Lime Technology's literature confirms that the panel systems are carbon negative in terms of their embodied energy.

The predictable nature of pre-cast panels, together with their availability in bespoke sizes to fit the building design, is attractive, especially for large-scale commercial builds. While the complexity of panel systems makes them inherently more vulnerable to thermal bridging and poor airtightness compared with cast-in-situ hempcrete – perhaps even more so than with blocks – if the design of the panels is sufficiently

Panels being installed on-site. *Image: Lime Technology Ltd* robust, these issues can be overcome through detailing and the addition of extra materials into the wall build-up. The published values for thermal bridging and airtightness achieved by Hembuild® and Hemclad® are certainly a demonstration of this. Unfortunately, however, the solution of using expanding tapes between panels to achieve airtightness means the addition of a high-embodied-energy, synthetic material into the wall build-up.

Cast-in-situ versus pre-cast hempcrete

The main advantage of pre-cast panels and blocks is that the hempcrete is already dried before it arrives on-site. This means that plastering can begin almost as soon as the wall construction phase is complete, whereas cast-in-situ hempcrete walls take several weeks to dry sufficiently for finishes to be applied, and this is dependent on local conditions. During the winter months this drying process makes casting hempcrete in situ a practical impossibility. With cast-in-situ hempcrete, factors such as temperature, exposure, humidity and effective management of drying need to be considered, accounted for and managed within the schedule of the build as a whole. The reliability and consistency of prefabricated panels or blocks are of great benefit in large-scale commercial or industrial applications, where the predictability of how the material will 'behave' once applied on-site allows for reduced costs, and is much easier to fit into a complicated, and often financially critical, schedule of works.

The cast-in-situ method, on the other hand, has the advantage of reduced labour costs because the casting and on-site construction are collapsed into a single process. The process of construction is also simpler, and is achievable with minimal mechanization. Cast-in-situ hempcrete, if it is hand-placed, needs only a mixer and a chain of people to ferry buckets of hempcrete, rather than (in the case of large pre-cast panels) a production

Hempcrete cast up against an outer skin of hempcrete blocks – combining some of the benefits of the pre-cast and cast-in-situ methods.

plant, machinery for drying, and heavy machinery on-site to hoist the panels into place.

The other main advantage of cast-in-situ hempcrete is its ability to form a continuous monolithic layer of insulating material within the fabric of the building, and to be cast into almost any shape required by the building design. This gives it a unique ability as an insulation material to minimize thermal bridging and provide exceptional airtightness.

Embodied energy

Given the appeal of hempcrete as an exceptionally low-impact building material, considerations about the embodied energy of the two methods may be pertinent to many people weighing up the pros and cons of each. Factors include the prefabrication process and transportation to the building site.

Transportation costs (both financial and environmental) may be lower for cast-in-situ hempcrete, since materials are brought straight to the site rather than first going to another location to be pre-mixed and cast. In theory the extra journeys implied in having an 'extra' stage (block or panel assembly at a factory) should equate to extra fuel in transportation, but in practice this will be dependent on, for example, the distances between farm, processing plant, factory, binder producer and building site, as well as the distance of contractor journeys to factory or site, and these all vary from job to job.

The reaction of the binder with water during casting adds some weight to the cast material, so for the same volume of finished product, the raw hemp and binder needed for cast-in-situ hempcrete are lighter to transport than pre-cast panels or blocks. Set against this, though, are the potential efficiencies of scale achievable in the model of full-load deliveries (of timber, hemp and binder) to a central production factory and then a single delivery of completed blocks or panels to site – depending on the scale of the build, the sources of materials and the distances involved. There is also the potential for greater efficiency in terms of minimizing waste at a large-scale production plant, for example by using offcut timber to heat the factory – although minimizing waste on the building site is also perfectly possible, depending on the awareness and motivation of the contractor.

The fact that energy (for fans and/or heating) is often used in the drying of pre-cast panels and blocks, and that additional machinery is required for on-site assembly of panels, means that cast-in-situ hempcrete may be expected to have a lower embodied energy than prefabricated blocks or panels in this respect. However, the unpredictable nature of the drying process for cast-in-situ material is a factor here: because the thermal efficiency of hempcrete (as with any other material) is much higher when it is dry, if finishes are applied too early, when the bulk of the hempcrete is still too wet, additional energy will be used in heating the building when it is first occupied, as the hempcrete continues to dry out.[1] In other words, depending on the skills of the contractor, the energy saved by not pre-drying the panels in the factory might instead be expended on heating the finished cast-in-situ building until the hempcrete has completely dried. This is a difficult question to settle, as detailed comparisons between the energy consumption in the two processes are required, and the type of binder or finishes used may have an effect on drying times. Further research, with full lifecycle analysis (LCA – a technique used to assess the environmental impacts associated with *all* stages of a product's life) of the processes involved, would be of great benefit.

Other uses of hemp in construction

Hempcrete is not the only material made from hemp in the construction industry. Hemp shiv is also used as a reinforcing and insulating addition to coarse lime plasters and renders, and the bast fibres, from the bark of the stem, are used in the same way to create fine finishing lime plasters. The bast fibres are also used to make natural quilt-type insulation.

A few years ago, hemp fibres were being used in the manufacture of a strong breathable hemp fibreboard for the construction industry, but at the time of writing no such board is available from natural building suppliers in the UK.

Lime–hemp plasters

Over recent years several natural and heritage building material suppliers in the UK have been supplying lime plasters that contain hemp shiv or bast fibres (see Resources). The main benefit of the hemp is to add a reinforcing structure to the plaster, in the same way that animal hair or wheat straw (and probably also hemp!) did when it was added to lime plasters historically. Tests have shown that the addition of hemp fibres to lime plaster increases its strength by more than 300 per cent.[2]

The addition of hemp also gives the plaster an increased insulation value, as a result of the air trapped in the hemp, although with suggested coverings of 20-50mm (depending on the manufacturer, product and substrate), the thermal performance is a lot lower than in a hempcrete wall. Since both the hemp and the lime within the plaster are vapour-permeable materials, these plasters preserve the breathability of traditional solid-wall structures.

Lime–hemp plasters are perhaps most often used in order to add some insulation to solid masonry walls in traditional and heritage buildings, or in sustainable new buildings where a thicker plaster may be required, for example when plastering cob, rammed earth or straw-bale walls.

In addition to the added insulation value, lime plasters reinforced with hemp have the following characteristics compared with other lime plasters:[3]

- They are more robust and so are suitable for areas vulnerable to cracking and knocks.
- They experience less shrinkage, and so need less tending after application and are more suitable for patching in and making repairs to existing plaster.
- No meshing or hair addition is required if the plaster is applied in coats of at least 10mm.
- They can be applied in a single coat of up to 25mm, depending on the product and the substrate.
- It is not usually necessary for the substrate to be wetted down before the plaster is applied,

A lime–hemp basecoat plaster created from raw materials on-site.

since they hold more water than a standard lime plaster.

- Because they hold more water, they also need less tending after application.
- They take longer to dry out – anything from a week to a month or more, depending on the substrate, the thickness applied and the weather conditions.

If you have built a hempcrete wall, unless it is a very thin one, then you already have enough insulation without adding it in the plaster, so at Hemp-LimeConstruct we have limited experience of these plasters and have not used any of the proprietary products available. We have, however, mixed our own lime–hemp plasters, with both coarse and fine hemp, when working on heritage buildings or when dubbing out uneven masonry walls. The extra structure the hemp provides enables a thicker coat of plaster to be applied, and we have found it an effective solution, and the plasters to be a pleasure to work with.

In the products currently on the market, different grades of hemp fibre are used to create plasters described as either coarse, medium or fine. Quite a variety is available from the different manufacturers, although most lime–hemp plasters are supplied as a ready-mixed 'wet' product made with air lime. Womersley's supply a plaster that is mixed from quick lime and hemp with pozzolanic additives to ensure that it sets throughout the depth of the plaster; perhaps because of this, the maximum depth of coat advised is higher than for some of the other lime–hemp plasters on the market.[4] See Chapter 3 for more information about different types of lime.

Hemp-fibre quilt insulation

The natural, breathable quilt insulation made from hemp bast fibres provides a sustainable alternative to conventional glass wool or mineral wool insulation products, such as is used for loft insulation. Various companies in the UK (see Resources) currently produce quilt-type insulation materials made from natural fibres: usually sheep's wool, wood, flax or hemp fibre. These offer a healthier and safer alternative to conventional synthetic quilt insulations, which are often made from irritant or toxic materials.

Natural-fibre insulations have an equivalent or better thermal performance than conventional quilt insulations, with a typical thermal conductivity of around 0.04W/mK and a typical U-value of 0.16 at a thickness of 250mm. (Thermal conductivity is a measure of a material's ability to conduct heat. A material's U-value describes the ease with which it allows heat to pass through it – this varies with its thickness.) There is also evidence that natural-fibre insulations remain effective over a longer period of time than synthetic products.[5]

Hemp-fibre insulation, in particular, provides additional environmental benefits. Thanks to the levels of carbon dioxide taken up by the hemp when it was growing (faster than wood, as hemp creates a woody stem in just months), hemp-fibre insulation can, like hempcrete, lay claim to having *negative* net carbon emissions – locking away more carbon in the product than was used in its production and manufacture. The production processes, according to manufacturers' literature, use significantly less energy than that for synthetic insulation products.[6]

The strength of the hemp fibres gives the insulation quilt a natural durability that allows it to keep its structure well over time, compared with synthetic insulation quilts, which often sag as they age and can collapse into a thinner layer in the presence of moisture, resulting in reduced insulation performance. This self-supporting structure makes hemp fibre suitable for warm


Hemp-fibre quilt insulation.

lofts (insulating between the rafters) and even, according to the manufacturers, for use in timber-frame walls.

The cell structure of the fibres, combined with the low density and open structure of the quilt, allows hemp-fibre insulation to attract and hold moisture from the surrounding atmosphere, releasing it again in response to a reduction in humidity. This characteristic ('hygroscopicity' – see Chapter 4, page 56) makes it especially suitable for buildings whose fabric is designed to be permeable to moisture vapour, such as heritage properties and hempcrete buildings.

Hemp-fibre insulation can absorb up to 20 per cent of its weight in moisture without any reduction in thermal performance, in contrast to many synthetic quilt insulations, which deteriorate significantly when they get wet.[7]

To consolidate the hemp fibres into the quilt insulation, there is a need for an adhesive binder, which is heat-sealed into the insulation during manufacture. This is typically recycled polyester, which means that such hemp insulation cannot claim to be a *completely* natural product. It is worth noting, for those wishing to minimize the presence of synthetic materials in the fabric of their building, that different manufacturers of hemp-fibre insulation use significantly different amounts of this substance in their products.[8]

Those who are building with hempcrete, but don't wish to use it for the roof insulation, may find that hemp-fibre quilt insulation is perfect as a complementary material. It can also be used in a hempcrete building as a convenient insulating material between suspended timber floors and partition walls. At Hemp-LimeConstruct we also use the insulation quilt to help provide airtightness at junctions between hempcrete walls and building elements made from other materials (see Chapter 21, page 297).

CHAPTER THREE

An introduction to lime

The main constituent of binders used for hempcrete is building lime: a product made from naturally occurring and plentiful sources of calcium carbonate, it has been used as a building material throughout history.

Over the last few decades there has been a reawakening of interest in the use of lime in traditional buildings. This has led to an increased awareness of the qualities of a range of different building limes, and an understanding of why these are so important – not only in traditional buildings but also in natural building today. There is now a wide range of books on this fascinating and sometimes complex subject, from introductory practical guides to detailed technical manuals, and on the history of building limes (see Bibliography for some examples).

For those wanting to work with lime for the first time, we strongly recommend not only further reading but also an introductory training course (at the very least), since the application of lime mortars and plasters often differs significantly from that of equivalent modern materials. A wide choice of training courses focusing on building with lime is now available across the UK: contact the UK Building Limes Forum (see Resources) for advice and information about courses and workshop events.

The various types of building lime available on the UK market today have a range of useful properties. Certain types of building lime are used when building with hempcrete – in the hempcrete binder itself and usually also in the wet finishes, both internally and externally. The following is an overview of the different types of lime.

Lime in building

Limes have been used in building for many thousands of years. Their importance as a constituent of bedding and pointing mortars, renders and internal plasters, and in the construction of floor slabs, not only underpinned the construction

Previous page: Natural breathable finishes such as lime plasters have been used for centuries, and are now experiencing a revival.

Traditional lime plasters, such as this lime putty plaster, form vapour-permeable finishes. The surface is rubbed back to 'open it up' and improve breathability (see page 240).

and survival of the great buildings of antiquity but also accompanies the story of technological developments in construction over the last 250 years or so.

Mortars and plasters made from building lime are vapour permeable in their finished state, which has important implications for the way the fabric of the building works: helping to manage humidity within the structure and thereby keep the materials used to construct it in good condition. Because lime is also hygroscopic, lime mortars and plasters help to 'buffer' humidity levels in the building, which is also beneficial to the health of the occupants (see Chapter 4, pages 56 and 58).

Lime for building is produced from calcium carbonate ($CaCO_3$), found naturally in quarried limestone, chalk, coral rocks or shell. The raw materials are burnt in a kiln, causing a chemical change to occur: carbon dioxide (CO_2) is given off, leaving behind calcium oxide (CaO) – a substance known as 'quicklime'. Quicklime is a highly reactive material that produces a large amount of heat when mixed with water. It needs storing and handling very carefully, as it can easily cause serious injury during handling and can start fires if it gets damp during storage.

When quicklime is mixed with water, in a process known as 'slaking', calcium hydroxide ($Ca(OH)_2$) is produced. This is called 'hydrated lime'. This lime, when applied to a building in the form of mortar or plaster, will harden slowly by 'carbonation' – reacting with carbon dioxide from the air.

Because the end result of carbonation is calcium carbonate – the same as the original raw material – the process of transforming limestone to quicklime to hydrated lime to hardened building lime is known as the 'lime cycle'. However, in reality the carbonated lime in the building is a very different substance from the original limestone, in terms of its appearance and properties and especially in its strength and hardness.

Air limes

When producing lime from relatively pure limestone or chalk deposits, such as those commonly found throughout the British Isles, there are two options for making hydrated lime through slaking:

- If slightly more than the sufficient amount of water needed to react with the quicklime is used, the small excess of water is driven off by the heat to result in a powder known as 'dry hydrate of lime'. This powdered hydrated lime (which is commonly sold in builders' merchants as 'hydrated lime') is generally used as an additive to give some extra workability to cement mortars. It is not of sufficient quality to produce reliable and consistent lime mortars or plasters.

- If significantly too much water is added during the slaking of the quicklime, then the resulting lime runs into a free-flowing 'milk of lime'. This substance is sieved and stored in a pit until it has settled into a dense white mass, called 'lime putty', covered by a clear liquid – a saturated solution of lime known as 'lime water'.

Lime putty is always stored under water until needed, to prevent the process of carbonation beginning. It is from this substance that high-quality lime mortars and plasters are made, and it can be diluted with water, and coloured with natural pigments, to form limewash, the protective coating applied as a paint to lime renders and plasters. The desirable qualities of lime putty improve with age, with the recommended minimum for production of a quality mortar being one-month-old putty; for plaster, the minimum is three-month-old putty. Lime putty is commonly sold as six-month-aged as standard, and many examples exist of lime putty being aged for many years under water and improving in quality and workability. The particular characteristics of any given lime putty will vary slightly according to the raw materials used to produce it, the quality of the production and storage processes, and how mature it is.

The processes of burning limestone and slaking quicklime, while traditionally undertaken on a small, local scale, are impractical for most people and are dangerous if undertaken by someone who does not know what they are doing. For those who wish to find out more about these processes, we recommend contacting the UK Building Limes Forum.

Hydrated limes, owing to their carbonation through reaction with the air, are usually known as 'air limes'. Other names for them are 'calcium lime' (CL), 'pure lime' or 'fat lime' (although sometimes different names are used to refer to different qualities, e.g. a mortar made from 'fat' – putty – lime being 'fatter' than one made from dry hydrate of lime). They are sometimes also referred to as 'non-hydraulic limes' to distinguish them from 'hydraulic limes' (see overleaf). Lime putties, and many products based on them, such as limewash and ready-mixed plasters and mortars, are sold in the UK by specialist suppliers of traditional or natural building materials, and their use has become increasingly widespread over recent years.

The limes just described, which set with carbonation in the presence of air, are usually produced

'Knocking up' a pre-mixed lime putty plaster to a workable consistency before use.

With skill and patience, lime plasters can be repaired selectively in historic work by patching in new plaster to the old, retaining the areas that were still sound.

from seams of limestone that are very pure, containing a high level of calcium and few impurities in the form of clay materials. This pure form of limestone deposit is the most common type found in the geology of the British Isles.

Hydraulic limes

Since air limes set slowly over several weeks or months on exposure to air, they are not suitable for all applications. For thousands of years, masons and engineers have experimented with the use of various types of stone, and found that different types produce building limes with a range of different qualities.

It was discovered that certain types of limestone, including some chalks, produced a building lime that was able to set relatively quickly on exposure to water (hydration), instead of slowly on exposure to air (carbonation). These limes also set somewhat stronger, and have a lower level of permeability to water and water vapour than air limes. These properties made these types of lime sought after for use in certain applications where a hard set, a fast set, a set under water or resistance to moisture ingress was required: mainly for significant structural engineering works and for bridges, dams, docks and canals, water tanks and drainage systems. The limes were also extensively used for foundations in damp soils, external renders in damp climates, plasterwork in bathrooms, and as a masonry mortar with certain types of stone (hard stones). Since the 1950s, ordinary Portland cement has been widely used for most of these applications (see page 47).

Because they set through hydration in the presence of water, these limes are known as 'hydraulic limes'. In early times, the hydraulic properties of the various types of stone were usually ascribed to visible characteristics, such as the colour of the stone, but from the eighteenth century onwards there was an explosion of interest and research into the science of building limes, and it emerged that the hydraulic properties were in fact due to the presence of impurities, usually in the form of clay, in certain seams of stone. These impurities, when fired appropriately in a kiln, combine with the lime to form active compounds which in turn react with water to produce the hydraulic set. This set is *in addition* to the setting by carbonation of any remaining 'uncombined' or 'free' limes. These limes are always slaked to a powder because clearly, being hydraulic, they cannot be stored under water like a putty lime.

The impurities present in the stone that create hydraulic compounds may be soluble silica

A moderately hydraulic lime mortar is used for pointing in this wall, since the stone is very hard. For softer masonry, an air lime mortar would be appropriate.

(SiO_2), which is the most active, alumina (Al_2O_3), or ferric oxide (Fe_2O_3); the presence of ferric oxide gives a slightly 'buff' colour to those hydraulic limes when they have set.

A range of limes with differing degrees of hydraulicity has always been available, due in part to the differing amounts of impurities present in the original stone, and in part to the temperature at which they are fired. Hydraulic limes are usually classified as 'feebly', 'moderately' or 'eminently' hydraulic, depending on their strength and other characteristics. In feebly hydraulic limes – the type most commonly found in the UK – there is still a lot of 'free' lime in the material, so much of the set happens due to carbonation, with a relatively weak accompanying hydraulic set. In moderately or eminently hydraulic limes, there is far less free lime present, and a stronger hydraulic set is responsible for the majority of the setting process.

Suitable limestone for producing moderately and eminently hydraulic limes occurs less often in the UK geology, and where such seams do exist they have been found to lack the impurities at consistent levels to produce limes with reliable characteristics. The best moderately and eminently hydraulic limes to be found close to the UK are produced in France.

'Natural hydraulic lime' (NHL), produced from naturally occurring impure chalk and limestone (in contrast to 'formulated hydraulic limes' – see overleaf), is sold in a range of strengths, for example feebly hydraulic (NHL 1, NHL 2), moderately hydraulic (NHL 3.5) and eminently hydraulic (NHL 5). These are sold in specialist builders' merchants in the UK, and more recently NHL 3.5 is also sometimes stocked, or at least available to order, in general builders' merchants. Hydraulic limes are easier to use than air limes for those who have experience of using Portland cement, since their preparation and application is more akin to that of cement.

Natural cements

In limestone in which a very high level of impurities is present, there is sometimes not even enough free lime to enable the lumps of burnt lime to break down on slaking. These types of hydraulic lime are instead ground to a fine powder, to which water is added to form a mortar. They set very quickly and give a very high strength on the addition of water, which has led to their description as 'natural cements'. In fact, natural cements are so quick to set that a retardant chemical is often added at the point of mixing, to give a longer working time.

Such extremely hydraulic limes were used by the Romans in many of their large-scale engineering works, and one particular naturally occurring cement was patented and marketed as 'Roman cement' by James Parker from the end of the eighteenth century. No seams of stone suitable for the production of natural cements exist within the UK; the nearest location in which they are produced is southern France.

One natural cement on the market today, which is now sold as a hempcrete binder, is Vicat's Prompt Natural Cement (see Chapter 6, page 80). Prompt is supplied with a retardant, Tempo (powdered citric acid), which is added on mixing to delay the setting and increase working time.

Other than the difference in production process (grinding rather than slaking) and the extremely fast and hard set, natural cements are largely the same as other hydraulic limes. They retain the important property of vapour permeability, but they are hydrophobic – they repel liquid water.

Natural cements were often used in Roman engineering works, such as this Roman watchtower in Nîmes.

Prompt Natural Cement is mixed with citric acid to extend its working time.

Pozzolans and formulated limes

Throughout history, wherever hydraulic limes were not available, people have added a range of other substances to air limes that react with the calcium in the presence of water to give the mortar or render a degree of hydraulic set, where this was desirable or necessary. The properties of such 'pozzolans' or 'pozzolanic additives' were probably originally discovered by accident, perhaps through the inclusion of swept-up waste materials on a building site into the mix for a mortar.

These pozzolans all contain a form of very finely divided clay, which combine with some of the free limes present in air limes to produce a hydraulic effect similar to that achieved in naturally occurring hydraulic limes. Examples of pozzolans include certain volcanic ashes (such as pozzolana, found in Pozzuoli, near Naples in Italy, which gave its name to this type of additive), crushed clay brick dust or pulverized fly ash (ash produced by power stations that burn pulverised coal).

The use of pozzolans to create artificial hydraulic limes continues today, especially in the UK, where there has always been a drive to achieve a more hydraulic set than is achievable with locally occurring materials.

Pozzolans can be added to air limes by the builder at the point of mixing or using the mortar or render, and are sold in their raw state from traditional building suppliers for this purpose. In addition, some companies have produced ready-mixed artificial hydraulic limes from dry hydrate of lime (sold as 'hydrated lime') and pozzolans. Such limes are known as 'formulated hydraulic limes' (usually called either FL or HL – to distinguish them from the 'natural' NHL), and are usually sold through specialist building material suppliers.

Portland cement

The increased interest from the 1750s onwards in the properties of different building limes led to many artificial limes being synthesized and patented in an effort to create mortars with particular desirable characteristics.

The most significant development was the patenting of Portland cement, by Joseph Aspdin, a Leeds bricklayer, in 1824. Portland cement is formed by the burning of specific quantities of limestone and clay-containing materials at very high temperatures. Since it has many of the same setting properties as natural cements, it took a long time for Portland cement to replace lime in the construction industry, owing to its initial high cost and the fact that limes had always been available locally. But its use really took off from the early twentieth century, and by the post-war period of the 1950s and 1960s, ordinary Portland cement had all but replaced hydraulic lime for mortars, renders and engineering applications in UK construction.

The main advantage of Portland cement over most building limes was its hard and predictable set, giving mortars with greater structural performance and strength in tension compared with the softer-setting lime. Also, cement's shorter curing time meant that builders could go on working into the colder months; masonry construction had traditionally been a seasonal activity, dependent on the minimum temperatures required while lime mortars and renders slowly re-carbonated. Building in the colder months meant an increase in productivity and profits, and if the weather became colder still, the proportion of cement in the mix could be increased from 4:1 to 3:1 (sand:cement) to decrease curing times still further. Of course these advantages were already available to builders through the use of natural cements, but since these tend to have a natural buff colour on drying, they were not ideal for one of their major uses: the imitation of stone in, for example, decorative cornices or statues. It was the desire to create a cement with a similar grey colour to that of many stones that was the driving force behind the first innovation in artificial cements.

Significantly, in contrast to those made from lime, mortars and renders made from Portland cement have very little permeability to moisture vapour. This characteristic was initially welcomed, and cement enthusiastically used to apply a 'waterproof' barrier, both in engineering works and to houses and other buildings as an external render.

Cement causes damage to natural materials because it is not breathable enough. Here, bricks originally laid in lime mortar have been repointed in Portland cement, which is harder than the brick. Any water that penetrates into the face of the brick, instead of wicking away into the softer mortar, now stays there – and when it freezes it expands, blowing the face of the brick.

The merits of the ubiquitous use of Portland cement in the new construction of the post-war period is itself questionable with hindsight, but its use for the repair of older buildings – originally built with lime mortars and renders – was disastrous. The application of cement stopped these buildings from working properly, allowing moisture to become trapped in the fabric of the building and leading to the rapid deterioration of the natural materials used in their construction.

Since the 1980s there has been a growing understanding of the damage done to traditional and historic buildings through the use of cement and, as we saw in the last chapter, there has been a huge resurgence in the use of lime mortars and renders in older buildings, especially in historically significant buildings, where the importance of lime in preserving these structures in good repair is now widely recognized.

From the point of view of those interested in sustainable building, limes are also preferable to cement for a number of other reasons:

- The burning temperatures needed for the production of limes are lower than for cement (approximately 900°C compared with around 1,400°C), so their embodied energy is lower in that respect.
- Those limes that set by carbonation *reabsorb* carbon dioxide during the setting process, thus taking *out* of the atmosphere at least some of the CO_2 that was given off during the manufacturing process.
- Limes can help to ensure a healthy indoor air quality in buildings, reducing the need for powered air-conditioning systems.

Gypsum

At about the same time as cement took over from lime in mortars and renders, the UK saw the use of lime in plastering almost completely replaced by gypsum.

The appeal of internal plasters made from gypsum (calcium sulphate, $CaSO_4$) instead of lime was primarily their ease of workability and fine finish. Gypsum plasters had been available for centuries, but were previously too expensive to be used anywhere other than in the grandest houses. Industrial quarrying and mass production methods in the early twentieth century, including

Lime and gypsum plasters side by side. The finish of the cream-coloured lime plaster around the window appears more textured and warm than the smooth gypsum on the surrounding walls and ceiling.

the ready availability of cheap pre-cast gypsum plasterboards, suddenly made gypsum plasters cost-effective in the post-war housing boom.

Like lime, gypsum plasters are hygroscopic, with a good ability to absorb moisture vapour. However, unlike lime, which allows moisture to pass in and out of it easily without significant damage to the structure of the plaster or mortar (such finishes are designed to be reapplied eventually), gypsum *holds on* to any moisture it absorbs. Moisture is locked within the structure of the plaster until it reaches saturation level, at which point the plaster's structure collapses and it falls off the wall. For this reason, gypsum plasters, usually used together with non-vapour-permeable paints, were not really a successful replacement for lime plasters in older buildings. Like cement, they contributed to the building not working as it was intended to (see Chapter 4, page 58).

Limes: summary

While debate has always raged (and continues to do so) in both the heritage and sustainable building industries about which type of lime is the 'most authentic' or 'best', such arguments are largely meaningless. A quick glance at the historical use of lime teaches us that building limes were always used, as they are today, in a range of forms to suit a range of requirements. The different characteristics of the different types of lime are each appropriate to different applications. The variety of limes available is perhaps best viewed as a kind of 'toolkit' of binders for use in mortars, renders and plasters, combined with a wide range of different materials. Anyone who claims to have a preferred form of lime is either missing the point or only ever does one kind of work.

In considering building limes, the key issue to understand, other than the techniques involved in applying lime plasters and mortars (which are varied and sometimes complex, and beyond the scope of this book to discuss in detail), is that of vapour permeability and the way in which this helps to keep the building in good health. See page 58 for more on this subject.

An important rule of thumb when considering the construction of a wall is to have harder, less permeable substances towards the centre of the wall, and softer materials, with greater permeability, towards the outside. This favours the transportation of moisture out of the fabric of the wall. It would therefore be advisable, taking a stone wall as an example, to use a moderately

Traditional buildings were kept healthy by the breathability of building lime. The walls of this cottage are built from a combination of natural materials: stone, brick and a timber frame. Lime was used in bedding mortars for the masonry, and probably in the wattle-and-daub panels in the timber frame, as well as in the plaster and render.

hydraulic lime for the bedding mortar, and to point and render with feebly hydraulic lime or air limes, rather than the other way around (see photo on page 48).

An overview of the types of naturally occurring lime, with their main characteristics and examples of each type, is given in the table below.

Characteristics of natural limes

Type	Example	Setting process	Speed of set	Structural integrity	Vapour permeability	Strength
Air lime / calcium lime (CL)	Putty lime	Carbonation	Slow ↑	Soft ↑	More ↑	Low ↑
Natural hydraulic lime (NHL)	Feebly hydraulic (NHL 1-2)	Mostly carbonation				
	Moderately hydraulic (NHL 2.5-3.5)	Mixture of carbonation & hydraulic set				
	Eminently hydraulic (NHL 5)	Mostly hydraulic set	↓	↓	↓	↓
	Natural cements, e.g. Prompt Natural Cement	Hydraulic set	Fast	Hard	Less	High

People concerned about sustainability who are using building limes in the UK generally consider that it is preferable to use air limes or feebly hydraulic limes, since the raw materials needed to produce these are found in the UK. This is a sensible assumption, as increased transport costs certainly increase embodied energy. However, as we saw in the last chapter regarding the different methods of hempcrete production, many factors combine to make up the total embodied energy of any given product, not least the energy used in the manufacturing process. And until all building materials are subjected to proper lifecycle analysis and carbon profiling (calculation of carbon emissions – both those associated with a building's use and in terms of embodied energy) – and companies are required to share this openly – it is hard to tell how much difference choosing a particular material will make. It may be that in countries such as France, where lime is more routinely used than in the UK, increased efficiencies of scale in manufacturing plant may offset the energy used in transportation to the UK. In any case, considering that many of the building materials used in the UK are shipped halfway around the world, getting lime from France could be seen as sourcing locally.

Lime in hempcrete building

Throughout this book we refer to hempcrete being a mixture of hemp shiv, water and a 'lime-based' binder. This is in order to convey the idea that various different hempcrete binders exist (and new ones are being formulated all the time), all of which are based on different combinations of naturally occurring lime products, sometimes together with pozzolans or other additives.

Due to the construction process used in cast-in-situ hempcrete, a pure air lime or hydraulic lime binder is not sufficiently strong, although they may be suitable in pre-cast applications such as panels or blocks, or if building up the wall *very* slowly. This is because in the cast-in-situ method the wall must support its own weight while it dries, but blocks and panels can be cast, and dried, flat on the ground.

Those binders currently used extensively and successfully in the UK for cast-in-situ hempcrete are either a natural cement or a proprietary formulated hempcrete binder. The proprietary binders' exact constituents are a closely guarded secret, but they are thought to contain a majority of air lime, possibly with some hydraulic lime or a pozzolan, and a proportion of Portland cement to give the fast hydraulic set necessary at the start of the setting process.

For more information on binders, see Chapter 6.

The use of lime in the plaster and render finishes for hempcrete walls, and in limewash if used, is discussed in more detail in Chapter 18.

CHAPTER FOUR

Key concepts in sustainable building

Before we go on to look in detail at building with hempcrete, it is worth briefly examining some key concepts and ideas that underlie the use of this construction material. A good grasp of these ideas will help to inform sensible choices during the design and construction phases of the build process.

Although most people who choose to use hempcrete today generally have a good understanding of these concepts, at present, in the UK at least, these vital factors are largely ignored within the legislative and regulatory framework relating to the construction industry. This means that there is also limited awareness of these ideas in wider society, which is an impediment to the wider use of truly sustainable construction methods.

Zero-carbon buildings?

We live in a world increasingly aware of the need to minimize fossil-fuel use and limit the emissions of carbon dioxide into the Earth's atmosphere. The construction industry in the UK is responsible for an estimated 64 per cent of all UK carbon emissions.[1] This enormous carbon bill comes both from the energy consumed in the construction of the built environment and from that used by the buildings' occupants during the lifetime of those buildings.

Clearly there is an urgent need to move to methods of building, and construction materials, that are responsible for less CO_2 emissions in their manufacture and use. In addition, to reduce the energy consumed during a building's lifetime (most significantly in heating and, in hot

Previous page: Hempcrete house in a new development in Oxfordshire, clad in local stone to reflect the local

A truly 'zero-carbon' building, built from cob (mixed from clay dug on-site), hempcrete and timber. The embodied energy associated with this family home is much lower than that for a conventional building.

climates, cooling the building) we need to ensure that the construction materials and designs are able to deliver energy-efficient buildings, which work passively to regulate internal temperatures and so need less fuel to heat or cool them. Third, since knocking down inefficient buildings and building new, efficient ones in their place would use far more energy than it saves, we urgently need to upgrade the thermal performance of our existing housing stock to bring it up to (or closer to) the current standards.

In February 2013 the UK government reaffirmed its commitment to its own target for all new homes to be 'zero carbon' from 2016. The concept of 'zero-carbon homes', as defined by the government, has always focused to a worrying extent on energy in use, ignoring the embodied energy in materials used to achieve 'carbon savings' in the building. However, after complaints from the construction industry about the cost of meeting even the energy-in-use target, there has been a relaxing of the energy-saving targets set for the industry, and the definition of zero carbon has now been watered down to an extent that makes it almost completely meaningless. The current definition is that:

> Zero carbon is achieved through good fabric energy efficiency, inclusion of on-site low-carbon heat and power technologies, and use of Allowable Solutions [carbon offsetting] to compensate for carbon emissions reductions that are difficult to achieve on site.[2]

Lamentably, not only does this definition appear to focus entirely on energy in use, with no reference to lifecycle analysis (LCA) or embodied carbon, but it even then offers contractors a 'buy-out' alternative to putting effective measures in place. In light of this, the chance that we will have anything resembling zero-carbon homes by 2036, let alone the government's target of 2016, seems increasingly unlikely.

Synthetic insulation

The insulation value of materials that can be introduced into our homes, both new and existing, to reduce energy loss through the building's fabric is of course a necessary focus. But unfortunately there has been no thought given in the regulatory framework to the *embodied* energy of any particular product.

Most highly efficient insulation materials are responsible for very high carbon emissions in their manufacturing process, and in many cases are made from the very carbon-based petrochemicals the use of which we are trying to limit. In addition, these materials are often made many thousands of miles away from the location in which they are used, and are therefore responsible for significant fuel use in their transport.

To properly assess a material's embodied energy means conducting a thorough LCA of the carbon emissions associated with it at every stage during its life. This includes the carbon cost of obtaining the raw material, the manufacturing processes, transport, how it is used, the implications of its use compared with an equivalent material, and removal and disposal or recycling at the end of its life. The failure to gather this information and use it for meaningful comparison between different materials has led to a rush towards the use of high-embodied-energy, synthetic insulation products and a blind assumption that 'any extra energy consumed now will be worthwhile for the energy savings further down the line'. Unfortunately, the more that we examine the true figures involved, this simply doesn't stack up, with synthetic solutions often consuming more energy in their production than they will save in the next 20-30 years.[3]

Furthermore, there is concern that the indiscriminate use of synthetic insulation products is contributing to hazardous indoor air quality conditions in many buildings. Lightweight insulation materials rely for their effectiveness on stopping the loss of heated air from the building. This obviously requires the elimination of any open channels or gaps in the fabric of the building where air can leak out – or in. These increased levels of airtightness in buildings have the effect of reducing the natural ventilation of the indoor environment which was historically the case.

Many synthetic insulations contain toxic chemicals or volatile organic compounds (VOCs), mainly in the form of adhesives and fire retardants added to the material, which are known to give off harmful gases into the indoor atmosphere. Because of this, the poor indoor air quality in some buildings in which high levels of synthetic insulation are combined with high levels of airtightness is increasingly becoming a cause for concern. The solution to this problem is usually to install mechanical ventilation and heat-recovery (MVHR) systems into buildings at great expense, thereby ensuring even more consumption of fossil fuels in their operation during the lifetime of the building. There is growing evidence that in some instances, especially where mistakes are made in detailing of MVHR systems and/or air vents, indoor air quality quickly falls far below standards fit for human habitation, owing to both the minimal ventilation and the high concentration of synthetic materials containing VOCs.[4]

Until we have proper carbon profiling and LCA of individual insulation materials, allowing meaningful analysis and comparison of the full range of materials available, it will be difficult to make truly informed choices of insulation material. Sadly, many of the synthetic insulation materials are produced by powerful multinational companies, who are a powerful lobby group with the UK government, which has obvious implications for regulatory decision-making about the true carbon cost and health costs of such materials.

Sustainable construction materials

Clearly there is a need for truly *sustainable* insulation materials: ones that are produced locally to where they are used, take their raw materials from a renewable source, and have the minimum of energy use associated with their production and use. To help reduce carbon emissions once in use, they must also achieve a high level of thermal performance.

The type of material urgently needed if we are to make meaningful progress in reducing the huge contribution made by the construction industry to CO_2 emissions might best be described as a *low-impact* material. This is one that represents minimal consumption of fossil fuels, has no negative impact on human health, and does not cause any harm to the wider environment in its production, use or disposal at end of life.

For some time now, proponents of natural building have been highlighting the benefits of using natural materials in construction, for example stone, timber, earth, clay, straw, hemp, sheep's wool and reed. Such materials have a proven track record over thousands of years in providing healthy homes, and in some cases they also boast significant thermal performance. Moreover, at the end of a building's life, natural materials used in its construction (if they are not reused in another building) can be buried or left to break down naturally, rather than needing to go into landfill or be disposed of carefully, as they do not contain toxic substances.

Not all natural materials are sustainable, however. For example, slow-growing hardwoods such as oak, while sequestering ('locking up') a lot of carbon, are not able to replenish themselves quickly enough through natural regeneration to constitute a sustainable resource. Others, such as wheat straw and hemp shiv, are fast-growing annual crops, which in both cases are essentially 'waste' or by-products from a useful crop. These are truly renewable, low-impact and sustainable materials.

The UK is not able to supply all of its own timber needs, and timber brought halfway around the world, whether or not it is from a monitored sustainable forestry, will never be truly low impact. In the case of stone, despite the presence of a large amount of stone suitable for building in the UK, the relative cost of extracting it, and market monopolies, has led to the importation of 'cheaper' stone from the Far East. Unfortunately, until the real cost (in carbon emissions) is priced into this market, or until fuel costs rise dramatically enough to affect market prices, these unsustainable practices are likely to continue.

Natural insulation

Because natural low-impact insulating materials, such as hemp, wood fibre, sheep's wool and straw, are not yet used in sufficient quantities to be widely available in general builders' merchants and DIY stores, and in some cases remain comparatively expensive owing to the current relatively low demand, they are often overlooked in favour of conventional synthetic products. However, there are great benefits to their use.

In particular, they are produced from materials that are sourced locally, and their manufacturing processes are often relatively low in energy. Lightweight insulation quilts made from natural fibres do usually contain a certain amount of synthetic polymer binder or chemical fire retardant, but denser natural insulations that are used as a solid walling material, such as straw bale and hempcrete, do not contain such additives.

A particular quality of most natural materials that is not shared by most synthetic materials is that they act in a 'hygroscopic' way. This describes the ability of a substance to attract and hold moisture from the nearby air. Cellulose-containing natural insulation materials, such as wood, hemp and straw, are good at doing this because of their micro-porous structure at a cellular level. Natural materials therefore have the ability to 'buffer' moisture levels in the indoor atmosphere, by absorbing water vapour during times of high relative humidity and releasing it again when the relative humidity of the surrounding air falls. This has important implications for the health of a building's occupants (see page 65).

A new-build housing estate constructed with structural timber frames and hempcrete or wood-fibre insulation.

Carbon negative (a positive effect!)

Because many natural building materials start their life as plants, they take up carbon dioxide from the atmosphere as they are growing. When they are turned into construction materials and used in a building, this prevents the re-release of the CO_2 back into the atmosphere, as would happen if the plant were left to rot down at the end of its life.

In effect, by using plant materials in building we are *sequestering* carbon: locking it away in the building's fabric, where it will stay for the building's lifetime (after which the materials will either rot down or may be reused in another construction).

Often, and this is the case with hempcrete,[5] natural materials are responsible for negative net carbon emissions – i.e. they lock up more CO_2 in the building than is emitted during their production, processing, transportation and any processes involved in their disposal at the end of the structure's life. This has led to such materials being described as 'carbon negative': a slightly confusing term which doesn't quite have the positive ring to it that it deserves. For this reason, other terms have been introduced in an effort to express the concept more clearly, such as 'better than zero carbon' and 'acting as a carbon sink'.

This last is probably a more accurate description, because if the material is left to decompose at the end of the building's life (instead of being recycled into another building), the CO_2 absorbed during the growth of the hemp plant would be released back into the atmosphere. If the building lasts for hundreds of years, however, the carbon storage at this crucial point in history, as the effects of climate changes become increasingly apparent, is a huge advantage.

The traditional breathable wall

Of course, building with local, natural, low-impact materials is nothing new. Before the industrial revolution, these were the only materials that were available to people.

This led to the construction of simple, functional buildings, which were often built by the people who would occupy them. The fabric of these buildings, more (we assume) by default than design, had an interesting quality inherent in the materials from which it was made. It was, with the exception (usually) of the roof covering, permeable to water vapour.

The significance of the building fabric being vapour permeable, or 'breathable', is that rather than moisture being kept out, as we try to do in modern construction, with damp-proof membranes (DPMs) and synthetic vapour barriers, it was free to pass in and out of the building fabric as water vapour. (Note that a material being permeable to water *vapour* does not mean it is necessarily permeable to liquid water. Modern vapour-permeable membranes – 'breather' membranes – for example, prevent the transmission of liquid water.) It was important for the moisture content in walls to remain below a certain level, for the thermal performance of the wall (through its thermal mass, see page 63) to be maintained. However, unless something had gone wrong, appropriate moisture levels were maintained passively by the permeable nature of the materials, coupled with the fact that the living space was heated with a wood fire: the two combining to ensure that moisture wasn't trapped inside the fabric of the building, where it could cause structural damage.

Traditional building materials allow moisture to pass through, keeping the structure in good 'health'.

It can be seen, then, that natural materials' 'breathability' maintained the structure of the building in good 'health' and ensured that the thermal performance of the fabric was not compromised. Unfortunately, in the second half of the twentieth century, the cheap availability of synthetic materials – which are usually not vapour permeable – and the widespread use of very hard cement renders and mortars externally, and gypsum plasters and non-vapour-permeable paints and varnishes internally, led to some ill-advised 'repair' work to older buildings. The application of inappropriate materials often stopped the 'breathing' wall from working properly and resulted in damage to the structure. Only in recent years have we understood the damage done to our older buildings in this way, and begun to put right the mistakes of the past.

Figures 1 and 2, on the following two pages, show a traditional breathable solid wall in good working condition and what happens when things go wrong.

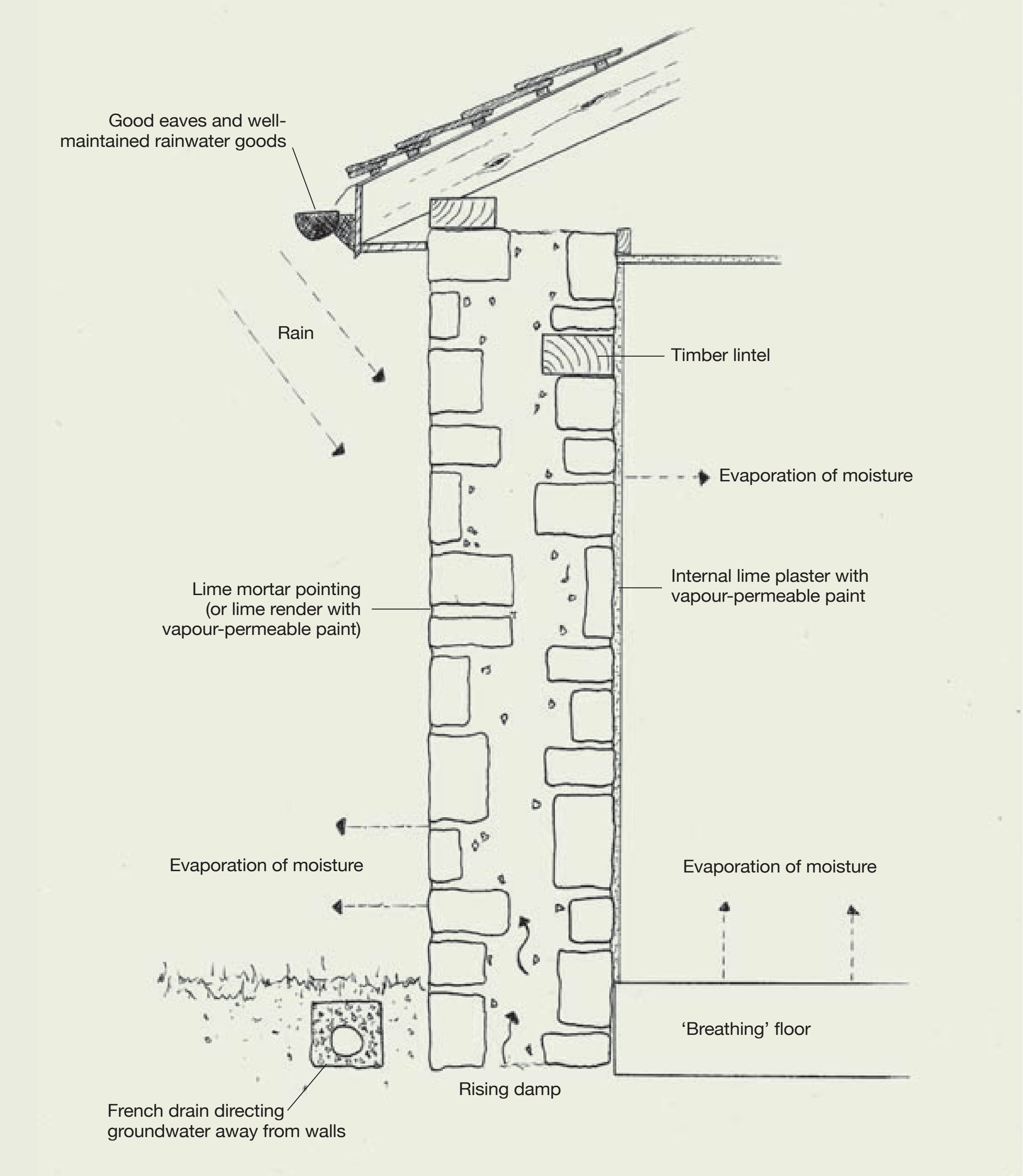


Figure 1. A wall in a traditional building working as it was intended to, with natural vapour-permeable materials allowing passage of moisture in and out of the building's fabric. *Based on an original image © Tŷ-Mawr Lime Ltd*

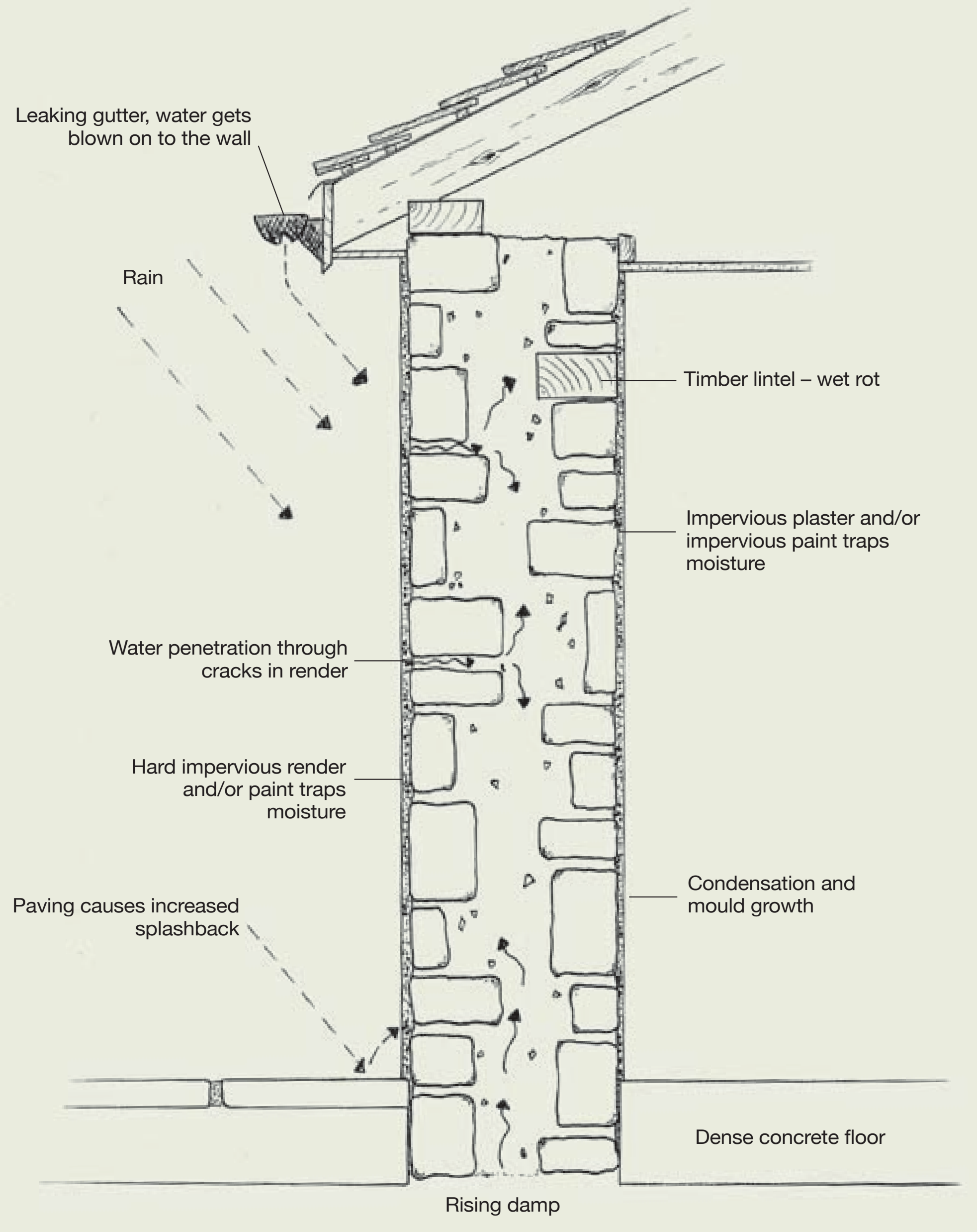


Figure 2. A traditional wall prevented from working as intended. Repair using non-vapour-permeable materials means that any moisture that enters the wall is trapped there. *Based on an original image © Tŷ-Mawr Lime Ltd*

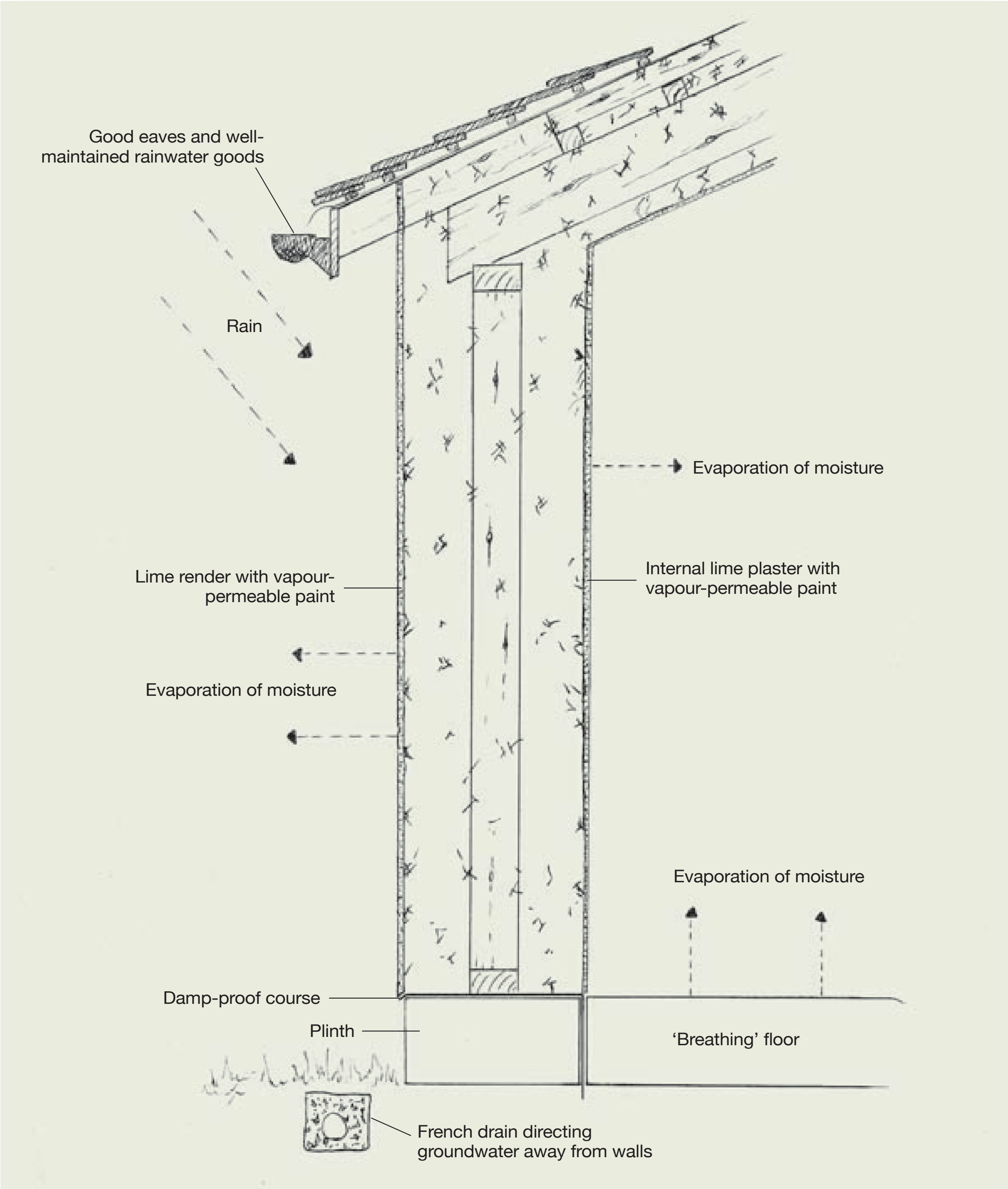


Figure 3. How vapour permeability works in a hempcrete wall.

In Figure 1, all the materials are vapour permeable, so any moisture that enters the wall (whether from rising damp, rain, or internal sources such as cooking) is allowed to leave again by natural evaporation before any ill effects are caused.

In Figure 2, the use of modern non-vapour-permeable materials has stopped the wall from 'breathing', so any moisture that finds its way in gets trapped there, reducing the thermal efficiency of the solid wall and potentially causing damage to the building's fabric. Such non-permeable materials were often introduced intentionally, as in the case of external cement render, which was frequently added as a 'weather-proofing' measure. Unfortunately, this barrier to rain only works for a few years before the brittle cement cracks in response to small movements in the building. Once cracks appear, moisture finds its way in, and then becomes trapped in the wall behind the (mostly) impermeable layer of the cement. Such well-intended repairs, and their unintended consequences – in particular the 'double whammy' of cement externally and gypsum internally – has given many old buildings an undeserved reputation for being cold and damp, which is often not the case when materials are replaced appropriately and the walls are allowed to dry out.

Figure 3 (page 61) shows a hempcrete wall, which is vapour permeable and shares many of the characteristics of a traditional wall. The main difference is that hempcrete walls are usually built with a damp-proof course (DPC) between the plinth and the hempcrete. This detail is borrowed from conventional modern construction methods, and is thought to be a sensible precaution to stop any transmission of rising damp up into the hempcrete, which, being a plant-based material, is more vulnerable to damage through prolonged exposure to moisture than brick, for example. In theory, however, with a suitably breathable plinth and free-draining foundation, there should be no reason why a hempcrete wall could not be built without a DPC.

Aspects of thermal performance

Finally, with hempcrete in mind, it is worth considering some particularly important characteristics that it possesses. These relate to its thermal performance, which after all is the driving reason for using any insulation material, whether natural or synthetic.

Insulation

Hempcrete is a medium-density material compared with other building materials and, in contrast to other walling materials (e.g. stone, brick or concrete), it is relatively lightweight, as it contains a lot of air. In the finished hempcrete wall, air is trapped not only in the microscopic pore structure of the hemp shiv but also in the air channels and pockets formed by the interlocking particles of hemp shiv in the cast material.

Because of this trapped air, a hempcrete wall provides a much better level of insulation than other general walling materials, although compared with specific insulation products, for example very lightweight fibre insulations such as hemp or wood fibre, or sheep's wool, hempcrete performs less well – at an equivalent thickness. However, because hempcrete is much cheaper than processed insulation materials, and because it is of medium density, it can be (and usually is) used to create the whole thickness of a monolithic wall, with only thin render and plaster finishes or cladding on the exterior and interior surfaces. This means that the thickness of the cast hempcrete insulation is commonly between 300mm and 400mm – the whole thickness of the wall – which is enough material to provide a very high standard of insulation. Typical U-values achieved for such a wall are 0.2-0.15W/m^{2}K (see Chapter 7, page 96), which exceeds the standards expected for wall insulation in new-build properties under UK Building Regulations. Furthermore, because of the combined effect of its insulative properties and its thermal mass (see below), hempcrete's thermal performance is regularly found to be better in real buildings than theoretical U-value calculations would suggest.

Thermal mass

Traditional buildings did not make good use of insulation in their construction, perhaps because of the ready availability and low cost of fuel (timber), but more likely because these concepts were not widely understood at the time. Instead, the construction of thick solid walling with a high mass was a way to provide reasonable thermal performance.

The 'thermal mass' of a building describes its ability to absorb heat from the nearby air and release it again slowly when the air cools down, thereby 'flattening out' temperature fluctuations in the surroundings. The high thermal mass of an old building's thick walls allowed the heat produced by the fire burning during the day to be slowly absorbed by the walling materials and just as slowly released again during the night, when the fire was banked down. In the summer, the walls had the opposite effect: absorbing and holding the heat from the sun during the day and releasing it at night (see Figure 4). In these day/night warming/cooling cycles, most of the heat would be released from the same side of the wall that it entered, because the heat would be stored near that surface of the wall, thus ensuring that in summer, the interior of the building remained cooler than the external daytime temperatures.

Hempcrete combines the naturally insulating hemp, a cellulose material, with a lime-based binder, which gives a moderate density to the cast material as it sets hard. For this reason, hempcrete is unique among natural sustainable materials in offering a substantial degree of

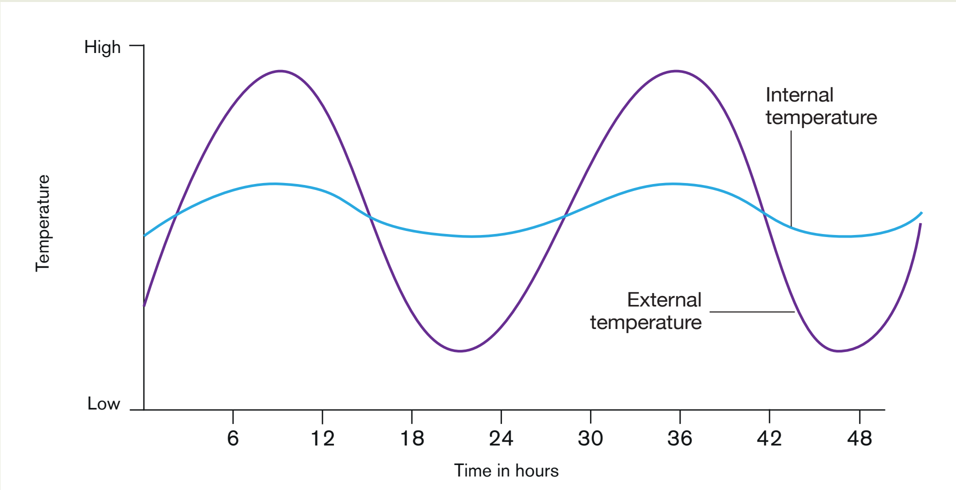


Figure 4. A building with high thermal mass 'buffers' daytime and night-time temperature variations, maintaining a steady internal temperature and thus reducing the costs of heating or cooling the building.

insulation combined with a good amount of thermal mass. In comparison, cob or rammed earth has high thermal mass but virtually no insulation value, and straw bale has good insulation value but virtually no thermal mass. Hempcrete is unique in providing both good insulation *and* good thermal mass.

The slow release of the heat stored in a hempcrete building's thermal mass, when the heat source is turned off, means that there is less fluctuation between extremes of temperature inside the building. The thermal mass in the walls *buffers* changes in internal temperature, meaning that the indoor temperature in a hempcrete building is slower to respond to changes in the outside temperature (increasing cold *or* heat) than in a building with less thermal mass.

This aspect of its thermal performance, combined with its good insulation value, makes hempcrete very efficient at regulating and maintaining internal temperatures. The building's heating and/or cooling system therefore uses less fuel than it would in an environment in which heat is lost quickly and the indoor air frequently has to be brought back up to a comfortable temperature from a low starting point.

For information on research into hempcrete's thermal performance in a building, see Chapter 7.

Thermal bridging

As described in Chapter 2, cast-in-situ hempcrete is wet-mixed and then cast as a single insulating mass, in a shape dictated by the construction of shuttering. It thereby forms a continuous flow of material around the walls – and sometimes the floors, ceiling or roof – of the building.

This feature of hempcrete as a building material, when cast in situ, allows for the easy elimination of thermal bridging, or 'cold bridging'. This often occurs at points around the structure of a building, where a material with higher thermal conductivity forms a connecting passage across the insulating layer, from the outside air to the inside. Such 'bridges' allow the escape of heat from the indoor environment through the 'tunnel' of the less insulating material, and often result in localized cold spots where condensation can occur, promoting mould growth.

Cast-in-situ hempcrete forms a continuous mass, reducing thermal bridging.

With hempcrete cast as a continuous mass, it is quite straightforward to design out cold bridging in a hempcrete building, compared with a building whose walls are constructed from a build-up of different materials. The most challenging area in which to avoid cold bridges is the insulation of the plinth at the foot of the hempcrete wall.

Airtightness

Airtightness is an important consideration in the construction of buildings to a modern standard. The increasing emphasis on the conservation of energy has led to a focus on the amount of energy wasted in 'leaky' buildings, through heat that escapes through holes that allow the passage of air. In conventional construction, certain materials, for example membranes, are used for the specific purpose of adding an airtight perimeter to the interior heated space of the building. Due to the complexity and multi-material nature of modern construction, however, this airtight perimeter is vulnerable where sections of this membrane overlap and are joined (usually by a tape), and at junctions with other materials.

The fact that hempcrete forms a continuous mass within the building's walls makes it comparatively easy to ensure airtightness. Although hempcrete is naturally porous, with an open surface, it achieves good levels of airtightness when plaster and/or render finishes are applied.

Due to its good thermal mass, hempcrete allows the use of natural ventilation of the interior space (see below right). This avoids the risks associated with high levels of airtightness in conventional buildings built with non-porous synthetic materials, and brings benefits in terms of air quality.

For more information on airtightness in a hempcrete building, see Chapter 22.

Indoor air quality

As we saw earlier in this chapter, synthetic insulation materials can cause health problems for a building's occupants, as a result of chemicals they contain 'off-gassing' into the indoor atmosphere. This is not an issue with hempcrete, which contains no toxic materials.

We have also seen that hempcrete is valuable in helping to manage humidity levels within the building because of its hygroscopic nature. This too is important for indoor air quality, because maintaining internal levels of humidity has important health consequences. If the humidity level drops too low, there is an increased risk of allergies and asthma, and if it is too high, the risk of the growth of moulds, fungi and mites rises. There is an increased risk of bacterial or viral infections, especially of the respiratory tract, if the humidity rises above *or* drops below the ideal range of 40-60 per cent relative humidity. 'Relative humidity' describes the amount of water held in a body of air, at a given temperature, expressed as a percentage of the maximum amount of water that body of air would hold if completely saturated.

The thermal mass of hempcrete also plays a part in achieving a good indoor air quality, because of its implications for ventilation practices (see box on page 311). In short, the indoor air quality in hempcrete buildings is excellent. In summary, this is achieved by:

- the hempcrete, together with lime or clay plasters, acting in a hygroscopic way – absorbing and releasing moisture and keeping the humidity of the indoor environment within levels optimal for human health
- there being no toxic chemicals or VOCs present in hempcrete to off-gas into the air
- the thermal mass of hempcrete enabling the storage of heat in the building's fabric, which is only released very slowly when the temperature of the nearby air cools, thus allowing some use of natural ventilation (i.e. opening windows) to maintain indoor air quality, without all the heat escaping.

These factors combine to ensure that a hempcrete building provides a natural, healthy and comfortable living environment with little or no recourse to mechanical ventilation systems.

CHAPTER FIVE

Getting the basics right

The main reason for constructing walls out of hempcrete is to equip the building with a very high standard of insulation without resorting to the use of synthetic insulation materials, which have a high embodied energy and are produced from non-renewable materials – usually petrochemical derivatives or synthetic fibres.

Hempcrete is a relatively new construction material, about which the general public is only just becoming aware. Perhaps because of this, we at Hemp-LimeConstruct frequently get enquiries, even from people seriously considering using the material in their building, from which it is clear that the basic principles of building with hempcrete are not fully understood. In the case of clients who are employing someone else to do the construction work, clearly there is a limit to the level of detail they actually need to know about the process. There are, however, certain concepts that they will need to understand in order to maintain their hempcrete building in good order.

For those considering building with hempcrete themselves, however, it is obviously important that they know what they are doing, and that the basic principles are understood at the start, so that mistakes are avoided later on. This chapter, therefore, provides an overview of the key principles of hempcrete building. Some of these themes have been introduced in previous chapters, and we return to them all throughout the book, but gathering them together here should serve to highlight their importance. At the end of the chapter is a brief overview of problems that can occur with hempcrete as a result of lack of understanding of the material and the construction process.

The nature of the material

Hempcrete is essentially a modern version of very old natural composite construction materials, such as wattle and daub or cob. While it is relatively low-tech in its composition and

Previous page: A freshly cast hempcrete wall.

application, the quality of workmanship throughout the construction phase can make a huge difference to the finished material.

The material is formed by wet-mixing hemp shiv (the chopped woody stem of the industrial hemp plant) with a lime-based binder. The cast-in-situ method involves casting it in 'moulds' made from temporary shuttering, which is taken down as the hempcrete begins to dry. Hempcrete is also available as pre-cast blocks or panels, but cast-in-situ hempcrete is the focus of this book.

Since hempcrete is not strong enough to be load-bearing, it is always cast around (or, in the case of pre-cast, built around) a structural frame, which supports the weight of the upper floors and roof and provides stability to the hempcrete. When subjected to excessive force in testing, hempcrete tends to 'fail' by bending, rather than breaking, and this flexibility of the cast material can be a very useful characteristic, for example enabling a hempcrete building to tolerate small ground movements over time.

Hempcrete has very good thermal performance, partly owing to the insulation provided by the air trapped within the cast material, and partly owing to the relatively high thermal mass of the finished material, which means it can store heat. For more details, see Chapter 4, page 62.

The lime present throughout the cast material helps to protect the various elements within the finished wall from rotting when exposed to moisture, and also inhibits insect attack. Hemp shiv is not, in any case, an attractive food source for insects.

Hempcrete provides a means of creating walls, ceilings and floors that are insulating, yet are made from sustainable materials (hemp is a renewable, locally grown plant, while lime is derived from abundant naturally occurring material and has a lower embodied energy than cement). It is particularly relevant to those wanting to build in a low-impact, sustainable way, and for upgrading the thermal performance of historic buildings in a way that works

Hempcrete is always cast around a structural frame.

Making use of hempcrete's excellent thermal performance: a walk-in hempcrete fridge.
Image: Margot Voase

harmoniously with the original fabric of the building.

Although the oldest hempcrete building is only a few decades old, there is no evidence to suggest that properly maintained hempcrete will not last for the lifetime of the average building, if not significantly longer. However, even in the event of a failure, since such buildings always contain a load-bearing structural frame, the hempcrete could be removed and re-cast without catastrophic effects on the building as a whole.

Because the lime binder has a lower embodied energy than cement, and because the hemp plant takes up carbon dioxide while growing, which is then locked up in the building, hempcrete acts as a 'carbon sink'. In other words, even accounting for the embodied energy in its production, transport and construction, a hempcrete wall represents negative carbon emissions: it is responsible for a net reduction rather than a net increase in atmospheric CO_2. This process is what is referred to as carbon sequestration. Timber products can also claim to be sequesters of carbon; however, hemp is superior to wood in this respect, since it absorbs CO_2 much more quickly, creating a very hard woody stem (2-4m in height) in only 4-5 months. The time taken for the production of timber is much longer, even for fast-growing trees.

A range of figures on the carbon sequestration of hempcrete is available, although further research is needed into this area to bring clarity. For example, one 2003 study suggests that a total of 325kg of CO_2 is stored in 1 tonne of dried hemp.[1] Lime Technology cite the following net carbon sequestration figures for their Tradical® shiv and binder system: sprayed hempcrete sequesters 110kg CO_2 per m^3 of hempcrete construction, and shuttered and hand-placed hempcrete sequesters 165kg CO_2 per m^3 of hempcrete, depending on the level of compaction during construction.[2]

Both the lime in the binder and the structure of the hemp plant itself contribute to hempcrete being a 'breathable', or vapour-permeable, material. This means that any water that gets into the wall is able to get out again, rather than being held inside it, where over time it is likely to cause damage to the building's structure and also reduce the thermal performance of the wall. Furthermore, both the lime and the hemp are hygroscopic, which means that the surfaces of the wall are able to absorb moisture from the air during humid times, and release it again when the air dries out. This has the great advantage of helping to maintain the quality of the indoor air, and is thereby beneficial to the health of the building's occupants. For more on this see Chapter 4, pages 58 and 65.

The breathability of the finished material must be maintained over time through the use of vapour-permeable finishes such lime plasters and render, and vapour-permeable paints or limewash, so it is important that the occupants of the building are aware of this.

While people have been building with hempcrete for decades, and thousands of hempcrete buildings now exist globally, the industry is still learning about its potential, developing new binder products and working towards agreement on best practice about construction methods. To some extent, every new hempcrete building at the current time is 'experimental' in that it adds to the growing body of evidence of how this material performs.

The build

The process of building with hempcrete is, of course, the subject of this entire book, but the fundamental principles are set out here. For a more detailed overview of the construction process, see Chapter 11.

It is important to understand the way in which adherence to the correct application technique (or otherwise) can affect the success of the build. Building with cast-in-situ hempcrete is essentially a three-stage process: the erection of a structural frame, the wet-mixing and casting of hempcrete around that frame, and the application of finishes when the hempcrete is sufficiently dry.

The main causes of problems are to do with the amount of water introduced at the mixing stage. In simple terms, there is a 'battle' for water in the mix between the dry hemp shiv and the powdered lime-based binder. The binder needs water to achieve a set, so there is a risk, if too little water is added, of a failure of the hempcrete caused by the binder not setting properly. On the other hand, too much water in the mix can cause problems by significantly extending the drying time of the wall. This can result in delays with the application of finishes, which in turn can slow down the progress of the build and end up costing time and money. These problems are discussed in more detail later in this chapter – see page 73.

A key skill in hempcrete building is knowing exactly how much water is needed, and maintaining a consistent high level of accuracy when measuring out ratios of hemp:binder:water as each mix is prepared. In addition, the builder needs to understand this process well enough to confidently and safely adjust the amount of water slightly in response to weather conditions.

Once the wet hempcrete is mixed, it is placed into temporary shuttering, which creates the shape of the finished wall like a mould. As each 'lift' is cast and takes its initial set, the shuttering is removed and moved up the wall to create the next lift, until the top of the wall is reached. The distinction between 'initial set' and 'drying

Freshly mixed hempcrete should not be too wet. The method of testing for the correct water content is discussed in Chapter 15.

time' is an important one. Various types of hempcrete binder are available, but each specifies a short period of time (usually overnight) after which the binder has set sufficiently that the cast hempcrete can support its own weight. The shuttering is then removed to allow the drying to start. The 'drying time' refers to the time taken for any excess water introduced during mixing to dry out of the wall. It normally takes several weeks until the wall is dry enough for finishes to be applied (see Chapter 16, page 215), so it is important not to increase this time through the inadvertent addition of surplus water.

The phrase 'drying time' does not mean that the wall dries out completely. In common with all natural materials, hempcrete always has some water within it. It dries until it reaches a natural equilibrium or 'resting moisture content', which fluctuates slightly depending on environmental conditions, because of the vapour-permeable and hygroscopic properties of the wall.

The other important aspect of application technique is the placing of the hempcrete itself. (Hempcrete is 'placed' rather than 'poured'.) The wet mix needs to be placed evenly and consistently within the void created by the shuttering. In particular, it is important to avoid over-compaction of the cast material. Over-compacting reduces the insulation performance of the finished material and also increases costs, as more hempcrete is needed to fill the void. In addition, the consolidation of the external faces of the cast hempcrete needs to be judged carefully, as this can also have implications for drying time, as well as the cost of finishes (less well-consolidated surfaces may allow faster drying of the wall, but require a greater thickness of plaster or render).

The above factors mean that, perhaps more so than with other natural building materials, variations in the technique or skill of the builder can have a significant effect on the progress of the build, and on the performance of the finished product.

The issues described above are discussed in more detail in Chapters 15 and 16.

The workforce

With the importance of technique in mind, it is worth turning our attention briefly to the people who will be doing the building.

Building with hempcrete is, at least on a building of any reasonable size, quite a labour-intensive process. This means that it can often be quite a fun and sociable experience, and since with a little training the process of casting the hempcrete itself is quite easy, pretty much anyone can get involved with that stage. The low-tech nature of the material and the opportunity to reduce costs

Mixing and placing hempcrete is a low-tech process.

by providing their own free labour makes hempcrete especially attractive to self-builders.

Skills and experience

A range of different skills are required at the different stages of the building process, but, on the whole, once the key principles are understood, the actual process of construction should be well within the reach of most people. Building the foundations, wall plinth and structural frame (see Chapters 12 and 13) requires skills that most general builders, carpenters and competent DIYers already possess. The typical studwork structural frame for cast-in-situ hempcrete is either completely encased within the hempcrete or at least hidden from view in the finished wall, so it is not necessary for this to be a beautiful feature with a high standard of joinery. As described earlier, the process of mixing and casting the hempcrete itself, while not exactly complex, requires a certain level of knowledge and skill to ensure mistakes are not made. However, it is also at this stage that best use can be made of inexperienced volunteer labour (see opposite).

When it comes to applying finishes, the skills needed will depend on the type of finish chosen. Finishes range from lime plasters and lime renders to cladding in a variety of materials, for example timber, brickwork or stonework. The application of lime plasters and renders is a distinct skill, different from working with gypsum plasters and cement render, and it should not be assumed that just because someone is skilled at the one, they will be able to do the other. That said, although lime plastering is a specialist trade, depending on the level of finish desired, many self-builders may also be tempted to have a go at doing this part of the work themselves. For more on this, see Chapter 18.

In developing the skills of the team, training courses may be a first practical step. Courses in building with hempcrete are available (see Resources), though still few in number. Courses in lime plastering are now readily available all around the UK, and attending one is recommended for those with no experience who intend to do their own plastering.

Training in lime plastering can be a worthwhile investment.

Whether or not it is possible to gain training in building with hempcrete, some first-hand practical experience, for example volunteering on someone else's build, is certainly advisable for those wishing to use this material for the first time. Such opportunities can be invaluable, because hempcrete is so 'different' from other construction materials, so the chance to see how it works and to experience the practicalities of a build is the best form of preparation. If this is not possible, we would recommend that you at least practise by building a small structure such as a garden shed or workshop, to experiment and perfect the technique before beginning the main build. In any case, before casting for the first time, it is important to construct a small section of frame and cast a test wall, so the technique can be reviewed and mistakes corrected before starting on the actual walls.

The different roles on a hempcrete build are explored in more detail in Chapter 19.

A note on volunteer labour

One of the many appeals of hempcrete is that costs can be kept to a minimum if volunteer labour is used. Many self-builders sensibly take the approach of working on the job themselves and getting friends involved during the build. However, if volunteers are to be used effectively, it is important to think carefully in advance about what tasks they will be asked to do. The issue can be complicated due to volunteers often coming and going through the course of the build rather than staying for the whole time, but it is important that some thought is given to basic training of everyone.

Given the importance of consistently high standards of workmanship for the success of the hempcrete material, as outlined in this chapter, it should be clear why there needs to be a balance between free labour and experienced personnel on-site. As well as providing basic training and an explanation of the key principles on a hempcrete build, it is important to maintain an appropriate level of supervision over inexperienced workers, whether paid or volunteer. At Hemp-LimeConstruct we have found that one experienced worker to three volunteers is an effective ratio; above this, it is hard to ensure that consistent standards are maintained.

Problems with hempcrete?

Over the past few years, as more hempcrete buildings have been built in the UK, there have been a number of reported problems with the material, which have caused some people in the sustainable building world to take the view that hempcrete 'doesn't work' or 'never dries out'.

These assumptions are obviously incorrect, and all the more unfortunate since in most cases these 'hempcrete problems' are entirely avoidable and are not the fault of the material itself but rather of the contractor who used it. Furthermore, the vast majority of these problems – which usually centre on slow drying of the cast material – are a short-term inconvenience rather than a catastrophic disaster. It would be a shame for hempcrete to get a bad name in the construction industry owing to problems that would not have occurred if there had been proper understanding of the material, and we hope that books such as this one will help to prevent this.

It is true, however, that when people with little experience of lime and/or natural building materials first try to build with hempcrete, problems can occur. Rather than ignore examples of bad press for hempcrete arising from these issues, we feel it would be useful to explain why they can happen, and to reinforce the message that a well-trained workforce which understands the materials is the only sure way to avoid contractor error.

Any problems that do occur are likely to be caused by one of the following factors.

Contractor error

This is the most common cause of problems, especially the problem of slow drying. Most of the perceived problems with hempcrete are in fact the result of builders being unfamiliar with lime, and with natural, plant-based materials, and in particular with the procedure for mixing and placing hempcrete. Issues occur because insufficient thought has been given to the time of year, weather conditions, drying times and management of drying once the material has been cast.

Well-publicized examples (including on TV programmes) have included novice hempcrete builders casting new-build houses on large-scale commercial projects during the winter months, using a slow-setting binder and applying finishes too early.

Incorrect amount of water

In particular, it is vital to understand the importance of adding exactly the right amount of water when mixing, as too little can result in the binder not setting properly, and too much can lead to excessive delays in the hempcrete drying. For more on this, see Chapter 15, page 192.

Applying finishes too early

Where this occurs, it is usually due to pressures of the build schedule, combined with inexperience of the contractor. The waiting time for the wall to be dry enough to plaster will be unnecessarily extended if too much water is added at the mixing stage, so contractor error at that early stage can have knock-on effects at the end of the process.

All finishes for hempcrete should be vapour permeable, so the cast hempcrete will continue to dry out through the finish. However, by applying finishes we reduce the amount of ventilation to the surface of the wall, especially with plaster/render finishes, which also reduce the wall's surface area. These two effects together can considerably extend the amount of time required for the wall to dry out, meaning that it takes longer to dry to moisture levels that are optimal for thermal performance, and occasionally that the internal environment is too damp for the building to be occupied.

In addition, if plasters and renders are applied too early then staining of these finishes can occur, as liquid moisture evaporates from the surface and leaves tannins, which have been carried through from the hemp shiv. This is a purely cosmetic problem, and the stains can be painted or limewashed over when the wall has dried sufficiently,

An extreme case of staining on plaster as a result of finishes being applied too early.

but it is unsightly and can incur extra costs (in terms of reapplying paint). In more extreme cases (see photo opposite), it is also a clear indication that there were serious contractor errors at the construction phase, and/or that the finishes have been applied when there is still a very high level of moisture in the wall.

For information on drying times and how to gauge when a hempcrete wall is ready for the application of finishes, see Chapter 16, page 215.

Faulty materials

This is a much rarer cause of problems, and one that could of course occur with any building material, but in practice it should hardly never happen, as long as materials are bought from a reputable source.

Faulty binder

A faulty binder might either not take a sufficiently strong initial set (so the wall is unable to support its own weight, and slumps downwards) or not cure properly over time, leaving a wall that is structurally unsound. Both of these problems are virtually unheard of in hempcrete construction except in the case of materials that have not been properly tested, such as the two described as follows.

This is the reason that we don't recommend making your own hempcrete binder according to one of the various recipes that have been made available online or in books (see Chapter 6). If you really have a desire to experiment with making your own binder, then treat it as just that – an experiment. *Never* use untested materials to construct a real building.

Worryingly, however, we at Hemp-LimeConstruct have recently seen two examples of complete material failure: one concerning a material sold for use as a hempcrete binder by a UK company and one concerning a complete ready-mixed 'hemp-limecrete' sold by an Irish company to a UK self-builder. In neither case did the material manufacturer-supplier accept any liability for the failure of the material, and in fact the Irish company refused to do a site visit or to accept recorded correspondence on the subject sent by the UK client.

In the first example, the desire (for reasons of sustainability) to develop a hempcrete binder that contained UK lime and no Portland cement led to a new product being sold to UK hemp-crete builders for use in buildings as a kind of 'in-practice test', with the consent of clients. Unfortunately, the binder material in question was completely inappropriate for hempcrete and failed even to hold its own weight, despite being built up to height quite slowly. After a week or two, gaps appeared at the top of the wall where the material had slumped down, and after a further two weeks a bright multicoloured mould appeared all over the surface (see photos below and overleaf)

Hempcrete wall made with a newly developed (and insufficiently tested) binder, two months after casting.

Hempcrete made with newly developed binder next to a neighbouring wall cast at the same time using a proper hempcrete binder.

'Hemp-limecrete' one year after casting.

and in the voids left where the material had slumped. The wall had to be removed at the expense of the builder and client, since the manufacturer refused to accept any liability for the material.

In the second example, a full year after application the 'hemp-limecrete' bore no similarity to any hempcrete we have ever seen, despite being recommended for exactly the same uses in the manufacturer-supplier's technical sheet. The material was clay-coloured and visually resembled an earth wall containing pieces of whole hemp plant, and a year after building it was still registering 100-per-cent moisture levels and had black mould on the surface, with mushrooms growing out of it (see photo above right). The material was so soft that a finger could be pushed into the surface with light pressure. The end result was that the UK self-builder had to pay to have all the material removed from the wall and the frame altered and treated with fungicide before contracting us to re-cast the walls using proper hempcrete materials.

Unfortunately, the current state of the hempcrete market in the UK, with its rapid growth in demand for hempcrete materials in the absence of any widely agreed industry standards, provides the ideal environment for irresponsible or unscrupulous people to market materials that have not been subject to rigorous standards of production and testing. Until such UK industry standards are developed, builders wishing to use hempcrete in the UK would be well advised to stick to the three binders described in this book (see Chapter 6). If you are considering the use of an alternative hempcrete material, always ask to visit buildings that have been built using it, and ask to speak to previous satisfied users of the product.

Faulty hemp

Poor-quality hemp in the mix can also lead to problems, mainly if an excessive amount of fines or dust is present in the hemp shiv. This is because both fines and especially dust can absorb excessive amounts of water, which can deprive the binder of the water it needs to take its initial set (see Chapter 15, page 192). This potentially causes a weak bonding of the hempcrete material, leading to a wall that slumps or even collapses entirely. The failed 'hemp-limecrete' material described on the previous page is advertised on the manufacturer-supplier's website as containing 'coarsely milled whole hemp including long fibre', which in our opinion is completely inappropriate as an aggregate for hempcrete.

In 2012 Hemp-LimeConstruct, along with others in the industry, were supplied with a batch of hemp that contained an excessive amount of dust. The result of this was that after ten days of placing hempcrete in a new-build property, the wall we had cast on the first day suddenly collapsed. This meant that the entire 40m^3 of hempcrete already cast had to be removed from the frame and re-cast using good-quality hemp shiv. The cost of replacement materials was borne by the supplier, but the removal and disposal of the old hempcrete and the reinstatement works were at Hemp-Lime-Construct's cost. Thankfully, our clients, while understandably very upset, didn't lose faith, either in hempcrete or in us!

Problems: summary

Our intention in including this section about hempcrete 'problems' is not to scare people away from using it; nor do we want to contribute to any idea that hempcrete is very difficult to use. In fact, once a few simple techniques and concepts are mastered, the construction process is relatively simple. Furthermore, the development of national (and international) standards for the production, testing and application of hempcrete materials will, it is hoped, put a stop to cases of faulty materials – and materials purporting to be hempcrete which in fact bear little resemblance to it – being sold on the UK market.

In fact, if proof were needed, the thousands of hempcrete homes and commercial buildings built in the UK, Europe and around the world over the last three decades stand testament to the fact that hempcrete is a viable construction material that for its success simply requires a level of understanding and competence from those wishing to build with it.

The catastrophic effects of excessive dust in hemp shiv.

CHAPTER SIX

Variations on the hemp–lime mix

In this chapter we look in more detail at the hemp–lime mix itself, outlining the variables in both the hemp shiv and the binder that can affect the characteristics of the finished hempcrete, and describing how the mix is adjusted for different applications.

Variations in the hemp shiv

In general, there should not be much variation found in the type of hemp shiv supplied for building, which should meet the requirements as set out in Chapter 2. That is, the pieces should be about 10-25mm long, and may contain a certain amount of fines, but as far as possible should not contain any dust (see page 26). The only variation commonly found is that a finer-grade shiv (with shorter pieces of shiv) is commonly used to make hempcrete for spray application, as the longer particles in the standard shiv can sometimes lead to blocking of the spraying hose.

When placing by hand, coarse-grade shiv should always be used, since the matrix these create when they are set in the wall provides an inherently stronger and more open (breathable) structure. The shorter pieces of hemp in spraying shiv do not create the same matrix structure, but the additional adhesion given them by the forced projection of the spray-applied hemp compensates for any loss of structural strength.

Variations in the binder

There are two stages to the setting of a hempcrete wall. The first is the initial set, which has to happen before the shuttering can be taken down. Because the shuttering needs to be removed as early as possible so that the hempcrete can start drying out, the initial set needs to be strong enough that the freshly cast hempcrete can support itself while the second stage takes place. This happens slowly, over a number of weeks, as the hempcrete sets fully and any excess water dries out of the wall.

Previous page: A lime, or lime-based, binder is used with hemp shiv to form hempcrete.

At the risk of stating the obvious, the binder is the part of the hempcrete that is responsible for both stages of the set. Although the binder for hempcrete is lime-based, choosing a binder is not simply a case of choosing your preferred lime, since there are several functions required of the binder, and most limes will not provide all of these by themselves.

A hempcrete binder needs to:

- provide the initial set to the hempcrete with enough strength to support the weight of the drying hempcrete wall (it needs a strong hydraulic set)
- allow the water to continue to dry out of the hemp shiv after the initial set (it needs vapour permeability)
- provide a full set to the hempcrete over time (it needs long-term structural strength).

Most types of building lime, including the feeble and moderately hydraulic limes, have a slow initial set (over several days) and take a long time to reach full strength. Even once the initial set has taken, most limes do not, by themselves, set sufficiently strongly at an early enough stage to support the weight of a hempcrete wall while it dries.

If a hempcrete wall is built with a lime that does not achieve a quick enough, or strong enough, initial set, the consequences can be severe. When the shuttering is taken down, the lower parts of the wall are vulnerable to compacting and slumping outwards at the face of the wall, or – in the worst-case scenario – collapsing completely (see Chapter 5, page 77).

To avoid this, it is essential that the binder contains something that ensures a fast, strong set within 24 hours so that the shuttering can safely be removed. Not only must a successful hempcrete binder achieve this strong initial hydraulic set, but also it must remain vapour permeable during and after setting, so that moisture can leave the hemp shiv and the wall as a whole. This double function is achieved in one of two ways by binder products currently on the market.

First, there are two proprietary binders specifically formulated for hempcrete, which are available in the UK at the time of writing. Although their exact ingredients remain commercially confidential, they are widely thought to be a mixture of air lime (hydrated lime) – the main ingredient – together with a certain amount of Portland cement, believed to be around 20-30 per cent, depending on the manufacturer, and possibly a small amount of other pozzolanic ingredients (see Chapter 3 for more information about lime, cements and other additives). The proportion of cement included is enough to give the required initial strong set, without being enough to inhibit the overall vapour permeability of the cast hempcrete. These proprietary binders are Tradical® HB, made by Lhoist, and Batichanvre®, made by St Astier. They were both developed in France, although Tradical® HB is now made under licence in the UK.

The second solution to achieving the required initial set is to use an extremely hydraulic naturally occurring lime, such as a natural cement. One such natural cement, Prompt, made by Vicat, while originally sold for other purposes, has also been tested as, and is now marketed as, a binder for hempcrete. Natural cements set very quickly and very hard, but retain the vapour permeability that Portland cement lacks. Prompt Natural Cement is made from a specific type of limestone, using the same process as that used to produce hydraulic lime, and is made in France, where this type of stone is found.

There is a further characteristic of hempcrete binders containing a high proportion of air lime that is worth noting here. Since air limes set very

Hempcrete binders.

slowly, through a process of carbonation with the air, and since the water introduced during mixing has to gradually evaporate out of the wall, it is usual for hempcrete made with such a binder to shrink slightly – often by 2-3mm at the edges – as it dries. This is not a problem for the cast hempcrete material per se, but it does have implications for airtightness in certain situations (see Chapter 21, page 296).

The main characteristics of the three binders are set out in the table overleaf.[1] At the time of writing, these three products are the only tested and reliable binders available for hempcrete building in the UK, but there are signs that the market is opening up. We understand that Vicat is currently in the process of formulating a hempcrete-specific binder based on Prompt Natural Cement, and we know of at least two other companies that are also in the process of developing a hempcrete-specific binder.

Some of the early literature on building with hemp included recipes for mixing your own hempcrete binder. This is not something we have ever done in a commercial context, and nor would we recommend it, for the following reasons:

- It is much harder, when mixing dry ingredients yourself on a small scale, to ensure a consistent mixture comparable to that achieved in a binder that has been blended using purpose-built machinery.
- Although potentially cheaper in terms of materials, it adds extra complication, and

Characteristics of the three binders available in the UK

Binder	Buildings built in UK have received building control approval	Local Authority Building Control (LABC) pre-approved	LABC warrantee available	Manufacturing company	Country of manufacture
Batichanvre®	Yes	No	No	St Astier	France
Prompt Natural Cement	Yes	No	No	Vicat	France
Tradical® HB	Yes	Yes	Yes (as part of the Tradical® Hemcrete® walling system)	Lhoist UK	UK (developed in France, now produced under licence in the UK)

Binder	Manufacturer advice re suitable temperatures for working	Initial set time (before shuttering can be removed)	Drying time (before ready for finishes)*	Suitable for spray application	Application suitability (as recommended by manufacturer)					
					Floors	Walls	Ceilings	Roof insulation	Solid-wall insulation	In hemp–lime renders
Batichanvre®	5-30°C	Minimum 30 minutes; up to 24 hours	6-8 weeks	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prompt Natural Cement	5-25/30°C	30 minutes	6-8 weeks	No	Yes	Yes	Yes	Yes	Yes	Yes
Tradical® HB	5-30°C	24 hours	6-8 weeks	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Binder	Can be used with hemp from a choice of sources	Binder-only supply available	Recommended finishes
Batichanvre®	Yes	Yes	Range of lime, or equivalent, breathable finishes
Prompt Natural Cement	Yes	Yes	Range of lime, or equivalent, breathable finishes
Tradical® HB	No – limited to use of Hemp Technology's Tradical® HF hemp shiv as part of system	No – supplied with Tradical® HF hemp shiv as part of system	If LABC warrantee is required, limited to proprietary finishes as specified within system

*Dependent on weather conditions

therefore time and cost, to the build process.

- For a commercial builder it would be very risky, as you would be taking on liability for the manufacture and quality control of the product, as well as for your own workmanship in constructing the building.
- The research, formulation and testing required to bring a home-made binder to a stage where it would be advisable to use it in a real building would take a great deal of time and financial commitment – something that very few people would find worthwhile.

Proprietary products and testing

There has been much discussion in recent years about the fact that although hempcrete-specific binders have always been marketed as proprietary products, and so far have been sold in a limited number of specialist suppliers, the constituent parts are readily available as existing products on the market. This has included debate in the industry about agreeing an open-source binder recipe, to enable increased availability of hempcrete binder materials across the marketplace, although at the time of writing this has not yet been achieved.

The main reason for this is fairly obvious: getting a product tested and approved is a costly process, and anyone investing in the initial costs of this process would be unlikely to get their money back from an open-source product. Such an open-source binder may come in future, alongside the eventual establishment of industry-agreed construction standards for hempcrete. The fact that hempcrete has been able to progress rapidly to the current level of demand in the UK market we owe principally to the manufacturers of proprietary binders; especially to Lhoist and Lime Technology for their development of the Tradical® HB binder in the UK.

It is fair to say, however, that many in the industry see proprietary hempcrete-specific binders as something of a double-edged sword.

On the one hand, companies have invested time and money over the last decade or so into developing and researching proprietary binder products and promoting hempcrete. As a result of this development work, a huge variety of hempcrete buildings now stand across the UK as testament to the potential of the material. On the other hand, the drive to develop these materials is, of course, underpinned by the need to sell a product. The commercial and competitive aspect leads to a number of problems from the point of view of the developing industry, and the contractor. For example, it means that while a lot of commercially funded research is carried out into proprietary materials, the results are not always shared across the industry as a whole. Nor are results always directly comparable with other studies, since differences in the materials used often make comparisons difficult.

Another issue arises from the fact that hempcrete construction requires specific skills and knowledge not currently found widely across the construction industry. The success of a hempcrete build, unless the 'work-around' of using pre-cast panels or blocks is employed, is highly dependent on the level of competence of the contractor. Because of this, some manufacturers and suppliers have at times, surprising though it may seem, appeared reluctant to allow their product to be used by anyone who cannot demonstrate the requisite knowledge. Admittedly, building with hempcrete is certainly more complicated than opening a bag of cement, mixing in sand at 4:1 and wetting it up to the desired consistency. But we would hope that the answer to the problem of the specific skills not yet being common in the construction industry will be in the training of the workforce rather than the restriction of access to materials.

Hemp shiv and binder waiting to be mixed.

At the time of writing, Tradical® HB is the only hempcrete binder that has been tested for LABC (Local Authority Building Control) pre-approval within the UK. It has been tested together with Tradical® HF hemp shiv as part of the Tradical® Hemcrete® walling system, so is pre-approved only when used with the specified hemp shiv. Using a product that has not been through pre-approval testing for building control does not necessarily mean that you will not be able to get building control to sign it off, however; it just adds an extra stage to the process. In practice, we have never had any difficulty getting hempcrete approved by building control, especially since it is a non-structural element of the wall build-up.

In France, where the hempcrete industry is more developed, there is a wider range of established sources of hemp shiv for building than exists currently in the UK, and these are not exclusively tied in to binder manufacturers. This has led to a situation where hemp shiv manufacturers have had their own shiv tested for French building control pre-approval with *each* of the available binder products. The result is the availability of easily accessible information, so that builders know whether a particular hemp shiv is suitable for use with a particular binder in a given application, as in the hypothetical example shown in the table below.

The UK hempcrete market is still some way from such a level of cooperation and flexibility, but it is to be hoped that as the market continues to increase and the marketplace for binders and shiv suppliers opens up, a time will come when UK builders have access to a similar level of information about the products available.

Variations for different applications

The ratios of hemp:binder:water required when mixing hempcrete vary slightly depending on which binder is being used, so the manufacturer's

Example of flexible product testing regime carried out for the French market

'Hemp shiv product X': pre-approval testing					
		Application			
		Walls	Floors	Ceilings	Roofs
Binder	Binder 1	✔	✗	✔	✗
	Binder 2	✔	✔	✔	✔
	Binder 3	✔	✗	✔	✔

guidelines should always be followed. It is important to adhere to the exact ratios, and mixing instructions, because having the right proportions of binder, hemp and water is critical in ensuring that the binder has enough water to set it, despite the tendency of the dry hemp shiv to 'compete' for the water in the mix. This concept is discussed in more detail in Chapters 15 and 16.

The 'standard' hempcrete mix can, however, be varied slightly in the proportion of binder to hemp shiv, as advised by the binder manufacturer, in order to produce hempcrete that is more suitable for a particular application. The mix ratio required to make hempcrete for a wall is usually seen as the standard mix of a binder manufacturer.

Increasing the amount of binder for the same amount of hemp shiv produces a higher-density mix, with greater structural integrity and thermal mass but reduced insulation value: more suitable for applications where the hempcrete will be subject to greater loading, such as floors.

Decreasing the amount of binder for the same amount of hemp results in a lower-density mix, which is lighter and more insulating but not structurally very sound, and not suitable for areas where it will be subject to heavy wear and tear, or required to carry a finish. This type of hempcrete is more suitable for cast-in-situ roof insulation.

Whenever specifying a less dense or more dense mix for roofs or floors, it is important to check that the materials you are buying are recommended for that particular application, and, again, to follow the manufacturer or supplier guidelines exactly.

More information on the use of hempcrete in these applications can be found in Chapters 17 and 22.

Hempcrete is used for walls . . .

. . . floors . . .

. . . and roofs.

CHAPTER SEVEN

Performance of hempcrete in a building

The performance of hempcrete as a building material is the subject of a growing body of research, both in the UK and abroad. However, because the material is still relatively new, more research is needed for a full understanding of the way it behaves and which factors influence its performance. Each new hempcrete building provides an opportunity for us to further develop and standardize good practice in hempcrete construction, and to gather more evidence about how the material performs.

Plant-based products in general are set to be a growth sector supporting a wide range of technologies, as the world makes the transition into a low-carbon economy. Within this context, the viability of hempcrete along with other bio-aggregate building materials is being studied in a number of research centres; notable examples are the University of Bath in the UK and the Université de Rennes in France.

Much of the research to date has been undertaken, or funded, by the manufacturers of proprietary products and has focused on proving the performance of their own products in relation to regulatory regimes for building products, which vary slightly from country to country. The comparison of data and research findings is complicated by the use of different materials, and different techniques for their preparation and application across different studies, as well as by differences in the particular focus and legislative context of the research. Furthermore, there has been reluctance from some quarters to make proprietary research available to a wider audience,

Previous page: Hempcrete acts as a continuous, breathable, solid mass of insulation.

and this creates an issue regarding the accessibility of the knowledge base about hempcrete to the wider industry.

While France has begun to address regulatory standards in material parameters, such as the characteristics of hemp shiv for building, there is not, at the time of writing, a set of nationally or internationally agreed standards available to guide manufacturers or builders in the UK. The lack of standardized procedures around hempcrete production and use in the UK is challenging, not only for builders but also for those wishing to draw conclusions from a wide and varied body of research.

It is worth stating at this point that a recurring theme in the research to date, as well as in the experience of day-to-day practical use of hempcrete, is the degree to which the properties of the finished composite material vary according to three key factors, namely:

- the individual characteristics of the component parts (the hemp shiv and the binder)
- the exact formulation (or mix ratio) of the component parts and water
- the technique used during the mixing and placing of the material.

For example, the quality and particle size of the hemp shiv can affect the structural integrity of the cast hempcrete and also its mechanical behaviour (how it reacts when it is subjected to a force which tries to stretch, dent, scratch or break it); the amount of binder in the mix ratio can affect the acoustic properties; and variation in the degree to which the material is compacted during placing can affect the thermal performance. In many cases, a particular characteristic of the finished cast material will be affected by two or more of these variables.

This concept might at first seem confusing, and indeed it is the main cause of unintended consequences when novice builders use the material, and the reason why hempcrete has developed an undeserved reputation in some quarters for being 'unpredictable'. In fact, it is anything but. Those who take the time to understand these basic variables will find that hempcrete is a versatile material with some important core characteristics, and that it can be adapted to suit a range of situations and applications through the manipulation of these variables. We hope that the themes that crop up again and again in the descriptions of hempcrete's performance in this chapter will demonstrate what we mean.

It is not our intention here to provide the reader with a full account of the biological, chemical and civil engineering background that underpins the use and performance of hempcrete. Rather, by summarizing key findings about hempcrete, with reference to relevant standards defined by the regulations governing building materials and buildings in the UK, we hope to aid a broad understanding of the unique way that the material performs in a building.

Those who would like more detailed information on the science of hempcrete would do well to start with one of two 2013 publications, which collate much of the research findings to date (for full details see Bibliography).

Sofiane Amziane and Laurent Arnaud's (2013) book *Bio-aggregate-Based Building Materials: Applications to hemp concretes* deals quite comprehensively at an academic level with a range of issues relating to the production and use of hempcrete, within the wider general context of plant-based aggregates. The authors investigate the factors that affect the performance of hempcrete, including binder type, variations in shiv parameters, and mixing and placing technique, and they present findings on its vapour permeability and the hygrothermal, mechanical and acoustic behaviours of hempcrete.

Covering much the same ground in a more accessible, although necessarily less detailed, way, a thorough review of the literature concerning the performance of hempcrete was carried out in 2012 by Patrick Daly, Paolo Ronchetti and Tom Woolley as part of the Irish Environmental Protection Agency's STRIVE Programme 2007-2013: entitled *Hemp Lime Bio-composite as a Building Material in Irish Construction*, it is published online. This study provides an authoritative analysis of up-to-date evidence from a wide range of sources on the performance of hempcrete, together with a discussion of whether hempcrete will meet Building Regulations in the Republic of Ireland, and identifies necessary areas for future research.

Hempcrete can be used for floor, wall and roof insulation and provides excellent acoustic, as well as thermal, performance.

For a less up-to-date, but still very useful and accessible discussion of hempcrete, including its performance in relation to UK Building Regulations and the wider industry context, see Rachel Bevan and Tom Woolley's (2008) *Hemp Lime Construction: A guide to building with hemp lime composites*.

Since we are builders, not academics, the information presented in this chapter owes much to the three publications cited above and is provided here as an overview of the properties of hempcrete, rather than as a specific guide to what you should expect in your building. For accurate information on the expected performance of specific hempcrete materials, it is important that builders and/or their clients refer directly to the supplier or manufacturer of those products.

Mechanical behaviour

Hempcrete is a composite material made from a porous plant aggregate (hemp shiv) and one of a choice of binders, which set through differing degrees of hydraulic and carbonating action. The aspect of hempcrete that most differentiates it from conventional composite materials used in building, such as mineral concretes, is the extremely porous nature, at a microscopic level, of the plant-based aggregate. This porosity gives the hemp shiv particles a natural flexibility, and this, together with the macroscopic porosity created by the arrangement of the particles of hemp in the cast material, results in many unique characteristics – lightness, absorbent capacity, and acoustic and thermal properties – not shared by mineral concretes, which usually contain hard, non-porous aggregates.

The flexibility and porosity of the hemp shiv also contributes interesting and useful qualities in terms of elasticity and flexural strength (the ability of a material to bend under a load without tearing). However, these same properties mean that hempcrete is not suitable in load-bearing applications.

The combination of the flexible hemp shiv particles with the rigid-setting binder produces a material which, in contrast to other building materials, also shows a high deformability under stress, a lack of fracturing and the ability to sustain significant changes in shape without breaking, even after the full mechanical strength of the binder has been reached. These properties, together with the significant improvement in racking strength that hempcrete brings to a frame (see opposite), have clear possibilities for seismic design, which aims to produce safe buildings in earthquake-prone areas: structures that are capable of withstanding the shock of earth tremors without collapsing. Further research in this area is likely to accompany the wider adoption of hempcrete in countries such as the USA and New Zealand, for example, where building with hempcrete is only just beginning to gain popularity.

Perhaps the most interesting thing about the mechanical behaviour of hempcrete is the way in which it can be easily manipulated by altering the ratio of binder to hemp shiv in the mix, which enables us to formulate different hempcretes tailored to specific applications. For example, a roof-insulation hempcrete requires a low-density mix, i.e. with relatively little binder, since the thermal properties are more important than the mechanical integrity of the cast material. Under a microscope, such a mix looks almost like a matrix of hemp particles with bridges of binder connecting them.

Walls require a more binder-rich mix, and floor slabs, which need to withstand the load of people walking on them, require a hempcrete with a much higher proportion of binder – a higher-density mix, in which the composite resembles a continuous binder matrix with particles of hemp buried inside it. Even these binder-rich mixes, however, retain the qualities of deformability and resistance to cracking, which are lacking in a mineral concrete floor slab.

Structural qualities

A large number of studies have looked into the structural properties of hempcrete, in a range of applications and using a variety of testing methods. Perhaps unsurprisingly, the results show a wide range of values for the structural performance achieved.

Hempcrete on its own

There is an issue regarding the suitability of assessing hempcrete using current methods for testing the structural performance of masonry and mortars, since hempcrete does not fail in the same way as these materials do. Instead of cracking or fracturing under compression, hempcrete fails by deforming – bending out of shape, with some recovery towards its original shape when the load is removed. Further investigation into the positive implications of hempcrete's ability to deform without breaking, in the context of the movement of buildings, would be worthwhile.

The main focus of research into hempcrete as a structural material has been in relation to pre-cast blocks, which are sometimes described as either 'thermal' (lower density) or 'structural' (higher density). In order to achieve blocks with the degree of compressive strength needed for load-bearing applications, a significant increase in hempcrete density is required. Since this is achieved by increasing the proportion of binder in the mix, sometimes with the addition of some cement and/or sand, increased structural

Owing to the unique mechanical properties of hempcrete, blocks still need to be cast around a structural frame.

performance can only be gained at the cost of some insulative value (which is the primary reason for the use of hempcrete) as well as an increase in the material's embodied energy. Therefore the normal use of hempcrete in blocks is as thermal blocks – used, as with cast-in-situ hempcrete, to infill around a structural frame.

There is little data on, and, to the authors' knowledge, no examples in use of, structural cast-in-situ hempcrete other than in floor slabs, nor have there been any studies to date on the effects of ageing on the structural performance of hempcrete, although it is thought that higher-density hempcrete is likely to age better than lower-density mixes.

Hempcrete combined with a timber frame

While not suitable for structural applications in isolation, there is no doubt that as part of the typical build-up of structural timber frame with hempcrete cast around it (or as infill), the material does perform an important structural role. Once fully hardened, hempcrete provides racking strength to the frame structure – adding significantly to its ability to resist lateral movement as a result of external forces, such as wind loading – and thereby removing the need for the timber diagonal braces traditionally used for this purpose. In fact, according to Amziane and Arnaud, the hempcrete infill provides almost ten times as much racking strength to the frame than does timber diagonal bracing. It also significantly reduces the amount of deformation the structure exhibits in the event that the frame does eventually break.

In construction practice, this ability of hempcrete to brace a timber frame has the advantage of reduced timber requirements (in terms of the number and size of diagonal braces, as well as the number of horizontal noggins for general rigidity). It also reduces the time spent on frame construction, since the diagonal braces are the most time-consuming frame element to construct and fit.

As hempcrete is a non-load-bearing insulating material cast around a structural frame, building control inspectors have little interest in it from a structural point of view, simply requiring that it meets fire regulations, levels of thermal performance, and acoustic insulation requirements as mandated by the relevant Building Regulations. However, when it comes to convincing building control inspectors that reinforcing and bracing frame members can be omitted from the structural frame, as the hempcrete provides this function, they start taking more of an interest.

Hempcrete terrace at a housing association development in Diss, in Norfolk, constructed from cast-in-situ hempcrete around a timber frame.

We have had varying success in convincing structural engineers and building control officers of hempcrete's properties in this regard, and have often been forced to include at least some diagonal timber or stainless-steel bracing, despite this being clearly unnecessary. Engaging a structural engineer who understands the material and/or an Approved Inspector (see Chapter 12, page 149) can be important in helping to make the case.

There is a need for the development of a protocol for testing the structural performance of hempcrete, to encompass appropriate tests which take into account the fact that hempcrete is a very different material in its performance from other masonry products. Such a testing procedure would also need to accommodate different shiv and binder materials, mix ratios and application techniques within the methodology. This would be a step towards enabling better comparison between individual studies in future.

Fire resistance

The formal testing of the fire-resistance properties of hempcrete has been limited; carried out mainly on proprietary products (both pre-cast and cast in situ) to test compliance with national regulatory regimes. However, the density and nature of hempcrete, with the plant-derived component encased within its lime binder, means it is very difficult to set fire to it. Moreover, the standard detail of cast-in-situ hempcrete encasing a timber frame means that the hempcrete forms a barrier between the timber structure and any fire.

Bevan and Woolley[1] cite fire testing carried out in France on a 250mm-thick wall of hempcrete blocks laid in lime mortar. The wall remained intact for 1 hour 40 minutes, although the mortar joints failed. No re-ignition or emission of toxic gases was noted. It is assumed that a solid cast wall of hempcrete would offer a superior fire resistance. These authors also comment on the fact that while the hemp shiv is flammable in its loose form, hemp does seem somewhat less flammable than comparable materials in some of its other forms, for example as hemp paper.

In terms of the resistance of cast-in-situ hemp-crete to fire, Daly et al. report that the BRE Group in the UK carried out:

> a fire resistance test on a 3m x 3m Tradical® Hemcrete®, non-rendered or plastered, wall in accordance with BS EN 1365-1:1999. The wall was subject to a vertically imposed load of 135kN and was cast from layers of hemp–lime mix, poured into a mould, and included eight vertical timber studs. The internal face of the wall was exposed to the fire and it resisted for 73 minutes in respect to integrity, insulation, and load-bearing capacity.[2]

The same authors note that testing undertaken by the French manufacturer Isochanvre produced results that indicated that hempcrete is a "non-flammable material", with fire-resistance performance improving over time as the binder continues to carbonate (this time factor depends on the composition of the binder: see Chapter 16, page 215).

In a conversation with ourselves, Graham Durrant of The Limecrete Company provided anecdotal evidence which appears to support this finding. A fire that broke out in a rooftop upstand on the Sustainable Enterprise Centre at Bradford University, shortly after it was constructed, resulted in damage to the timber cladding but not the hempcrete. The structure was a twin-frame design, with the structural timber frame on the internal face of the wall, and an external, non-structural frame to support the timber cladding. The cladding burnt away, as did the cladding battens and the supporting frame sank flush in the face of the wall, but the hempcrete itself and the structural frame on the inside face did not combust.

Further research is needed, particularly into the effects that various factors (different binders, varying the mix ratio, and the presence of render and plaster finishes) have on hempcrete's fire resistance. However, the data currently available suggest that hempcrete is suitable for applications where fire resistance of 60 minutes is required, and that this might easily be increased to 90 or 120 minutes' fire resistance with alterations in the specification.

Vapour permeability and hygroscopicity

Hemp shiv is a naturally vapour-permeable material, meaning that it allows water vapour to travel through it, thanks to its porous nature: it has a microscopic structure of tiny capillaries created by the cell walls, orientated in the direction of the plant's stem. This capillary structure accounts for the hemp shiv's hygroscopic behaviour – its ability to attract and hold moisture from the surrounding atmosphere, releasing it again in response to changes in the humidity of the environment.

The qualities of permeability and hygroscopicity are shared by the building limes which (depending on the binder) make up the majority or the whole of the hempcrete binder. These properties of the hempcrete vary according to the type of lime used and in what quantity: binders rich in calcium lime (i.e. air limes) allow a greater degree

The open matrix structure of hempcrete assists vapour permeability.

of vapour permeability and hygroscopicity, while those containing hydraulic limes or a higher proportion of Portland cement allow less.

Thanks to the nature of the internal structure of hempcrete – the interlocking pieces of hemp shiv forming an open matrix in the cast material – hempcrete is also porous, and so vapour permeable, at a macroscopic level. The degree of macro-porosity is to some extent dictated by the parameters of the hemp shiv used, namely the particle size distribution (i.e. the average length, width and thickness of the particles in a given sample of hemp shiv).

The ability of the hemp shiv to allow water vapour to condense on the interior surface of its pores when environmental humidity is high, and to reverse this process when the air dries out, inhibits the formation of condensation (and therefore mould) on the surface of the walls. This is beneficial for the indoor air quality, and also has implications for the thermal performance of hempcrete, as described on the following pages.

Resistance to damage by moisture

Hempcrete's 'openness' to water vapour is a characteristic it shares with all organic materials (since all materials of organic origin are made up of water to some degree). This vapour permeability may seem an alien concept to anyone who has worked with conventional synthetic building materials over the last 50 years or so, since 'advances' in material technologies have often centred on the production of building materials that were intended to form a vapour barrier, keeping moisture out of the building. In recent years there has been a growing understanding that such materials rarely continue working indefinitely and that they also work to keep moisture *in*, causing damage to traditional building materials and creating damp, cold and unhealthy interior environments.

Since the aggregate in hempcrete (hemp shiv) is a very hard cellulose material, similar to wood, it can withstand repeated absorption and desorption of moisture over an almost indefinite period of time without ill effects, as long as it is not left standing in or exposed to a constant flow of water.

Bevan and Woolley report that there are several anecdotal examples of test panels of hempcrete being cast and left out in the rain, without rendering, for periods of up to several years without any deterioration of the material, and in spray-testing by the BRE Group, hempcrete performed extremely well in resistance to water ingress (see Chapter 21, page 291). However, in most hempcrete buildings a render or cladding finish is used to assist with shedding rainwater,

Hempcrete and neighbouring brick houses at Haverhill in Suffolk, which were monitored as part of a BRE study into the viability of hempcrete as a building material.

and to provide a level of protection against more extreme weather.

More formal research is required to build up data on how a variety of factors, including different materials, mix ratios and finishes, may alter hempcrete's resistance to damage by moisture. But the evidence currently available, from tests and from practical experience of examples in use, suggests that it performs extremely well in this regard.

Thermal performance

Perhaps more so than any of its other characteristics, the thermal properties of hempcrete set it apart from other building materials. The intense focus in today's climate (both economic and environmental) on the need to conserve energy, and increasingly stringent requirements for buildings to be constructed in a way that ensures the maximum conservation of fuel and power, has meant that this aspect of hempcrete's performance has received a great deal of attention and been the subject of many studies.

Across the wide body of research in this area, experimental methods have varied considerably, meaning that direct comparison of different studies is not always easy. That said, very positive results have been achieved in both laboratory experiments and in monitoring in situ. As with other aspects of hempcrete's performance, the ratio of binder to hemp shiv and the degree of compaction as the hempcrete is placed are significant factors in the thermal performance of the finished cast material, with a lower-density hempcrete performing significantly better.

As described in Chapter 4, page 62, hempcrete does not, thickness for thickness, insulate to the same degree as lightweight insulation materials. However, because the cast hempcrete fills virtually the whole thickness of the wall, the total insulation values (U-values) achieved are very good, as shown in the table below. These are approximate values based on laboratory testing (calculated from the thermal conductivity of the material in solid-state testing, by means of probes on either side of a material sample to measure how quickly heat is transferred through it). The exact U-value achieved varies slightly depending on the specific binder used in the hempcrete and the degree to which the material is compacted during application.

These U-value figures for hempcrete are impressive. However, in-situ tests of hempcrete have repeatedly shown that it performs *even better* in the dynamic context of real building than theoretical U-value calculations would predict. This is because there is much more to hempcrete's thermal performance than insulation alone.

Increasingly, it is recognized that U-values and associated steady-state heat losses are limited in their capacity to accurately model dynamic heat flows in real buildings, and this is especially true in the case of hempcrete. This is partly because of the unique combination of thermal mass and insulation, but another explanation is the fact that hempcrete exhibits hygrothermal behaviour – a characteristic resulting from the interaction between humidity and temperature. In other words, hempcrete's vapour permeability and hygroscopicity have a direct effect on its thermal performance.

This is a complex subject, but, broadly, the key is the difference in the thermal conductivity of still air (very low) and water (20 times higher). During periods of high relative humidity in the adjacent air ('relative' because the amount of water vapour the air can hold varies with temperature), water vapour is absorbed by the hempcrete wall, and some of this condenses to form liquid water on the interior surface of the pores in the hemp shiv. It will continue to do so until the pores cannot hold any more water. As the relative humidity drops again, water evaporates out of the wall back into the air, but during the time when some of the air in the wall is replaced with water, the thermal conductivity of the hempcrete changes, since water is far more thermally conductive than air and also has a higher specific heat capacity (a greater ability to store heat).

This dynamic change, as water vapour moves into, through and out of the wall, has a constantly varying effect on how heat is stored within, or transferred through, the hempcrete. Furthermore, as moisture goes through the state change from water vapour to liquid water and back again, it gives off or absorbs energy (as its specific heat capacity changes), and this also affects the temperature and insulating properties of the cast material.

This intriguing aspect of hempcrete's performance helps to account for its ability to 'buffer'

Typical U-values for hempcrete

Hempcrete wall thickness (mm)	250	300	350	400
U-value (W/m^2K)*	0.23	0.2	0.17	0.15

* W/m^2K = watts per square metre per degree kelvin

300mm walls of cast-in-situ hempcrete easily achieve the thermal performance required for a new building.

temperature changes, maintaining more constant ambient indoor temperature, which reduces the demand on power for heating or cooling (see Chapter 4, page 63). The hempcrete wall passively regulates temperature *and* humidity through a combined dynamic mechanism: increasing comfort in both summer and winter by stabilizing the daytime and night-time temperatures and reducing heat build-up on the surface of the wall, while also managing humidity levels and minimizing the build-up of condensation, by constant take-up and release of moisture through the wall's surface.

To date, attempts to reproduce this hygrothermal behaviour in currently available models used to predict a building's energy use have proved problematic, which is unfortunate, since it may account for an underestimation of hempcrete's actual thermal performance. Work is currently under way to integrate this dynamic behaviour into commonly used modelling software, so that the full scope of hempcrete's complex thermal performance can be demonstrated.

The fact that cast-in-situ hempcrete is cast in a continuous monolithic slab means that, once sealed with render finishes, it has a unique advantage in achieving good airtightness (in-situ tests have shown excellent airtightness levels, according to all sources) and reducing thermal bridging, both of which have very positive implications for its overall thermal performance in well-detailed buildings.

As discussed in Chapter 4 (see page 55), hempcrete also has wider benefits in terms of energy consumption over its whole 'lifecycle', which cannot be measured in thermal performance tests, notably its low embodied energy and carbon sequestration.

Acoustic performance

The micro- and macro-porosity of hempcrete, as described earlier, are as beneficial for hempcrete's acoustic performance as they are for its thermal performance. It appears that these different levels of porosity within the material lead to an acoustic quality which is – as with its other characteristics – unusual and distinct from that of conventional building materials.

All three of the key factors outlined at the start of this chapter have the potential to alter the acoustic properties of hempcrete. In particular, the choice of constituent materials, not only the binder but also the type of hemp shiv and its particle size distribution, is important. The porosity of the material is the critical factor in the physical processes of sound insulation and absorption. Additionally, the density of the finished material, according to specific mix ratios used, and the casting technique can both play a significant part.

As our understanding of this aspect of the material's performance develops, Arnaud and Amziane point out, the possibility emerges of producing a hempcrete that is designed to a particular specification of acoustic performance for a given situation, by manipulating the variables described above.

Perhaps equally interesting is the idea that – since the nature and particle size distribution of the hemp shiv are such good predictors of acoustic performance – by inverting the data recorded on the acoustic properties of a range of hempcrete materials we may be able to devise an acoustic test to determine the characteristics (e.g. particle size, apparent density and porosity) of different hemp aggregates. This is interesting because currently there are few techniques available for assessing these characteristics. An acoustic measure would make it possible to describe the characteristics of hemp shiv based on a sample volume that is representative of a wall, rather than by microscopic analysis of individual particles. Furthermore, this technique would offer the opportunity to assess the quality of finished hempcrete in situ in a non-invasive way, by the analysis of its acoustic parameters.

According to Amziane and Arnaud, tests on hemp shiv in its raw state showed that a shiv with smaller particle size distribution is more effective for sound absorption, mainly because less variation in particle size means that the gaps between the particles are also smaller, and so there is less airflow through the material. It seems that for this reason the macro-porosity (inter-particle pore size) of the shiv has a greater effect on the acoustic properties of hempcrete than does its micro-porosity.

When combined with a binder, however, the effects of particle size distribution are less dramatic. Examination of the effects of binder choice on sound absorption showed that both hydraulic and hydrated lime (air lime) performed equally well. However, the use of (higher-density) Prompt Natural Cement produced a hempcrete with a lower sound absorption capacity, indicating that for acoustic applications the use of a hydraulic or hydrated lime binder is a better specification.

Because of the significance of macro-porosity, variations in the density of the finished material have a notable effect on its acoustic behaviour. It follows, then, that the two main factors affecting the density of hempcrete – the amount of binder in the mix and the amount of compaction during construction – will have a strong influence in producing a material that is more, or less, acoustically efficient.

Further research will continue to add to what we know of the acoustic performance of hempcrete, but it is clear that it is effective in meeting sound insulation requirements and furthermore that specific solutions for the detailing of particular buildings can easily be achieved through manipulation of the factors outlined above.

Toxicity and indoor air quality

The only health risks associated with hempcrete relate to the non-toxic dust produced during the processing of hemp, and the caustic nature of lime, which requires precautionary measures both in the processing of the raw material and in the construction phase. As a natural material with no inherent toxicity or risk of off-gassing, hempcrete presents no risk from toxic emissions during the use of the building, or at end-of-life demolition.

As described earlier, hempcrete's exceptional hygroscopic qualities help to regulate humidity in the internal environment and to discourage condensation on interior surfaces. This contributes to a healthy indoor air quality, buffering humidity levels and restricting the growth of potentially harmful moulds, other spores and bacteria.

The thermal mass of hempcrete also makes it easy to maintain indoor air quality, because the storage of heat in the fabric of the building allows for natural ventilation of the indoor space by opening windows and doors, without concern that the heat in the building will be quickly lost. For more on indoor air quality, see Chapter 4, page 65).

A note on materials and workmanship

A common theme throughout the findings outlined in this chapter is the degree to which different materials, mix ratios and application techniques, especially with regard to the amount of compaction, affect the performance of hempcrete.

At the present time, while individual proprietary materials (Lhoist's Tradical® Hemcrete® system) have been tested for Local Authority Building Control pre-approval (see Chapter 6, page 84), the UK still lacks any industry-agreed standards or guidance, either for the desired characteristics of hemp shiv and binders for making hempcrete, or for correct application techniques.

As can be seen from the information in this chapter, hempcrete is a versatile material whose performance can be adapted within a range of parameters, according to the requirements of the building design or the specific application. However, rather than being known for this versatility in the UK, hempcrete is seen in some quarters as being unpredictable and difficult to use. This says more about the current knowledge and skills of the UK construction industry in this area than it does about the material itself.

It is true that a real issue with hempcrete currently is that the eventual thermal, acoustic and mechanical performance of the material in the finished building is heavily dependent on the knowledge and skills of the contractor, and that these are not always at the level required. Thus, variations in these aspects of the material's performance that are found from building to building, far from being different by design, often occur quite randomly, owing to contractors not really understanding the potential of the material or how this can be best unlocked.

The development of recognized standards for materials and construction techniques would not only assist the industry in regulating the standard of new hempcrete buildings in the UK and providing a valuable 'Kitemark' for construction professionals using hempcrete, but would also help to provide a more structured framework for continued research into the performance of this remarkable material.

CHAPTER EIGHT

Tools and equipment

The equipment needed when building with hempcrete varies slightly from project to project according to a range of factors, including the specific application and construction details, the type of binder used and the scale of the job (as well as how much of the rest of the build you may be undertaking). However, the core tools remain the same, and a list of our standard toolkit is provided below.

Most of the hand and power tools required are commonplace and will already be owned by most builders and keen DIYers, and the bigger power tools and plant can always be hired for the duration of a project. But there are bound to be a few new purchases to be made when building with hempcrete for the first time, and a little thought at the outset may result in significant savings, especially when it comes to power tools. That said, there are some tools on which it is worth spending extra money.

Quality versus cost

The relative cost of electric power tools has fallen dramatically in recent years, especially with the proliferation of cheap generic models, which are churned out in the Far East and stamped with the 'own-brand' label of the DIY store they end up in. The low price is a reflection of the quality of the manufacturing, and often of the quality of work achievable with them. Sadly, the cost of these inferior products has now fallen so much that we often hear people talking of how it is cheaper, for example, to buy four cheap planers to do a job, throwing each one away when it dies, than to buy a model from a good-quality brand.

Of course, even if we move up a level from throwaway tools, there is always a balance to be struck between cost and quality when buying any equipment, whether hand or power tools. With experience comes an awareness of which tools (for any given task) need to be of high

Previous page: A small mixer is useful for knocking up plaster.

quality and which are less critical, so that a less expensive model will do the job perfectly well and money can be saved.

Where quality counts

With the above in mind, it is worth remembering that when working with cast-in-situ hempcrete you are using a construction system in which the structural frame (although not usually visible in the finished wall) and the temporary shuttering around it are the main determining elements in the straightness and plumb (or otherwise) of the finished wall. When the shuttering is removed, the face of a hempcrete wall is a very flat surface with many small voids and channels in it, created by the matrix of hemp fibres where they were pushed up against the inside of the shuttering. This is an ideal surface on to which to apply a render or plaster basecoat: the usual finish for a hempcrete wall.

When taking the shuttering down, an easy day at work can suddenly turn into a very hard one if you realize at this point that mistakes or inaccuracies in the construction of the timber frame or the shuttering have left a hempcrete wall surface that is not in the plane that you want it to be in. The remedy, unfortunately, is to first let the hempcrete dry out a bit so it is hard enough to take the treatment, and then spend hours painstakingly scratching the surface back with a nail float, level and straight edge until it is put right. This is not only soul-destroying work but is also quite physically tiring, because by this time the hempcrete has hardened significantly. It is also remedial work that was not accounted for in the original estimate of labour, so if you make mistakes on the frame or shuttering, you stand to lose money or time, or both, depending on your situation.

Hopefully this example serves to illustrate the importance of accuracy when building the frame

A large slide mitre saw can speed up the work considerably.

and shuttering, and hence the importance of having quality tools for the job. Happily, the most critical tools for this are hand tools and are therefore relatively inexpensive, even for top-quality brands. It is especially important to ensure that measuring tapes, levels, squares, hand saws, etc. are of good quality and are looked after properly – i.e. put away after use and not left lying around to get knocked or trodden on, and cleaned up at the end of the day. It is good practice to ensure that squares and measuring tools are regularly checked for accuracy, in the hope that any damage that would affect their accuracy is discovered before you have built a wall with them.

Essential tools and desirable tools

The decision about whether to buy large power saws, such as a slide mitre saw, and possibly a table saw, for building the structural frame is a personal one. Whether the outlay is worthwhile will depend on the amount of framing you have to do and whether you will get any use out of these tools after the project is finished. Not only can a slide mitre saw and a table saw, especially the former, speed up the work considerably, but in the hands of someone who knows what they are doing they greatly improve accuracy. If you are going to buy these, there is certainly no point in buying cheap ones, as the low price is always reflected in the level of accuracy that can be achieved with the tool.

Buying a professional-quality model will probably mean that there is some resale value if you don't need the saw for another job, but don't forget to check this out in classified ads before buying, and weigh up what you're likely to lose against the cost of hiring from your local tool hire company, as this option might be more economical for the amount of time you actually need the saw. Buying these tools second-hand yourself is also an option, of course, but if you decide to go down this route make sure you know exactly what you are buying. Always check the saw over carefully (including testing it in use) before buying, as you don't know what kind of life it has had; buying somebody else's damaged saw will do nothing for the accuracy of your framing, and will probably cost you more than you've saved in the long run.

In addition to the levelling and measuring tools already mentioned, a laser level can be extremely useful when setting out the frame. Again, quality models are expensive, and cheap ones are rarely worth buying. Quality laser levels can be hired quite cheaply, so this is probably the most sensible choice for a one-off project.

A battery-powered circular saw is extremely useful.

While the above-mentioned tools might be considered desirable, others are essential. For the framing stage, these include a jigsaw and small (165mm or 190mm) circular saw, and these *do* need to be high quality, since cheap versions will not only compromise accuracy but also frequently fail to make the grade in terms of the power needed to cope with the work. The circular saw needs to be powerful enough to rip 'eight by four' (2400mm x 1200mm) sheets of hardwood ply and OSB (oriented strand board) with a good accuracy of cut. We have found an 18V cordless circular saw to be best for convenience of use around site, but while these are powerful enough to cut, for example, 11mm-thick OSB sheets, they are not really up to anything thicker or denser, and so we always carry the mains-powered version of this saw as well.

Most circular saws are supplied with a metal rip fence which slots into the base plate and guides the saw by running along the edge of the sheet being cut. This rarely gets used, as you will most often be ripping or cross-cutting in the middle of the sheet, for which the fence is too short.

Some good-quality saws can be bought with an optional guide rail that clamps down on the wood, so the saw can be run along it for a straight cut every time. These are without doubt handy, but they tend to be expensive, and a similar result can be achieved using an offcut of ply (remembering to run the saw along the *factory cut* edge!), or even a chalk line and a steady hand. Remember that we are usually only talking about the edges of shuttering here, so straightness of the cut, while desirable, is not absolutely critical. Cutting sheet material that is to remain in place (timber cladding, for example) is a completely different matter, and this is where a good-quality table saw comes in handy.

Impact drivers are useful for framing and erecting shuttering.

When choosing tools for shuttering work, remember that you will be *reusing* shuttering boards. These inevitably come away from the wall with some binder and pieces of hemp on them, and, while bigger bits can be brushed off, there will always be some that set hard on the board. While this is not a major problem, don't forget that you will then be cutting these again with your circular saw. Also, while you should be removing all the screws that were used to fix the shuttering in place before re-cutting the sheet, in practice some screws will often get hidden in the timber strands of the OSB. A sensible choice, then, for those who expect to be doing a lot of this work and are therefore looking to buy rather than hire, is tools that are accurate but not excessively expensive to replace, as you will inevitably be abusing them a little. A good mid-range professional circular saw is likely to be a more sensible choice than the more expensive top-of-the-range versions.

The other essential tools for framing and shuttering are a decent cordless drill, preferably with a very low torque setting, and a cordless impact driver. These are useful both for the construction of the frame itself and for the repeated driving in, and extracting, of the heavy-duty fixings that hold the shuttering in place. Precision is not the main issue here, but you will find that good-quality tools will save a lot of time and frustration, and will therefore contribute to the accuracy of construction of both the frame and shuttering. A more obvious requirement with these tools, which are often in almost constant use, is power and durability. If you are aiming to do a lot of this type of construction, the initial outlay on quality tools will be paid back tenfold.

Another time-saving tool for the framing stage is a nail gun. If you are going for one of these, double-check that you can buy stainless-steel or hot-dip galvanized nails to fit it.

Good-quality nickel-cadmium (NiCd), or nickel-metal hydride (NiMH), battery-powered tools can now be purchased quite cheaply, since most people are moving over to the newer lithium-ion (Li-ion) battery systems. For those who can justify the extra expense, Li-ion tools provide quicker charging and a lighter, more powerful battery that takes much longer to discharge when not in use; it also has no issues with partial discharging, as there is no memory or 'lazy battery' effect.

Our standard toolkit

To build the typical hempcrete wall, and assuming that the foundations and plinth have already been constructed, the following is our standard toolkit at each stage of the build.

Frame and shuttering tools

- **Slide mitre saw.** Indispensable in terms of improving speed and accuracy, it's really useful for repeated cutting of timbers to the same length, and for angled cuts in timbers. It is also the quickest and most accurate way of cutting the plastic tubes (used in fixing the shuttering) to length – and their length is critical.
- **165mm or 190mm circular saws** (mains and 18V type). As discussed, it's useful to have both types to hand, but if you can only afford one, make it the mains-powered version.
- **Hand saws** (cross-cut). Usually one decent one kept for fine work, and a 'rough' one for cuts in recycled shuttering and shaping hempcrete after casting.
- **8V jigsaw.** A jigsaw is handy for cutting funny shapes in shuttering boards, e.g. where they have to fit snugly around a beam.
- **18V impact driver** and **18V drill.** Make sure they are good quality, as they'll be getting a proper hammering.
- **Nail gun.** With stainless steel nails for fixing the timber frame together.
- **Basic set of wood drill bits** and **impact-grade driver bits.** The long screw fixings used are usually supplied with a new bit in each box.
- **Good-quality bit holders.** Get a good supply as they always go missing, including an impact-grade extension bar bit holder.
- **Spade bits** and/or **hole saws** covering sizes from 10mm to 45mm.
- **Good-quality spirit levels** of varying lengths from 300mm to 1.8m.
- **Large set squares** and/or a **laser level** for setting out the frame.
- **Try squares** of various sizes and a **combination square.**
- **Tape measures, pencil, marker pen** and **chalk line** for marking out.
- **Small pry bar** (150mm length). Useful for removing difficult fixings.
- **Small disc grinder.** For those fixings that just refuse to come out.
- A **tool belt** with pouches is handy.
- **Buckets** for collecting the fixings for the shuttering and moving them around the building as they are put in and taken out repeatedly.

Tools for hempcrete application

- **First aid kit, including eye station with mirror.** Hopefully you won't need it, but make sure it's the first thing that goes in the van.
- **Mixer.** Usually either an 800-litre forced-action pan mixer powered by an engine of some description, or sometimes, for small-

A large pan mixer is ideal for mixing hempcrete.

A selection of tubs and buckets is essential throughout the build.

A multi-tool is useful for carving and shaping hempcrete.

scale applications, an ordinary bell (or 'drum') concrete mixer (see Chapter 15).

- **Long hose** for water supply and for cleaning the mixer.
- **Gorilla Tubs** (large-capacity, heavy-duty, lightweight, flexible containers – other brands are also available). Ten or so; used for measuring water for the mixer and for ferrying the mixed hempcrete, as well as for sweeping up into. The 30-litre size is most useful, although it can be handy to have one or two of the 45-litre ones too.
- **Block, pulley and rope** and a couple of **strong clips such as climbing carabiners.** For lifting tubs of hempcrete up on to scaffolding.
- **Protective clothing and equipment.** Including goggles, masks, gloves and protective clothing.
- **Stanley knife** or similar. For opening bales of hemp and bags of binder.
- **Broom** and **shovel.** For tidying up, obviously, but the broom is also handy for helping the hemp down through the grille of a pan mixer.
- A **nail float, rough saw** and **powered multi-tool.** For scratching back and shaping hempcrete prior to finishing, and for cutting channels.
- **Dehumidifiers** are useful for minimizing drying times of the cast hempcrete internally once the building is enclosed. They can be hired, and the temperature can be raised (if the heating system has not yet been fitted) with the aid of **electric heaters.** Gas-fuelled heaters are not recommended because of the extra moisture they introduce into the atmosphere as a by-product of the burning gas.

Tools for plastering and rendering

- **Mixer.** It will probably be a bell mixer this time, depending on the number of people you have working at one time.


Grid, sponge and nail floats: used for finishing plaster and shaping hempcrete.

- **Long hose** for water supply and cleaning up.
- A **powered plasterer's whisk.** The proper heavy-duty sort, not the flimsy type you put into a power drill for mixing paint.
- **Gorilla Tubs** (or similar) again. For transporting the plaster, sweeping up into and soaking/cleaning tools in.
- A **plasterer's bath** or similar, to work out of.
- A **gauging trowel**, some **12.5-litre buckets** and a couple of **1-litre plastic measuring jugs** for accurately gauging amounts when mixing.
- **Hawks** and your personal selection of **plastering trowels.** Usually including trowels of various sizes, margin trowels, corner trowels, and probably also a 'small tool' and some trowels of unusual shape for difficult-to-get-at places.
- **Floats.** A selection to achieve different finishes as desired, including grid and sponge floats.
- **Straight edge** and **levels.**
- **Bucket trowel.** For scraping out every last bit of plaster.
- **Sheeting.** To protect the floor and other areas as necessary.
- **Masking tape** (usually the 50mm width). For masking off the edges of adjacent surfaces.
- **Electric heaters.** If plastering in winter months in an unheated building.
- **Latex gloves** and **goggles.** For working above head height (absolutely essential for ceilings).

Other tools and equipment needed

- **Access equipment:** hop-ups, extending ladders, stepladders, trestles.
- **Lighting.** Preferably LED or fluorescent-tube type, rather than halogen (halogen lighting can cause your plaster to dry out too quickly!).
- **Basic toolkit** containing commonly used hand tools: hammer, crow bar, Stanley knife, adjustable spanner, screwdrivers, pliers, staple gun and a 'rough' chisel.
- **Hessian.** To hang over lime work on a cold day, or to soak and hang over lime work on a hot day.
- **Heavy-duty plastic sheeting** such as the type sold for damp-proof membrane. To staple up to protect work from the rain, as necessary.

If you are building the plinth at the bottom of the wall, or using a masonry cladding for the outside of the hempcrete wall, you will need a **bricklaying trowel, pointing trowel** and other tools for masonry construction.

CHAPTER NINE

Health and safety

Health and safety often gets a bad press nowadays, especially in the context of the overzealous attitude many organizations have to it in today's increasingly litigious culture. At best, health and safety at work is not the most thrilling topic, and this chapter is unlikely to be the first that readers turn to when they pick up this book. However, we would emphasize that there are some very important health and safety factors to be kept in mind when building with hempcrete.

Of course, working on any building site is potentially dangerous, with many hazards that have the potential to (and do) cause accidental injuries and deaths. Common risks include trips and falls, falls from height, accidents with power tools and machinery, exposure to hazardous substances, crushing injuries, head injuries and electrocution, to name but a few. This has resulted in the development, over the last 40 years, of a range of legislation, working practices and procedures aimed at improving safety by reducing the risk of accidents as far as possible, and minimizing their impact on individuals when they do happen.

Plenty has been written about health and safety on building sites, and we do not intend to reproduce it here. Suffice to say that it is the responsibility of everyone on-site to ensure that, in line with Health and Safety Executive guidance, safe working practices are followed at all times, the correct personal protective equipment (PPE) is used, materials are safely stored and tools and machinery are operated safely by trained personnel.

The main health and safety issues associated with hempcrete are to do with the nature of the materials; specifically the lime binder. Because these issues may not be immediately obvious to those who have not worked with building lime before, it is important to ensure that everyone is aware of them before starting work on a hempcrete build. Reading the advice in this chapter may give you the impression that working with

Previous page: Gloves for mixing or placing hempcrete.

lime is a highly dangerous occupation, involving constant injuries and burns. This is not the case. When proper procedures are followed and precautions taken, untoward incidents are very much the exception rather than an everyday occurrence. However, like everyone else who works with lime, we started off by getting burnt a lot more often than we do now, and we've picked up a few tricks along the way. We thought it would be a good idea to pass them on.

Always refer to the safety guidance provided by the manufacturer of all materials before starting work, but in general you should assume that the following issues and precautions will apply.

Dust is inevitable where binder is stored.

Main hazards

There are no particular hazards associated with the hemp shiv, although some people may find that they are sensitive to the dusty particles contained within it. However, shiv for building should contain an absolute minimum of small dust particles; also, the only time that dry bales are opened should be when mixing the hemp-crete, and the person doing this will in any case be wearing a mask for protection from the binder dust.

The lime in the hempcrete binder, on the other hand, is a strong alkali, and in its dry dust form it can cause irritation to the skin, eyes and mucous membranes of the nose and throat. When wet, lime can cause contact burns to skin, eyes and mucous membranes.

The most serious hazard is lime coming into contact with the eyes: this has the potential to cause serious health problems, including loss of eyesight. *Any case of lime getting into someone's eyes should be treated very seriously and without delay* (see page 114).

Precautionary measures

Despite your best efforts you will not be able to completely avoid people coming into contact with the binder dust, so the most important precautionary measure is to always have an appropriate first aid kit on-site (see page 113).

As with any hazardous substance, the first step to minimizing harm is the correct storage and handling of bags of binder. These usually arrive on a pallet, with the inevitable thin layer of loose dust over the outside of the bags from where bags have burst at some point in the warehousing or transport systems.

If moving pallets of binder around with a forklift, take extra care not to burst any more bags. If moving bags around by hand, for example when feeding the mixer, use the correct PPE (see opposite) and gently shake the loose dust off each bag before lifting it. Try to avoid holding the bag against your body; for example, you could put four bags in a barrow and wheel them across, rather than making four trips on foot with a bag held on your shoulder, rubbing the dust against your neck. Try to avoid inhaling the dust.

Binder should be stored in a cool, dry, draught-free place, which is ideally separate from the working area, to minimize the number of people who have to come into contact with the dust. Care should be taken to avoid the bags of binder coming into contact with moisture.

Any spills of binder dust should be dealt with straight away, either by carefully vacuuming the dry dust or by wetting down with a water spray and then carefully sweeping it up and shovelling into bags. Never sweep up dry dust, as this just disperses it into the air.

Empty binder bags should be promptly and carefully disposed of into plastic sacks kept near the mixer. These sacks should be closed up so that dust is not dispersed from the empty packaging.

Personal protective equipment

At Hemp-LimeConstruct we always keep the following full range of PPE with us: masks, goggles, gloves (both latex and thick PVC chemical-resistant types), waterproof clothing (long-legged and long-sleeved), knee pads, barrier creams and moisturizers. However, it's not the case that everyone needs to be wearing this stuff all the time!

Different roles on a hempcrete build come with different levels of risk of exposure to binder dust or wet binder material: from putting up shuttering (low risk), to placing hempcrete (moderate risk), to mixing the hempcrete (high risk). The suggested PPE for each role is outlined here, but bear in mind that different people have different degrees of sensitivity to the irritation caused by the dust, so anyone should wear extra PPE if they feel it is necessary, especially if working close to the mixing area, where despite best practice there will inevitably be some dust getting into the air.

The suggested personal protective equipment for each role is as follows.

Shuttering

Low risk, whether constructing or removing shuttering. Wear standard builders' gloves when removing shuttering from freshly cast material.

Mixing hempcrete

High risk. Wear PPE as described overleaf for placing hempcrete, and in addition wear goggles and dust mask at all times when mixing. The mask should be at least 'P2' rated, of strong construction, and of the type that uses replaceable filters. Depending on the water set-up at the mixing area, and how much water is splashing around when you are doing a mix, consider waterproof boots and clothing.

Goggles and a high-quality P2 dust mask are essential when mixing hempcrete.

Placing hempcrete

Moderate risk. Wear a long-sleeved top and trousers, and consider using barrier cream and moisturizer under your gloves. Wear latex gloves under thick PVC chemical-resistant gloves. Wear goggles when placing hempcrete above head level, for example if stuffing hempcrete up under the eaves. In wet weather, wear waterproof clothing, waterproof boots and knee pads.

Applying lime plasters and renders

Moderate risk. Wear long-sleeved clothing and gloves. In this case you will probably only wear latex gloves, or thinner chemical-resistant ones, as the thick PVC gloves are too bulky to enable the light touch that plastering demands. Consider using barrier cream and moisturizer. Always wear goggles when working above head height – plastering a ceiling is the classic way of getting lime in your eyes. When mixing up lime plasters, wear mask and goggles whenever there is lime dust flying about.

Working practices

Safe working practices during the mixing and placing of hempcrete play an important role in keeping harm to a minimum. They can be summarized as follows:

- Keep people clear of the mixing area unless necessary, whenever a mix is being prepared.
- Put barrier cream on your hands at the start of the day, as lime will inevitably find its way under your gloves somehow.
- At the end of the working day you may find that low-level exposure to binder dust, while not actually causing irritation, has dried out your skin, especially on your hands, to the point where it starts to crack. At this point it is essential to apply a heavy-duty moisturizer to replenish the moisture levels in your skin, otherwise the next day binder dust will easily find its way into the cracks in the surface of your skin and will cause irritation.
- Unfortunately, the freshly mixed hempcrete contains thousands of small particles of wet, binder-coated hemp shiv, which are the perfect delivery system for lime burns. These small particles tend to work themselves inside gloves or clothing, and then remain there to rub against your skin. This is the reason that we wear latex gloves under the thick PVC gloves, but it is also important to check your clothing and gloves regularly and remove any particles of shiv at the earliest opportunity.
- Be aware that latex under-gloves rupture fairly easily, so check them from time to time and don a new pair as necessary. At break times and the end of the day, shake out the thick PVC gloves (which last ‘forever’), in order to remove small particles of lime-covered hemp, and at the end of the week, give them a wash out and hang them up to dry.

Small particles of binder-covered hemp can get everywhere.

- Wear dressings over any open cuts, especially on your hands, to prevent lime entering them.
- At breaks, and the end of the day, and whenever you know you have been exposed to binder dust, wash your hands, arms and face (or any affected area) thoroughly and apply moisturizer as required.
- If binder dust or wet hempcrete gets on your clothes, brush it off straight away, and wear fresh clothes every day.
- Although mixed hempcrete is less prone to flying about in the air than binder dust, remember that small particles can get blown around in windy conditions. When tipping hempcrete into the shuttering on scaffolding, be aware of people working below you.
- When handling tubs of fresh hempcrete, take care to avoid spillages, and don't leave full tubs standing around where they may accidentally get kicked or people may trip over them.
- Sweep up any mix dropped during placing straight away, especially on shuttering, where, if left, it can fall on people or blow around. Mix dropped on scaffolding boards is, in any case, usually clean enough to be placed into the shuttering or chucked back into the next mix.

Wet weather precautions

Wet weather is not great for hempcrete placing, for a number of reasons (see Chapters 15 and 16), not least of which is the increased risk of lime getting inside people's clothing. Not only does the rainwater help the binder to run inside clothing and gloves, but by making it wetter it increases the likelihood of burns occurring.

When placing hempcrete in wet weather, waterproof clothing and boots are essential. If placing at a height where you are kneeling on scaffolding to reach inside the shuttering, wear waterproof trousers, or knee pads, to stop the soaking-wet dropped mix on the scaffolding rubbing lime in through your trousers to burn your knees.

In extremely wet weather, stop hempcrete placing completely, unless your mixer area is under proper cover and you are able to place hempcrete from inside the building or from under a temporary roof structure. (This is advisable not only for safety reasons but in order to maintain the correct amount of water in the mix – see Chapter 16.)

First aid

Despite your best efforts, there will always be times when exposure to lime causes irritation or burns, from mild to severe, so it is important to keep a well-stocked first aid kit on-site, containing plasters and dressings, treatments for skin irritation and burns, and eye wash. A proper eye station is advisable, which comes complete with a mirror and individual squeezy bottles of sterile water.

Keep an eye station close at hand when working with lime.

The following first aid procedures should be followed where contact with lime requires treatment.

Skin

In cases of mild irritation caused through exposure, wash the skin immediately with plenty of water (but not soap, which could cause further irritation). Remove and wash any contaminated clothing.

In cases where prolonged exposure, or exposure to very wet lime, has caused severe irritation, apply a topical treatment such as a strong over-the-counter dermatitis cream. Some people swear by a strong solution of water and white vinegar, based on the theory that since the vinegar is acidic it can help to neutralize any active lime left in the damaged skin. Feel free to try this and judge for yourself, but bear in mind that rubbing even a mild acid into damaged and inflamed skin might well do more harm than good! If topical treatment does not cure the inflammation and pain, seek medical attention.

If lime gets in a cut, you should feel it immediately, as it is quite painful. Stop what you are doing and wash the cut thoroughly with lots of clean water until the pain reduces. Seek medical attention if you are still in pain.

Eyes

If lime gets in your eyes you will be in excruciating pain. Speed is essential. Wash the particles out immediately using eye wash or clean water, until you have got everything out. It's usually best to get someone else to help with this, as they will be able to see your eye better than you can. Also, owing to pain and panic, the person affected does not usually have the steadiest hands at this point. Even if you think you have got it all out, seek medical attention to be on the safe side. It's your vision at stake.

If you cannot get all the particles out of the eye despite washing with water or eye wash, go straight to the nearest Accident and Emergency department.

Nose and throat

In the unlikely event that you inhale significant amounts of binder or lime powder, wash out your throat and nose with clean water for at least 20 minutes, being sure to spit it all out, and then seek medical attention as a precaution.

In the even more unlikely event that you swallow some, wash out your mouth with water, and drink copious amounts of water. Seek medical attention if necessary, especially if you experience stomach pain.

Long-term health risks

Although the main health issues with lime occur at the time of contact, it is also worth bearing in mind that prolonged or repeated contact with the skin may result in severe dermatitis, requiring more extensive medical treatment. Likewise, prolonged or repeated inhalation may result in lasting damage to the respiratory tract and lungs, and could potentially cause serious and debilitating lung disease. For these reasons, people who work with lime on a regular basis should be even more careful to avoid even minor exposures.

As on any building site, the usual safe working practices must be observed, such as using the correct access equipment when working at height.

CHAPTER TEN

Planning the build

Before moving on to look at the construction process in detail, in this chapter we briefly discuss some aspects of building with hempcrete that are helpful to keep in mind during the planning and building design stages.

For a more detailed examination of the factors involved when designing hempcrete buildings, see Chapter 21.

Inspiration

Anyone in the fortunate position of being able to design their own building is likely to draw their inspiration from a range of sources. In theory, the only limit is what your imagination can do within the constraints of the materials you are using, although in practice local and national planning policies, building control and consideration towards neighbours will also restrict what is possible in any given situation. Whether the new building is to be a home, workplace or community building, or a smaller living space such as an extension or garden building, the first step in the design process is the spark of an idea about why the building should take a particular form or look a certain way.

With the explosion of interest in self-building that the UK has experienced over recent decades, those designing their own building are hardly short of information about other people's projects from which to draw inspiration for their own plans. The choice of hempcrete as a building material should not limit you in the type of building you design, although the decision to use it would suggest that you are aiming to design an energy-efficient, low-impact building.

While hempcrete is used to create a wide range of types and styles of building, it is our hope that most people seeking inspiration for designing with hempcrete will take as their starting point the natural materials involved, and so look for inspiration to other buildings in their local area that have been constructed with sustainable,

Previous page: A newly renovated seventeenth-century cottage, with external hempcrete solid-wall insulation.

natural materials. Usually this means looking at the elements of design visible in traditional buildings.

We use the phrase 'traditional buildings' to refer to small buildings in a given area built at any time before about 1850. Commonly known as vernacular buildings, these usually include houses, barns, workshops and small-scale community buildings such as village halls, chapels and pubs. Vernacular buildings usually exhibit a distinct style, which varies significantly according to, and helps to define the character of, the local area. In contrast to grander, architect-designed formal buildings (large houses, churches, town halls and the like), these buildings were usually designed and built by ordinary people – either the eventual occupier of the building, or local craftsmen who were part of the small community that the buildings served.

Vernacular buildings were built without any formal plans or access to architects, according to 'patterns' of building developed over thousands of years by the population of the local region and handed down through the generations, gradually being refined and incorporating new technologies (such as clay tiles or window glass) as the years passed. The style of these buildings varies dramatically across different parts of the UK (and across the world), but all vernacular architecture reflects the sum of centuries of finely honed knowledge about how to use locally sourced, natural materials to best effect in the geography and climate of any particular region. This 'lost knowledge' of our ancestors extends to the siting and orientation of buildings within the landscape to make best use of natural features such as shelter, exposure to the sun and drainage, thereby creating buildings that work passively *with* the local climate to minimize the fuel consumption needed for comfortable habitation. The sensible siting and orientation of buildings can easily reduce energy in use for little or no extra cost, but sadly it is something that is hardly ever considered during the planning process.

The shape of vernacular buildings is usually very simple, which allowed them to be built without complicated structural techniques and machinery,

The orientation and shape of vernacular buildings can be a good source of inspiration for building design.

but in their simplicity they are often beautiful buildings that are inherently pleasing to live or work in. Examples that survive today are a self-selecting 'best of the bunch': the fact that they have lasted so long is a sign that their builders knew what they were doing. All of these attributes combine to make local vernacular buildings a particularly appropriate source of inspiration for the self-builder or designer who wants to create a natural, sustainable building.

Cost

It would be unusual if the cost of building with hempcrete were not a factor in the decision whether to use it, and indeed this is usually one of the first questions people ask us at Hemp-LimeConstruct.

Costs do, of course, vary slightly with the design specification, as well as the particular materials chosen and where they are sourced from. Prices of materials are not discussed in this book, as the information would rapidly go out of date.

In comparing the cost of a hempcrete build with other methods it must be remembered that the simple monolithic hempcrete wall contains the structural element of a building's walls *and* a high-spec level of insulation *and* replaces everything required for the wall build-up in other building systems, up to the level of plaster finishes. When you sit down to consider what is replaced in terms of materials within a conventional masonry or lightweight timber-frame wall build-up, the simplicity of hempcrete starts to look very appealing indeed.

The construction cost of having someone build a hempcrete building for you should be broadly similar to that of a conventional construction (e.g. brick-and-block with a cavity and high-spec synthetic insulation).

A monolithic wall made from timber and hempcrete replaces many different materials that are required in a conventional modern wall build-up, e.g. bricks, blocks, cavity insulation, membranes and wall ties.

This cost comparison is of course made without pricing in the exceptional thermal performance over the lifetime of the building of hempcrete compared with conventional materials (in contrast to hempcrete, lightweight insulation materials – especially synthetic ones – may lose their shape and sag over time; they also have negligible thermal mass), which significantly reduces the running costs of heating and cooling systems. It also doesn't take into account other benefits of hempcrete, which might be considered in terms of costs, albeit of a non-monetary sort:

- the significant benefits to the health of the building and its occupants
- the fact that conventional construction

materials generally have a very high embodied energy, whereas hempcrete acts as a 'carbon sink', locking CO_2 away.

For those undertaking the build themselves or providing some of the labour, costs can be reduced still further, but this does need to be planned for properly in the build, to ensure enough labour will be available when needed (see opposite).

Design

In practice, many of those who have creative control over the design of their building will feel more comfortable working closely with a professional architect than taking on the task of designing it themselves. Bear in mind that, at the time of writing, it is still rare to find architects who have direct experience of specifying hempcrete in building design, although they should know where to access more information about it, especially if they specialize in designing sustainable buildings.

As hempcrete is a relatively new material, it's important for anyone considering using it to understand its key properties, the structural limitations on how it can be used, and how these factors interact with each other in the design of a hempcrete building, before proposing construction details. This is something that client and building designer need to discuss at an early stage, to ensure that everyone involved in the design process understands the material, and that if they don't, that specialist consultants will be involved at an early stage of the design process, as mistakes can be expensive to correct at a later stage of the build.

It is to be hoped that anyone designing and building with natural materials, hempcrete included, will take a holistic view of how the building will work. This makes far more sense than, for example, just putting in a hempcrete 'feature' within a building made up of different materials, including conventional synthetic materials that do not complement hempcrete at all. Switching over from natural to synthetic materials within the same building for the sake of aesthetics not only risks creating a disjointed feel but also often fails to make use of the most useful features of hempcrete and other natural building materials, which tend to work best as a whole building system.

For example, hempcrete, as discussed in previous chapters, has the potential to offer great benefits in terms of insulation, airtightness and reduction of cold bridging, owing to its cast-in-situ application method. Since it can be used for floor slabs and roof insulation as well as walls, this creates the opportunity to construct super-insulated buildings, with hempcrete as the insulating material throughout the whole thermal envelope, as long as designers understand the advantages of this and consider the concept at an early stage.

Another key aspect of the design process is to research the different binders available, and to get a feel for how the different options could affect the design of the building, especially with regard to:

- the thickness of wall necessary to achieve a required level of thermal performance
- expected drying times and other characteristics of the material that may affect the schedule of works
- the types of finishes that are specified by the manufacturer.

Given the limited choice of binders currently available, this research should not take long. However, you would be surprised at how often we encounter people who are all set to start building in a couple of weeks' time but haven't yet chosen the binder they will be using.

Practicalities

For careful planning of the build stage to ensure that everything goes as smoothly as possible, it is worth keeping in mind two key aspects of working with hempcrete that can have an effect on the timing and success of the build.

Workforce factors

The skill of the workforce is essential to the success of the cast material and to the smooth progression of the build, so it is important to ensure that the people responsible for the building works are trained in the use of hempcrete, and have sufficient knowledge and experience to be able to undertake the work they are doing.

While volunteer labour can reduce costs, a certain number of skilled people is essential.

Since hempcrete is quite a labour-intensive process, many self-builders understandably try to reduce costs by supplying their own labour or getting friends and family to help with the hempcrete-placing phase. Using volunteers can be a good way to reduce costs. However, it is vital that basic training is provided and that the work of volunteers is well supervised throughout the build to ensure consistency of workmanship. Also, we have found that when people are not being paid for their work, despite the very best of intentions they do sometimes see their attendance on the day as something that is entirely their own choice, right up until the last minute. There will always be some folk who don't see anything wrong with phoning on the morning they are expected (or not phoning at all) to say that they've changed their mind and won't be coming.

Clearly, it can be difficult to find a balance between being able to rely on the necessary number of people turning up and having lots of extras wandering around that you don't know what to do with. In our experience, it can be worthwhile (especially when volunteers are looking at the experience as a training exercise) charging a nominal fee in advance, say £10 per day to include all tea and coffee, lunch and provision of PPE: this can make the difference between people turning up or not.

See also Chapter 5, page 73, for more on using volunteer labour.

Drying times

Since hempcrete is a wet-mixed material, which takes several weeks to dry out sufficiently for finishes to be applied, and because this time can vary depending on local weather conditions during and immediately after the construction phase, obviously this can affect the build in ways that need considering at the planning stage.

A common complaint, especially on commercial builds, is that the hempcrete is taking too long to dry out and that the delay in applying finishes means that extra costs are being incurred (usually because external scaffolding cannot be taken down until the render has been applied).

This is a problem that can be anticipated and designed out, for example by the use of a cladding finish with a vented air gap, which can be applied much sooner than a render finish, or by arranging the schedule of works to accommodate this drying stage.

If drying time is properly planned for in the schedule of works it should not be an issue, and if necessary, after a few weeks finishes can be applied to the external face of the wall and the scaffolding removed while the wall continues to dry to the inside. This needs considering at the design stage, since it would not be possible in certain situations, for example if internal permanent shuttering board was used.

Good 'drying management' once the hempcrete is cast can speed the process considerably, and, again, with proper planning this can be incorporated into the schedule of works from an early stage so that everyone on-site understands what their responsibilities are in this regard. For more information on drying of hempcrete, see Chapters 15, 16 and 19.

This new-build community centre, cast during an exceptionally wet summer using a slow-setting binder, was rendered a year after the hempcrete was cast.

Since drying times are affected by weather conditions, it is important to work *with* the seasons to speed up drying as much as possible. It is, in any case, not possible to use lime-based binders in temperatures lower than 5ºC, and for most hempcrete binders 10ºC or more is recommended. Casting hempcrete towards the end of the autumn is not, therefore, advisable, and even if you get away with it, you are certainly unlikely to be applying render finishes before the spring. Of course there is nothing (except scaffolding costs) to stop you plastering the inside of the building during the winter, where you have control over the temperature, and applying renders in the spring.

With the best will in the world, virtually every build gets delayed, and at Hemp-LimeConstruct we are often booked to come and build hempcrete walls in May, which then turns into June, and then into July and August, as more and more delays occur on-site meaning that clients are not ready for us. This is not necessarily a problem, as long as everyone is aware of how this will affect drying times, and contingency planning has been done to manage this eventuality.

Our advice is to plan to start building as early as possible in the year. Indeed, approaching the problem from another angle: wherever possible, we would advise that you plan for the external walls to remain un-rendered for several months or more, to give the hempcrete plenty of time to dry out. There is no reason, unless the walls are unduly exposed to the prevailing weather, why hempcrete walls cannot be left unfinished externally for months while the interior is plastered and fitted out and the building occupied and heated, which of course can only speed up the drying process.

Focus on self-build 1: Agan Chy

Inheriting a field with a dilapidated concrete barn on it gave Bob and Tally Moores an opportunity to fulfil what was, for Bob at least, a long-held dream of building his own house. Planning permission had been refused on the barn once, but after some detective work Bob and Tally found an old map which convinced the council that, contrary to previous opinion, the barn sat within the village boundary, and permission was eventually granted for demolition of the barn and construction of a house.

Bob is a carpenter, used to timber framing, so his house was always going to be based around a green oak frame, and having worked for a supplier of traditional and environmentally friendly building products, he was familiar with lime and other natural materials. He was doing an MSc in Sustainable Architecture at the Centre for Alternative Technology, from which he says he learnt a lot, but couldn't understand why everyone was talking about easy-build bolt-together timber-frame houses with lightweight insulation, which needed to be sealed up tight to keep the heat in and then ventilated using mechanical systems to maintain indoor air quality. Bob says, "Up to the point when we built the house, I had lived mainly in vernacular buildings, built from local, natural materials that had stood the test of time. I wanted the same feeling of permanence from the house I was going to build myself . . . to know that, as well as being a high-thermal-performance eco-house, it would stand a chance of being there for centuries to come, and I didn't think I would get that from a lightweight insulated timber-frame house." The more Bob thought about it, the more it seemed to him that thermal mass was the key to passively storing heat, whether created by heating systems or from the sun, and slowly releasing this energy to maintain a constant comfortable temperature inside.

The final design included a green oak structural frame, with a softwood studwork frame built off this to take the hempcrete. The principles of passive solar design were followed: highly efficient glazing on the south-facing elevation and a minimum of windows on the north side, together with a good overhang so that the windows are shaded in summer but allow direct sunlight in during the winter, when the sun is lower in the sky. All the external walls are 300mm hempcrete, with additional thermal mass provided by a deeper-than-usual concrete floor slab and slate floor covering in the open-plan living area. The roof is insulated using wood-fibre insulation panels. Being in an exposed location close to the Atlantic coast in north Cornwall, Bob and Tally have sensibly used a larch rain-screen cladding over the hempcrete on the exposed walls (most of the house); on the south side, they used a breathable render. Bob's motto for the build was 'Low-tech – high performance', and this comes out in the solidity and strength of the materials that surround us as we stand in the kitchen: oak posts and beams, solid black slate flooring, black slate windowsills, lime plasters and thick hempcrete walls. The house, on a scorching July day, feels reassuringly cool and comfortable, despite the fact that we are sitting next to the large south-facing windows and the external doors are open, allowing a direct connection with the heat outside.

In the winter, heating is provided by a wood burner in the living room, the flue of which

1. Agan Chy.
2. ‘Solid and built to last’, yet light and airy.
3. Larch cladding was used as a finish for the hempcrete.
4. Natural materials complement each other at Agan Chy: natural slate sills and roof covering, and lime renders or larch cladding over hempcrete.
5. Warm in winter and cool in summer, despite the large windows, due to hempcrete’s unique thermal performance – insulation *and* thermal mass – together with the passive solar design.

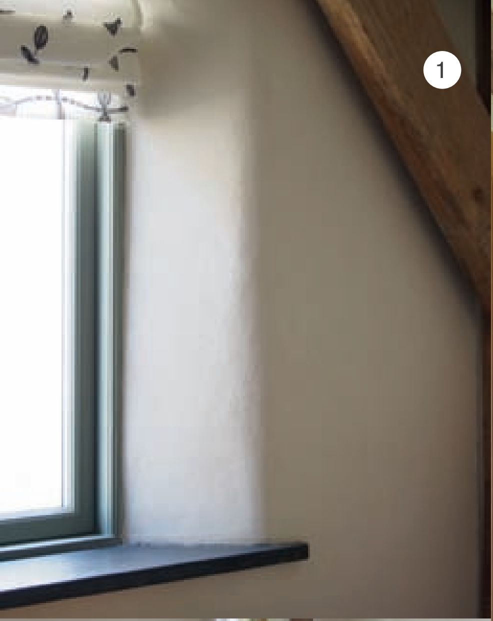
passes through the master bedroom on its way to the roof, allowing the passive transfer of heat into the bedroom. There is a solar domestic hot water system, and an air-source heat pump to supply underfloor heating, but Bob and Tally find that they hardly ever need to use it. Even in very cold winters, the heat from the wood burner alone is more than enough to maintain a comfortable temperature throughout the house "at least 90 per cent of the time – and to be honest a lot of the time we probably have it on for the atmosphere rather than heating. The only time we turn the heating on is when we've got guests in the spare bedroom and we feel we should heat up the 'north wing' for them," says Bob.

Bob designed the house with architect Roderick James, and the hempcrete details were worked out by Bob together with Chris Brookman from Back to Earth, who supplied the hempcrete. The build took eight months of full-time work, and another eight months part time. A friend, Ollie, worked with Bob on the construction of the frame, and then Bob and Tally finished the rest of the build by themselves. Bob says he found the hempcrete easy: "It's great to work with – putting up the shuttering was the hardest bit." He enjoyed the low-tech nature of hempcrete as a material, and found it refreshing being a pioneer doing something that not many others had attempted at the time, and so being able to "make it up as I went along" – a pleasant change from conventional construction.

At the time, Bob worked out what it would have cost to build the house out of brick-and-block, and "it was pretty much the same – and that includes the 'cost' of my own labour, but if you think of the advantages from the thermal performance of hempcrete there's no comparison". Bob and Tally found that using hempcrete brought no disadvantages in terms of getting a mortgage, and there were no issues with planning either. For building control they used an Approved Inspector, and would recommend this to others: "Because he was directly employed by us, he took the time to listen and understand the material and what we were doing, and instead of being suspicious of something out of the ordinary he was interested and really got behind the project."

Reactions from friends and family have been interesting: "In the early stages, lots of people were curious, if not openly amused," Bob says, "but once they have experienced what it feels like to be in the house, they all get it. Everyone is blown away by it." Bob's musician friends particularly enjoy the acoustics created by the solid hempcrete. "Not being a musician, it's an aspect of the material I'd never really thought about," says Bob, "but they rave about it." Anyone wishing they could experience the feel of a hempcrete house for themselves can do so, if they fancy a summer holiday in Cornwall, as Bob and Tally rent their house out for eight weeks of the year.

Following completion of the build, Bob was surprised to get a personal call from the energy assessor who had visited their house. "He said that he never rang people up, but he was calling to advise me to get an airtightness test done, because ours was one of the most thermally efficient houses he had ever assessed, and with favourable airtightness results it might put our rating up from A+ to something even higher – the very highest rating, which only a very few buildings in Europe ever achieve." Bob has not in fact had an airtightness test carried out, as "I didn't feel it was worth spending the money, and because we wanted to use passive ventilation we've got trickle vents. I'm not really interested in super-airtightness if it means using powered mechanical heat-recovery ventilation systems; anyway, we're happy with how it performs – it's warm in winter and cool in summer, and it achieves my criterion of feeling like a solid house – something that's built to last!"



1. Curved window reveals accentuate the natural feel.
2. Lime plaster and windows on three sides give the master bedroom a light, soft atmosphere.
3. The wood burner is the only heating Bob and Tally need most of the time.
4. The stove pipe passes through the bedroom, making use of the flue itself for additional heating.
5. Traditional, natural materials are used to create a building with a contemporary feel at Agan Chy.
6. Bob outside his hempcrete home.

PART TWO

Hempcrete construction

CHAPTER ELEVEN

The hempcrete wall: an overview

There are several ways of using hempcrete within the structure of a building, but its 'standard' use, which is probably the most familiar to those who have seen or worked with the material, is the construction of solid (monolithic) walls to form the thermal envelope.

This chapter describes the principles of construction and the typical construction method for a cast-in-situ hempcrete wall. There are other ways of using the material in walling, depending on the specific application and the specifications of the architect or building designer, but the basic principles are the same.

Later chapters in this part of the book provide an expanded discussion of the methods used and skills involved at each stage of wall construction. Other than the information given in this chapter on services, all topics relating to the wall build-up are covered more thoroughly in the rest of Part Two. The purpose of this chapter is to give a broad overview of the entire walling system.

Hempcrete wall construction principles

A hempcrete wall is built with natural materials and provides a very high level of thermal and acoustic insulation and is 'breathable', so provides moisture buffering – passive regulation of humidity, which is beneficial both for human health, because it improves indoor air quality, and for the fabric of the building. Different levels of insulation can be achieved by casting different thicknesses of hempcrete, but a standard thickness in new build would typically be 300mm or 350mm. The thermal performance achieved varies according to the exact materials used.

As a monolithic cast-in-situ walling system, hempcrete effectively minimizes the chance of thermal bridging, by forming a continuous sheet of insulation material all around the building. The wall build-up, in its simplest form, uses only two or three different materials (lime, hemp, timber), which adhere closely to one another,

Previous page: Hempcrete internal walls in an Elizabethan timber-frame building.

Glulam roof structure in a large hempcrete building.

and it contains no cavity, thus minimizing the risk of interstitial condensation.

More information about the benefits of using natural insulation materials and the thermal, moisture management and other properties of hempcrete can be found in Chapters 4 and 7.

Hempcrete walls are cast around a structural timber frame, as they are not strong enough to be load-bearing. Although they have some strength in compression, this is not enough in itself to support the weight of the roof and upper floors. The set hempcrete, though, does provide a good strength in tension, which provides racking strength to the timber frame, meaning that the use of timber can be minimized in a well-designed frame.

It is perfectly possible to construct large buildings, including those with structural frames of glulam, steel or concrete to accommodate several storeys or cross large spans, using cast hempcrete. However, these are more likely to involve complicated frame designs, and in the case of very large buildings it is likely to be quicker and more cost-effective to use prefabricated hempcrete panels or blocks or sprayed cast-in-situ hempcrete than to place the hempcrete by hand.

For buildings of up to two or three storeys, hand-placed cast-in-situ hempcrete provides a natural, sustainable and low-tech walling system which, though relatively labour-intensive, is easy to construct and is comparable in cost to conventional masonry. Big savings can be achieved by self-builders and community groups who can provide their own labour.

The fact that the hemp aggregate is a natural plant material has implications for the design of the building, for which 'a good pair of boots and a good hat' is generally recommended. In other words, the building should have a good-sized masonry plinth to lift the bottom of the hempcrete above the ground, to protect it from standing water or being constantly wetted by splashback from rain hitting the ground, and a good roof overhang to throw rain away from the wall. In practice, however, many hempcrete buildings have been built with alternative, compensatory eaves details without causing problems. The degree of roof overhang should be considered carefully alongside the choice of external finish for the walls.

A large eaves overhang is not always necessary on hempcrete buildings: at Callowlands in Watford, a hidden gutter and a specialist hydrophobic lime-based render allow the overhang to be eliminated.

These factors, together with the requirement to keep all finishes breathable, the extended drying time, and the need to give some thought at an early stage to fixing into the finished walls, are probably the elements that will be the most unfamiliar to designers and builders of conventional buildings. Other aspects of hempcrete construction, such as the timber-stud framing, the shuttering, the mixing of a binder with an aggregate, and the plaster or cladding finishes, will be familiar to most people in the construction industry.

Internal walls

Hempcrete is often specified only for the external walls of a house, because of its insulative properties, but there is no reason why it cannot be used for internal dividing walls as well. Hempcrete internal walls create a continuation of the 'feel' of the building into the interior space, and provide a good thermal and acoustic barrier between rooms. Interior hempcrete walls can be cast at a much-reduced thickness, and they make it easy to avoid the use of non-natural or high-embodied-energy materials such as gypsum plasterboard and synthetic insulation to construct stud walls.

Using hempcrete for internal walls also allows the continuation of the use of natural finishes such as lime or clay plasters throughout the interior space, although in many cases architects apparently do not consider this, or see no benefit in it. Switching to gypsum board and skim for the internal walls may influence the moisture-buffering capability of the internal structure, and also inevitably creates an awkward cross-over point somewhere between the two types of material, which in our experience usually leaves the interior finish feeling disjointed and clumsily stitched together. An alternative to casting hempcrete for the internal walls would be to use a carrier board suitable for lime plaster, such as wood wool board, for internal stud walls. It may be that the failure to continue the use of natural finishes throughout the building is a reflection of designers seeing them as a 'necessary evil' for finishing the hempcrete, rather than as a beautiful and functional feature which enhances the comfort of the building's occupants.

Wall structure and finishes

The lime in the hempcrete binder, together with the breathable nature of the cast material, serves to protect the hemp aggregate and the timber frame from rotting. This means that untreated softwood can be used for frame sections that are encased in the cast hempcrete, with no extra measures to protect it from moisture. Although, to our knowledge, no specific research has investigated the longevity of untreated softwood in this situation, this is a generally held principle across the industry, and countless examples exist (the vast majority of hempcrete buildings in the UK) where this detail has been used with no detrimental effects reported.

If the idea of using untreated softwood in a structural application does not appeal to you, or if it fails to satisfy local building control authorities, or for parts of the frame where the timber is more exposed, three options exist. Clearly, treated softwood could be used throughout, although this is not to be recommended owing to the toxic preservative and pest-resistant chemicals with which it is impregnated, which

Untreated softwood and glulam beam making up the frame for a hempcrete wall.

could potentially cause health problems through off-gassing into the home. A hardwood frame could be used, but would be significantly more expensive; also, hardwood normally constitutes a less sustainable material, as hardwood usually takes far longer to replenish through regrowth. A compromise option, then, would be to use locally sourced hardwood timber or damp-proof vapour-permeable ('breather') membranes at parts of the frame that are more exposed or are inherently more vulnerable to moisture ingress. (See overleaf, and Chapters 13 and 18.)

The wall is constructed around the timber frame by erecting temporary shuttering, which is then filled with hempcrete. A permanent shuttering board made from a breathable plaster carrier board (usually wood wool) can be used on one side of the wall, but on at least one side the shuttering must be removed to let the hempcrete dry out after it has been cast.

When the hempcrete has dried sufficiently, it can be finished internally with lime or clay plasters, with these being applied directly to the surface of the cast hempcrete or to the breathable permanent shuttering board. Or, if the texture of the face of the hempcrete wall is to the occupant's taste, it can be left as cast, with just a natural, breathable paint applied directly on to the hempcrete. All paints used on hempcrete, whether applied directly to the wall or on top of finishes, must be breathable.

Externally, a hempcrete wall is usually finished with lime render, but might alternatively be clad with a natural material (e.g. timber, slates, tiles, brick or stone), as long as a ventilated air gap is left between the cladding and the face of the wall, and breathable lime mortar is used for any masonry. For a rendered wall, again, breathable paints or limewash are used externally. The principle of the 'breathable' wall made with natural materials is discussed in Chapter 4.

Structural maintenance

It is worth reminding ourselves here that, while all natural materials used in a wall allow the absorption and desorption of moisture by the wall over time without damage to its fabric, this does not mean that hempcrete walls are maintenance-free! As with any building, periodic maintenance is required over the years, to keep it working as it should. Sadly, you can walk down any street and see examples of conventional structures where the failure of the occupants to carry out simple maintenance tasks, such as cleaning out or repairing gutters, or replacing slipped roof tiles, is causing problems with damp and structural deterioration. Finally, a key principle to bear in mind when using any plant-based natural building material (e.g. hemp, straw, timber, reed) is that any exposure of such materials to standing water, or to water constantly running through them, will eventually lead to the material rotting. Of course this is nothing unusual, since most materials, not just natural ones, will deteriorate if exposed to standing water! This is another good reason to keep up with maintenance (especially of the roof), and it has implications for the design of the building, as discussed on page 133.

Hempcrete wall construction method

This section describes the process of constructing a typical new-build hempcrete wall. Other chapters in this part of the book address in more detail each aspect of the construction. For a full discussion of hemp and lime materials, see Chapters 2 and 3.

Foundations and plinth

The foundations in a hempcrete building are much the same as in any other building, serving to transfer the load of the building safely to the

A good-sized plinth keeps the hempcrete wall in this new-build house well above ground level.

ground. Hempcrete's low density allows some reduction of the amount of concrete used in some foundations, thereby reducing the embodied energy of the build (most commonly, where the ground calls for a raft foundation instead of the standard trench – see Chapter 12, pages 148 and 150-1). Free-draining foundations can be very useful in hempcrete buildings, to reduce the potential for moisture being held against the bottom of the hempcrete wall.

At the base of the walls, built off the foundations, is a plinth, usually of masonry construction, which serves as the 'good pair of boots' for the building. The plinth has a damp-proof course (DPC) running along the top of it.

For more detail about the foundations and plinth see Chapter 12.

The structural frame

On top of the plinth and the DPC, the structural frame is constructed. The usual method is to build a simple studwork frame consisting of a floor plate, studs and a wall plate of untreated softwood timber. The cross-sectional dimensions of the wood required vary depending on the size of the building, and of course for buildings of several storeys or which include wide ceiling spans, a steel or glulam frame may be necessary. All fixings must be alkali-resistant (stainless steel or, in the case of nails, hot-dip galvanized), as they need to resist corrosion by the lime in the hempcrete (see Chapter 21, page 299).

Further details on timber-frame design are provided in Chapter 13.

The frame is usually encased centrally within the cast hempcrete wall, but can be positioned flush with the surface of the hempcrete, either internally or externally, to make fixing into the wall easier. For example, a wall that is to be clad with timber or masonry externally would benefit from the frame being flush with the external face of the wall. Likewise, in a room where a lot of heavy-duty fixings will need to be made into the wall (e.g. for hanging kitchen wall cupboards), then it is normal to have the frame flush with the internal face of the wall. Positioning the frame flush with either surface of the wall necessitates some additions to the frame to ensure that the other two-thirds of the wall are properly supported.

A note on fixing into hempcrete walls

Hempcrete, when properly applied, should not be tamped hard into the shuttering, but instead spread evenly around in the void with a gloved hand (see Chapter 16, page 211). This should result in a finished wall of low-density ('light and fluffy') hempcrete, which has a high insulation value because of the air trapped in the wall. A low-density hempcrete also dries more quickly.

Despite the 'open' matrix structure created by the particles of binder-coated hemp within the wall, it sets very hard and strong when fully dry, and is perfectly strong enough to fix into for light-duty fixings, for example for pictures or small mirrors, using wall plugs as you would with a conventional masonry wall.

For more heavy-duty fixings, such as wall-mounted radiators, guttering downpipes and wall-hung cupboards, a hempcrete wall may not have sufficient density to support the weight hanging from it. There are two solutions: the first is to use wooden rails cast flush with, or just behind, the surface of the wall. Including a horizontal wooden rail in the frame design at, say, 900mm and 1800mm enables a strong fix anywhere in the room at dado and picture-rail heights. Clearly this needs to be integrated into the design at the wall build-up stage; if this is not done, and strong fixings are required once the hempcrete has set, the solution is to use wooden wedges hammered into the dried wall to take a fixing. These are set so that the wide end sits flush with the wall surface and screws can be fixed straight into the wedge, and have the advantage that they can be set in at the exact place where the fixing is required. You may have seen this method used in Victorian houses as a way of providing a fixing for skirting boards. It is particularly effective with hempcrete, since the set hempcrete has elasticity and 'bends' under excessive pressure rather than breaking. This means that the hempcrete around the wedge gets pushed outwards, and becomes denser in the immediate area surrounding the wedge, thus holding it more firmly.

As an alternative to fixings, remember that, since hempcrete is a cast material, it is relatively simple to create attractive and functional recessed alcoves and shelving by making a mould to use as part of the shuttering and casting the hempcrete around it. With this in mind, take the time to plan your use of each room carefully before you start work.

Where the timber frame is buried centrally in the wall, it is well protected, by the vapour-permeable nature of the hempcrete, from moisture being held against it. Furthermore, the lime in the binder not only protects against rot but also acts as a barrier to insect infestation and as an anti-fungal agent. It is therefore acceptable to use untreated softwood for parts of the frame that are encased in the wall (see page 134).

Where the frame is flush with the external face to assist with tying cladding to the wall, this part of the frame needs extra protection from water ingress. For details, see Chapters 13 and 18. Where the frame is flush with the internal face, we have always used untreated wood, but this will be a decision for you and for your building control inspector. An internally exposed frame is obviously less vulnerable to damp ingress, but

Hammering a wooden wedge into a hempcrete wall.

Downpipe fixed into hempcrete with wooden wedges.

depending on the types of insect prevalent in your area, you might still have to consider treated wood or an appropriate hardwood. The timber may be covered with 10mm or more of lime plaster, which itself gives a decent level of protection from insects for as long as it remains intact.

The frame design is a part of the process that is well worth spending time on, in order to gain the maximum benefit from possible variations of design around the building. Frame design needs to take all of the above factors into account, and the designer also needs to think about the temporary shuttering system at the frame design stage, so that it is clear how the two will interact. This aspect is often overlooked, perhaps because designers rarely have direct experience of building with hempcrete.

Shuttering

Shuttering for hempcrete walls is either temporary, constructed on-site from a lightweight reusable timber board (11mm OSB is usually the preferred choice), or permanent, constructed from any breathable carrier board that will take a lime or clay plaster over it, and which will not laminate away from the surface of the hempcrete behind it (typically a wood wool board).

Temporary shuttering is fixed to the frame using very long heavy-duty screws, and is held at an exact distance off the frame by spacers (usually made from plastic waste pipe cut to length). Permanent shuttering needs a frame detail which includes studs positioned on one side of the wall, to which the shuttering board is fixed.

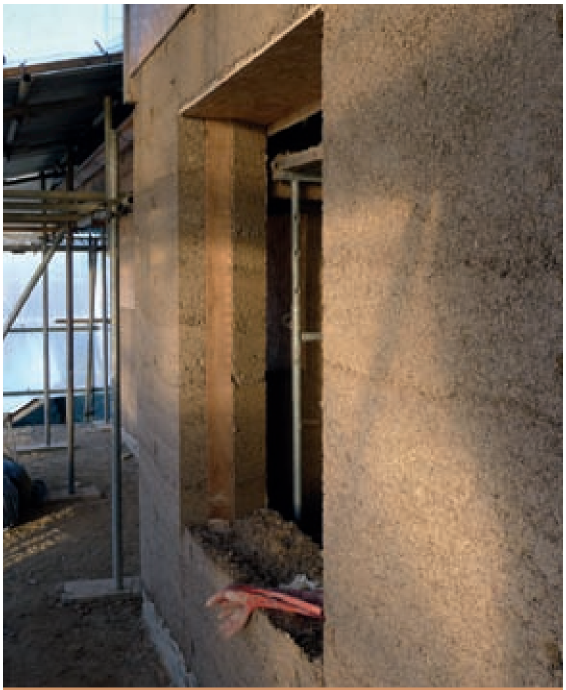
After the placed hempcrete has taken its initial set (usually overnight, but the time varies according to the binder used), temporary shuttering is struck, and moved along or up the wall to the next place it is needed. In this way the total shuttering board required on-site is restricted to a little more than the amount needed to shutter up what you can fill in a day and a half (see Chapter 14, page 171).

Care must be taken to ensure that shuttering is true, plumb and square, so that the face of the finished wall is straight and vertical.

For more detail about shuttering, see Chapter 14.

Openings for doors and windows

Openings for doors and windows are created as part of the structural frame, or by an additional



The framework for a window is left flush with the surface inside the reveal to provide a fix for the window frame.

The shuttering boards used to form the window reveals are fixed to the framework for the window.

Angled window reveals are attractive within a deep hempcrete wall and maximize the amount of light.

framework secured to it. In either case vertical and horizontal timbers define the opening and provide a fix for the window or door frame (see Chapter 13). Shuttering, either temporary or permanent, is constructed to run around the inside of this framework, so that when the hempcrete is cast, that section of the wall is left open, with the framework for the opening flush with the surface of the hempcrete in the reveal.

Where shaped reveals are desired, these can either be formed using the shuttering or the hempcrete can be shaped after it has been cast (see Chapter 22 for more details).

The hempcrete

Hemp shiv (the chopped-up core of the hemp stem) is mixed with a binder in a forced-action pan mixer or a conventional bell concrete mixer, and transported by hand (it is relatively light) in tubs to be placed into the wall. The hempcrete mix should be quite dry and is tipped out of the tubs, rather than poured, before being distributed evenly with a gloved hand. It is important to make sure that the entire void is filled consistently, especially around intricate frame details, where small corners are often created between the frame and shuttering.

Care must be taken to measure all the constituents accurately and to ensure that the binder has coated all the aggregate evenly in the (rather dry) mixed material. An important factor is the 'battle' for water between the dry hemp shiv and the binder, which needs the water to activate it (see Chapter 5, page 70). The correct amount of water, and no more, should be added to the mix so that the drying time of the cast material is not extended unnecessarily.

The thickness at which hempcrete is cast varies with application and individual building design, and the U-value achieved obviously varies with the thickness cast (see Chapter 7, page 96). The UK Building Regulations on insulation, at the time of writing, require around 250mm thickness of hempcrete wall for new-build walls. The norm is to cast at 300-350mm, which is a good balance between achieving a high level of insulation and avoiding an excessively long drying time.

Roughly the same labour is required to construct a 350mm wall as a 250mm wall, so significant savings are not likely to be made by choosing to cast at 250mm, especially considering the reduced insulation values. If the U-values achieved at 350mm are higher than desired, then it is accepted practice to add a layer of another breathable insulation (perhaps wood-fibre board-type insulation) to the wall build-up,

Shuttering partially removed from a hempcrete wall.

rather than more hempcrete. Obviously the addition of a different insulating material requires alterations to the timber frame and a more complicated design.

When the hempcrete has had time to take its initial set, the shuttering is removed carefully – the walls are still relatively soft at this stage – and the work moves on to the next section of wall. Over subsequent weeks the hempcrete dries out and hardens to the extent that finishes can be applied to it. This usually takes a number of weeks, depending on a range of factors (see Chapter 16, page 215), but can be longer depending on weather conditions and site practices.

The procedures for mixing and placing hempcrete are discussed in detail in Chapters 15 and 16.

Finishes

Once the walls have dried sufficiently, finishes can be applied. As noted earlier, these are breathable plaster or render finishes or, externally, cladding with a vented air gap. Cladding may be chosen as an aesthetic alternative to a rendered finish, or as an improved screen from rain on exposed walls.

Plasters and renders are usually specified by the hempcrete binder manufacturer, and are typically a standard two-coat lime finish, although three-coat work might be specified internally if a very fine finish is required. In principle any breathable plaster can be used, as long as it is at least as vapour permeable as the hempcrete behind it (preferably more so), and although

A variety of breathable finishes can be used on hempcrete buildings, such as the mixture of timber cladding and lime-based render at the Tomorrow's Garden City development in Letchworth.

lime is the norm, clay plasters can be an attractive alternative.

Lime plastering or rendering is a distinct skill, with certain important differences in technique compared with the application of cement render and gypsum plaster, and it is important that the people doing this work have the necessary skills and experience. There is no reason why a plasterer should not be competent in both lime and gypsum, but very few are, as the use of gypsum is so ubiquitous across the UK. Assuming that a gypsum plasterer can work with lime (or vice versa) can result in mistakes that are costly to correct. The fact that the application of lime plaster requires some specialist knowledge, and a more thoughtful approach than the application of gypsum or cement, means that a competent lime plasterer may be harder to find and more expensive than a plasterer for standard gypsum work.

For more about the finishes for hempcrete walls, see Chapter 18.

Services can easily be brought through a hempcrete wall.

Services

The supply of water, gas and electricity to a hempcrete building requires exactly the same skills and encounters the same issues as supplying these services to any other property. The only slight advantage hempcrete brings is the potential of the monolithic wall to reduce the work of plumbers and electricians. In a hempcrete wall there are no obstructions to services from additional layers (e.g. membranes) in the wall build-up, so the construction of a services void is not necessary, and services can be run within the wall as soon as the frame is constructed, before the hempcrete is cast.

All plumbing works should be carried out by a suitably competent and preferably qualified person, and all electricity supply works should either be carried out by a competent qualified person, or carried out by a competent person and checked thoroughly and signed off by a properly qualified person before the supply is connected. All gas works should be carried out by a qualified person.

The following is a brief description of how the various services interact with the hempcrete wall in a typical building.

Water and gas

In new buildings, supply and waste water pipes and gas supply pipes will normally enter and exit the building through the floor. These are fixed in place before the floor slab is laid, and there are no special considerations if your floor is to be made up of breathable materials and includes a hempcrete insulation slab.

It is not recommended practice to run water supply pipes within hempcrete walls, as the pipes will be difficult to get at, to find or remediate leaks, and leaking water within a wall could cause damage to the plant-based material. However, in theory this is less of a problem with the flexible plastic pipes that are commonly used nowadays, as long as no fittings or connectors are buried in the wall. Ideally, water pipes should be hidden under suspended floors, but there will always be instances where water pipes supplying heating or sanitary fittings need to travel through a wall.

Where copper pipes pass through a wall, they should run within a plastic conduit a few millimetres bigger in diameter than the pipe, to protect the copper from the corroding alkaline lime in the binder, and to allow for expansion and contraction of the pipe. For plastic pipes this should not be necessary, but always follow the manufacturer's guidelines.

Waste pipes fitted by drilling through the hempcrete.

If it is necessary to run water pipes through from one side of a hempcrete wall to the other, these are best put through before the wall is cast, but if necessary they can easily be drilled through afterwards with a core drill. The process of placing the hempcrete should be considered at the plumbing stage to ensure that the location of the pipes does not make it difficult to place the hempcrete later.

When a pipe is placed through the wall before casting, holes need to be cut in the shuttering for that section. These holes do not need to be millimetre-accurate, as the hempcrete will not fall out through gaps up to around 20mm wide, and if a little does get pushed out around the pipe it is easy to scratch it back later while the hempcrete is drying out.

Any shrinkage of the hempcrete away from the pipe as it dries could cause a passage for air through the wall, but this can be mitigated by wrapping the pipe in a thin layer of soft natural insulation material such as hemp-fibre quilt insulation, which will be compressed by the hempcrete cast around it and will be springy enough to fill the gap left by any shrinkage.

Drilling out holes for pipes after the wall is cast is perfectly possible, but it is likely to result in a pipe being fitted with a small air gap around it right through the wall. From an airtightness point of view, casting with the pipe in place is the recommended option. If drilling through afterwards, care must also be taken to choose a location that avoids the structural frame and any electricity cables within the wall.

Electricity

To save time, money and mess it is better for the electrician to come in as soon as the structural frame is complete, in order to run all cables within the wall structure. Cables need to be run inside plastic or metal conduit. This has two functions:

- it gives a little extra protection to the cables (against badly aimed drilling in the finished wall and against accidental damage on-site before the hempcrete is cast).
- It allows air to flow around the cable, which minimizes the risk of overheating caused by the cables (which get warm as the electric current flows through them) being too closely surrounded by the insulating hempcrete.

Conduit containing electricity cable is easily run along the frame timbers and, where necessary, can be fixed securely in place with conduit mounting clips.

Where a socket or switch is to be mounted on a hempcrete wall, the back box can be screwed directly to the frame, or to special extensions to the frame. It should be positioned so that the front of the box sits exactly level with where the face of the wall will be. The temporary shuttering can then run along the front of the box with no cutting of boards required, and the hempcrete can be cast around the back and sides of the box, with the front left visible in the surface of the wall.

If permanent shuttering is used internally, plastic dry lining boxes can be used. This reduces the need for extra frame timbers to support electrical installations.

Although it is sensible for electrical installations to be fitted before the hempcrete is cast, sometimes it is necessary for them to be retrofitted. In this case, channels can be chased out of the surface of the wall, once it has set, using a powered cutting tool such as a multi-tool or disc cutter. Electric cable in conduit is inserted, and held in place with clips hammered into the hempcrete. A hemp–lime–sand mix can be made up and used to fill in the channel. When refilling these channels, it may be useful to use Prompt Natural Cement as a binder, since it sets very quickly.

Conduit and cables are run in the wall before the hempcrete is cast.

Chapter Eleven • The hempcrete wall: an overview


Back boxes are fixed to timber supports so that they sit flush with the face of the wall.


Any holes around fittings can be filled by hand after the wall has been cast.


If necessary, electrical cables and other fittings can be chased into the hempcrete after it has set.


Wiring for wall lights is run through timber supports, which also provide a solid background for the light fitting to fix into.

CHAPTER TWELVE

Foundations and plinth

The foundations for a hempcrete building are similar to those required by any other, with some minor differences, which we explore in this chapter. The plinth, which sits directly on top of the foundation, is really a part of the wall itself, but it is significantly different in nature from the hempcrete part of the wall.

In many respects the plinth has more in common, both conceptually and in its materials, with the foundation than with the hempcrete above it. For this reason these two elements are discussed together in this chapter, which explains their roles in providing a sound basis for the hempcrete structure above them.

Foundations

The foundations for your building will usually be specified by an architect and/or structural engineer or geotechnical engineer, and built to that specification by you or your contractor. The building control inspector will check the ground conditions on-site once the excavation stage is complete, and advise if further depth is required.

The foundation exists for the purpose of transferring the load (weight) of the building safely down to stable ground. Foundations for a hempcrete building follow broadly the same principles as for any other building, although the low density of hempcrete as a walling material does allow for other possibilities in the type of foundation that can be used. This may translate into a lower embodied energy, since a foundation usually demands high fossil-fuel usage, as it involves casting several tonnes of concrete.

Concrete foundations

The most common type of foundation is called a 'strip foundation'. This means digging a trench along the footprint of the load-bearing walls until solid ground (e.g. firm clay or rock) is reached, and then filling this with concrete to create a solid footing.

Previous page: The plinth for this hempcrete building is constructed from natural stone and lime mortar.

If this approach is used for a hempcrete building, then the foundation will be no different from that for any other building, because the strip trench is dug as deep as necessary until solid ground is reached. However, when building in an area in which the ground conditions do not include an easily accessible solid-ground layer (e.g. where soft clay, gravel, loose silt or landfill is found for some distance below the surface), a strip foundation is not suitable. In this case the engineer will usually specify either concrete piles reaching deep into the ground to make contact with firm ground, or a raft foundation – a concrete slab that simply 'floats' on the poor-quality soil.

In this situation, a hempcrete building has the advantage that, being of low density, it is lighter than a building of conventional masonry construction, and therefore the piles can be smaller (in diameter) or the raft slab thinner than for a masonry building. This means a significant reduction in both the amount of earth to be excavated and the amount of concrete used. Remember that engineers and building control inspectors will usually be unfamiliar with the properties of hempcrete, so as a self-builder, or contractor, you may have to take responsibility for ensuring that an alternative foundation is considered at the design stage, and provide the necessary information to support this.

Foundations without concrete

As noted, the several tonnes of concrete used in a typical foundation make a significant contribution to the overall carbon footprint of the building. For those wishing to construct strip foundations without concrete, either to save

This hempcrete extension was built on a raft foundation (see step-by-step photos on page 150).

money or reduce the embodied energy of the finished building, the relatively light weight of hempcrete works in your favour, as this means it is much more feasible to use non-concrete foundations. These could be made from, for example, rock-filled gabions (heavy-duty wire mesh containers, as pictured below right), a trench filled with compacted crushed limestone, or a trench filled with limecrete. The use of free-draining foundations such as crushed limestone or rock-filled gabions is especially appropriate for hempcrete, since it minimizes the risk of excess moisture being retained in the plinth near the bottom of the hempcrete part of the wall.

Whether or not a non-concrete foundation is suitable for the site will ultimately be decided, and the details specified, by the structural engineer for the build or a specialist geotechnical engineer. The work will then need to pass inspection by building control. Bear in mind that, unless you have an engineer and inspector who are used to low-impact building methods, the process of getting alternative foundation types specified and approved may be an uphill struggle. If you are determined to avoid the use of concrete in your foundations, then it is best to start having this conversation at an early stage of the structural calculations for the build.

Tips for the self-builder

On a smaller build, for example an extension under permitted development, where no architect is involved you may be able to create a standard strip foundation yourself without providing drawings for it, as long as the ground conditions are straightforward. For example, by looking at geological maps of your area or digging a trial hole, you can find out if your site is in an area of firm clay, where strip foundations may be suitable. If this is the case, you can just dig a trench 500mm wide and to a depth of at least 500mm, or deeper until you hit firm clay. The building control inspector then checks your excavations before you pour the concrete, and if necessary may tell you to go a bit deeper. Between 750mm and 900mm is a normal depth.

As an alternative to using the building control inspector from the local council, it is possible to privately engage a building control Approved Inspector. Approved Inspectors assist the builder or owner to achieve building control approval and in some cases may provide a more 'client focused' service than the local council's inspector does. The increased cost associated with hiring an Approved Inspector may be worth every penny, especially if you are able to find one who understands the issues involved when building with hempcrete, or is willing to learn.

If a concrete strip foundation is not possible, then any other type of foundation will need to be specified by a structural engineer or other specialist contractor, including all calculations, before works start, with drawings submitted to building control. In a case where a strip trench is not suitable owing to poor ground, then you

Gabions can provide an alternative to concrete foundations.

Building a raft foundation

1. Compacting the sub-base layer.
2. Damp-proof membrane with reinforcement mesh.
3. Pouring the concrete raft.
4. Concrete raft levelled.

may wish to suggest a raft foundation, as you can construct this yourself. For piles, a specialist contractor will have to carry out the work.

For a self-build raft foundation the process is to get a structural engineer to design the raft based on your drawings for the building, and then for you or your contractor to build it, with building control inspection as usual. The slab specified will normally be concrete slab with steel reinforcement. Larger rafts will have a thicker ring beam of reinforced concrete directly under the load-bearing walls of the building.

Plinth

The bottom of a hempcrete wall consists of a plinth, built off the foundation and rising to at least 250mm above the ground, to protect the hempcrete wall above from splashback as rain hits the ground, as well as from any pooling water at ground level. The main principles and construction issues are outlined below, and further information can be found in Chapter 22.

This plinth is typically of masonry construction and has a damp-proof course (DPC) running along on the top of it, underneath the sole plate of the timber frame, which is fixed to the plinth and/or the floor slab. The plinth is usually visible on the interior surface as well as the exterior surface of the wall, and although internal floor position varies depending on a number of factors, the top of the plinth might be around 200-300mm above internal floor level (see Figures 22, 23, 25 and 26, pages 313-16).

The most natural and sustainable way of constructing a plinth is probably to make it from local stone, or local traditionally made bricks, using lime mortar or natural cement. If the plinth is to be constructed from stone and lime mortar, this is best done by someone experienced in the use of these materials, as it involves ensuring two things:

- that the mortar used is softer than the stone used, while also being as resistant as possible to water ingress from the outside
- that the stonework is structurally able to bear the load placed on it and transfer it safely to the foundation.

Normally the plinth is the same width as the hempcrete wall it supports, which allows for a small overhang in the drip detail at the bottom of the render. This means that any rainwater running down the wall can drip off the bottom of the rendered hempcrete and on to the ground. However, the requirements of the particular stone and lime mortar used may necessitate a wider plinth than normal, since lime mortar is weaker in tension than Portland cement, so a stone-and-lime construction may not be structurally stable at a width of 300-350mm. The width needed will depend on the type of stone, the construction method and the load being carried. If the plinth is to be wider than the hempcrete wall above it, the 'shelf' should be placed *inside* the building, so that it doesn't create a ledge at the bottom of the hempcrete for rainwater to collect on.

Regrettably, for budgetary reasons the plinth is sometimes built from concrete blocks, or simply a cast concrete upstand, usually faced with something more attractive such as stone or brick. If the plinth is to be cast concrete, a more sustainable (i.e. lower-embodied-energy) option would be a lime–pozzolan concrete made from NHL 5 with GGBS (ground-granulated blast-furnace slag: a pozzolanic additive which is a by-product from iron and steel making) together with whatever suitable stone aggregate is found locally. Keep in mind, though, that the most local NHL 5 to the UK is quarried in France, and the embodied energy saving achieved in the production process (of using lime as opposed to

A brick plinth for a hempcrete wall in a listed building. The bottom of the render curves in towards the wall, disguising an unusual hidden drip detail, included to meet conservation aesthetics requirements.

cement) has to be offset against any possible increased transport costs.

If you are using concrete blocks then you may as well use a cement mortar to stick them together, and indeed the use of water-impermeable cement mortar in this situation is arguably an advantage, in that the job of the plinth is to prevent water from coming into contact with the bottom of the hempcrete wall. However, it does carry an increased risk of cracking with any later movement of the building, compared with lime mortars, which are naturally more flexible and can tolerate small movements in the building. There is no reason, other than increased cost, why NHL 5 or a natural cement could not be used in a concrete-block plinth instead of ordinary Portland cement.

Other ideas for a low-embodied-energy plinth, which probably warrant further investigation, although to date we have never seen them used for hempcrete walls, include rammed-earth car tyres (a cheap – usually free – recycled material filled with a suitable subsoil excavated from the immediate area) and gabions filled with relatively small rocks or rubble from site.

If you want to use either of these solutions, it is worth trying to assess the potential carbon savings associated with the method. Ensure that a structural engineer has calculated that your plinth design is able to support the weight of the building above, and has signed off on this. In addition, it is necessary to consider very carefully how the DPC, if used, will work in conjunction with either method, and also how the timber frame could be securely fixed.

Damp-proof course

The standard DPC will usually be some kind of rubberized, plastic or chemical synthetic material, although if you happen to have a lot of reclaimed slate lying around, you can do what they used to do in some vernacular buildings and use coursed overlapping slates to provide a damp-proof layer in the wall. If you have to buy the slate, this option will be significantly more expensive than plastic DPC. Also, unless you want to spend an absolute fortune, any new slate you buy at the moment is likely to originate in Portugal, Spain or even further afield and therefore has high embodied energy as a material.

Assuming you are using the usual rubberized DPC on a roll, there are various ways of working it into your plinth design, depending on the plinth construction and the floor detail inside. As well as lining the top of the plinth, a vertical damp-proof barrier is also required, to resist lateral movement of water through the plinth from outside. Where exactly the vertical layer should sit within the plinth depends partly on how you are proposing to insulate the plinth (see below). If your floor is not breathable, you will be including a damp-proof membrane (DPM) in the floor build-up, and you can simply overlap this with the DPC in the plinth. See Chapters 17 and 22 for more about breathable floor detailing.

We have received one anecdotal account of hempcrete de-bonding from and shrinking away from plastic DPC as it dries. While this has never been our own experience, and the effects of gravity would seem to make it unlikely, the potential for this problem to occur and cause issues with airtightness should be considered during the design stage, and if necessary testing should be carried out before building commences. Such an issue might be resolved through the use of an alternative binder with different shrinkage characteristics, or through a physical detail such as the use of expandable metal mesh (to provide a key) or hemp-fibre quilt insulation (to expand and fill any gap) placed along the top of the DPC.

Plinth insulation

This can be done in a number of ways, but it *does* need to be done! It not, the dense masonry plinth acting as a massive continuous cold bridge around the bottom of the wall.

The requirement is usually achieved by constructing part of the plinth from load-bearing insulation. For example, in a plinth made from three 100mm-wide concrete blocks, the inner two could be load-bearing thermal blocks (recycled glass foam or aerated concrete). Alternatively, a plinth of the same width could be built of two blocks with a central cavity to be filled with expanded clay aggregate – although this would not be suitable if the timber frame sat centrally in the hempcrete wall above, as the centre of the plinth would be insufficiently stable for the frame to bear on.

Whatever the design, the key principle is that the insulation layer should be kept inside the vertical damp-proof layer, so that the insulation remains dry and therefore operates to its full potential.

An alternative way of solving the problem of cold bridging through the plinth is to have an insulated floor inside, which is above the level of plinth (an example is illustrated in Figure 24, page 315). This is a perfectly viable solution, and might, for example, be built up from a hempcrete insulating slab below a timber floor finish. The floor-level hempcrete slab could be designed to connect with the bottom of the hempcrete walls to minimize cold bridging and increase airtightness. However, having the floor above the plinth height is not necessarily practical, since the raised floor would necessitate ramps or steps to enter the building, and also require a corresponding increase in the height of the building in order to maintain the internal room heights.

Load-bearing glass foam blocks used in a plinth.

CHAPTER THIRTEEN

The structural frame

Hempcrete is not a load-bearing material, so it is always used in conjunction with a structural frame to take the load of the roof and upper floors safely down to the foundation. The hempcrete is typically cast around the frame, and provides racking strength to it. For buildings of up to three storeys, the frame will generally be made from softwood timber. Hempcrete is perfect for casting around timber frames as it has a certain level of natural elasticity and is able to cope with the slight movements that are normal in timber-frame structures.

Various types of structural frame can be used with hempcrete, and the frame is usually designed by, or at least its structural members specified by, a structural engineer and is subject to close scrutiny from building control. In larger buildings, where the frame is likely to be glulam (glued laminated timber), steel or concrete (see overleaf), a softwood sub-frame is still required to support the hempcrete. You will need to provide your engineer with a set of drawings containing at least floor plans, elevations and your intended wall section, showing where ideally you would like the structural frame to be positioned. Your engineer will also need to know what type of roof covering you are going to have and the position of any heavy mechanical or electrical equipment intended for the roof (e.g. solar panels). He or she will also need details of the density of the hempcrete you are using, and will need to understand the implications of casting hempcrete around a timber frame in terms of reducing horizontal frame members. From this information the engineer will be able to specify the size of structural members within the frame and provide a set of calculations to satisfy the appropriate Building Regulations requirement.

Your engineer may not have come across hempcrete before, so if you want to simplify the frame, to reduce costs and make placing the hempcrete easier, you may have to inform him or her about its characteristics. The frame design has the potential to make the process of placing the hempcrete very easy or very difficult.

Previous page: A softwood timber frame for a new-build hempcrete extension.

Large buildings

A very large hempcrete building usually has a substantial structural frame, especially where it has either a very heavy roof or is supporting four or more storeys. Large frames can either sit within the hempcrete wall or be set away from the wall inside the building. It is beyond the scope of this book to discuss the design of massive structural frames in detail, and those who are constructing such buildings will have engineers to design a frame with the suitable structural capabilities. For engineers seeking to adapt such frames to be suitable for hempcrete, the principles outlined below can be followed.

There are three likely options for the frame:

- **Steel.** The main consideration with steel is the risk of corrosion, owing to the alkaline nature of the lime binder in the hempcrete. Ideally, the two materials should be kept separate. Where the frame does need to interact with the hempcrete, it should be protected with a painted coating; the same applies to any fixings, which could alternatively be made from an alkali-resistant metal such as stainless steel.
- **Glulam.** If the glulam is to be encased or partly encased in the hempcrete, check with the manufacturer that the wet environment of the freshly placed hempcrete will not have an adverse effect on the glues in the beams. If there is a risk that it will, a protective coating may need to be applied.
- **Oak, and other hardwoods.** A traditional pegged hardwood frame does not have any of the issues of the above materials in its interaction with hempcrete, but there are limits to the size of frame you can create in this way.

Steel and glulam interact in the frame of a large superstore built using Lime Technology's Hembuild® panels.

An oak frame, with hempcrete walls under construction.

A steel supporting frame in a hempcrete community centre.

Glulam provides a more sustainable alternative to massive hardwood beams or steel joists.

Smaller buildings

Buildings of up to three storeys can be constructed using a simple studwork frame, and this is the usual approach taken for any hempcrete building up to the size of a large house. The discussion in the rest of this chapter relates to the timber frame for a hempcrete building on this scale. The frame can usually be constructed from untreated European softwood, which is a natural and sustainable resource.

For very simple builds, such as small extensions or simple one- or two-storey buildings, those who have the necessary skills may wish to design their own frame. The stud frame required for these types of building is simple enough that building control inspectors will be familiar with its structural limits. Whether you are undertaking the design of the structural frame yourself or whether it is being done by an experienced engineer, we advise that the standards of construction set out by the Timber Research and

Development Association (TRADA)[1] are followed.

The standard simple stud frame design for hempcrete walls consists of the following basic elements:

- A **sole plate**, which sits on top of the damp-proof course (DPC), usually on top of the plinth.
- **Structural studs** extending vertically from the sole plate. Normally designed to sit in the centre of the cast hempcrete, these provide a key for the hempcrete to resist lateral movement, as well as providing the load-bearing strength necessary to support the roof and upper floors.
- A **wall plate**, which runs around the top of the studs, to which the roof structure is attached.
- **Diagonal timbers**, which provide racking strength as necessary.
- Where there are two or more storeys, it is usual to include an **intermediate plate** for upper floor joists to bear on, with further studs extending from this plate to support the wall plate at eaves level.

All frame fixings that are exposed, however slightly, to the hempcrete should be of stainless steel or painted with a protective coating once fixed, so that they resist corrosion by the lime in the hempcrete.

Increasingly, engineered timber joists are incorporated into roofs and floors to cut down on the section size of timbers used in bridging large spans. They contain less timber, which makes them lighter and easier to handle, and also means that timber of smaller sections is used. This is more sustainable, since it can be harvested from younger trees.

There are three main options for engineered joists:

- **Glulam beams**, which are constructed from glued softwood timbers.
- **Trussed joists**, constructed from two small-section timbers joined with a metal web.
- **Timber I-joists**, constructed from two small-section timbers joined with OSB.

The manufacturers and suppliers of these products are very helpful, and given basic drawings they will be able to specify joists for a given situation.

For a more in-depth discussion of frame design, see Chapter 22.

Position of the frame within a hempcrete wall

The stud frame can be positioned at different places within the hempcrete wall. Often the position varies in different walls of the building.

Central frame

The default position for the frame is to have it encased in the centre of the hempcrete wall, and this is preferred, as here the structural timbers are well protected from moisture and insect attack. Another advantage is that the frame provides a more stable structural support to the hempcrete when placed centrally, since the weight of the hempcrete is evenly distributed around it. This type of frame requires the most work to erect the temporary shuttering, but with careful planning this can be well streamlined.

Exposed frame (internally or externally)

The structural frame can be placed flush with either the internal or external face of the wall. This may be done for various reasons, most commonly:

- because permanent shuttering is being used (usually internally)

A softwood frame buried centrally in the wall is the standard design.

Exposed frame on the internal face of the wall.

Exposed frame internally for permanent shuttering, showing horizontal rails.

- for practical reasons internally, e.g. to facilitate the fixing of heavy objects such as kitchen cupboards to the walls
- for aesthetic reasons internally, for example because a beautiful, hand-crafted hardwood frame has been used, and it is preferred to have this on view
- for practical reasons externally, e.g. to facilitate the tying in of timber, tile or masonry cladding to the outside of the wall, which may be done either for aesthetic effect or to provide extra rain screening to exposed walls.

With this approach, because the weight of the hempcrete is not distributed evenly around the studs, there is the potential for the wall to fall away from the studs. For this reason additional horizontal rails, commonly of 50mm x 25mm roofing batten, are added to the frame, to provide a good key and lateral resistance for the hempcrete wall. These are fixed to the side of the stud that faces the interior of the wall, and run the whole length of the wall at 600mm vertical centres (as pictured above).

Double frame

In situations where external cladding *and* internal permanent shuttering board is desired, a double-frame design can be used. This comprises an exposed frame flush with the internal face, which acts as the structural frame, into which the permanent shuttering is fixed, and a second, non-load-bearing frame flush with the external face to provide a fix for the cladding. The non-load-bearing cladding frame is usually of smaller-section timber.

The two frames are connected using rectangles of OSB or plywood screwed into the side face of each stud so that the edge sits flush with the external face of the timbers. The dimensions of the rectangles of board varies according to the design and width of the wall, and they are fixed at regular centres going up the studs, as specified in the frame design.

The double frame is quicker and easier to shutter than a single frame, but takes longer to build and is not the ideal frame design, because of the potential for thermal bridging and air leakage caused by the connecting squares of OSB.

Elements of the frame

The following discussion of individual elements of the frame incorporates the basic elements, as described previously, together with some other elements that are not necessarily present in all frames.

Sole plate

The sole plate is positioned on the plinth above the DPC, or, in some circumstances (if the plinth is narrower than the foundation), sits inside the plinth and bears directly on the foundation blocks. It is either fixed directly to the surface it bears on to, or sits on the plinth and is tied back to the foundation or floor slab using long metal straps (bent straps). These straps are usually available only in galvanized rather than stainless steel, and so need painting after fixing to protect them from corrosion.

The function of the sole plate is to provide a solid fix for the studs, and also to stop them moving independently of one another. The sole plate should be joined continuously along its whole length, which sometimes means doubling up timbers and overlapping to ensure a strong join between two lengths of timber.

The section size of the sole plate timber is dependent on the section size of the studs that are fixed to it, with the same-section timber being used for both.

Studs

The function of the studs is to take the load of the roof and upper floors down to the foundations, and to provide support for the hempcrete. Studs

Metal straps are used to secure the sole plate.

are fixed to the sole plate with skewed stainless-steel nails or screws (or hot-dip galvanized nails), or stainless-steel angle brackets, and extend to the wall plate at the floor or roof above (see Figure 5). They are spaced at regular centres, usually 400mm or 600mm depending on the specifications of the frame.

The section size of the studs depends on the load they are taking, the height they extend to and other aspects of the frame design, such as whether a particular spacing is desired, for example to tie in with floor joist spacing. A 100mm x 50mm stud is usual for single-storey buildings, while a two-storey building normally requires 150mm x 50mm studs.

Multiple or reinforced studs

These are studs fixed together to make larger-section timbers, which are positioned under areas of greater loading where additional strength is required. For example, they may be used to support a large beam or a lintel (see Figure 6 overleaf), or at the corner of a building.

They are fixed together using nails, screws or even coach bolts if they are very large, and may require additional fixings to the sole or wall plates via stainless-steel angle brackets.

Wall plate

The wall plate runs along the top of the studs and is fixed on to them from above, using two stainless-steel nails or screws per stud. The function of the wall plate is to provide a fix for the top of the studs, stopping them moving independently from each other, and also provides a solid surface for the roof timbers and/or upper floor joists to bear on. The wall plate is usually identical in construction to the sole plate and, again, should be continuously joined along its whole length.

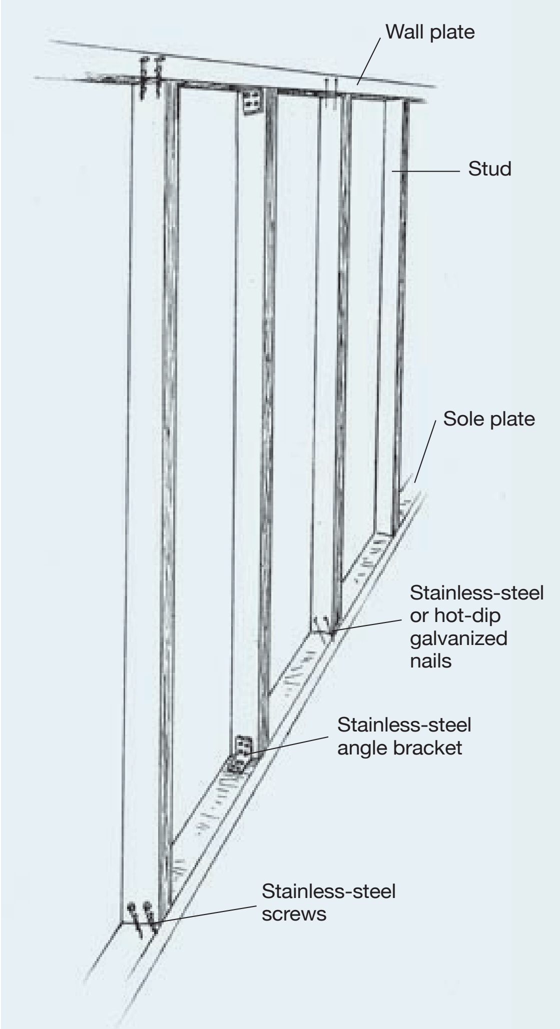


Figure 5. The basic frame, showing alternative methods of fixing the studs to the sole and wall plates.

Floor and ceiling joists

Floor and ceiling joists obviously create the upper floors, but within the frame they also serve to tie opposite walls to one another, creating a stable box section, which prevents walls from leaning outwards. These joists can run in only one direction and therefore don't connect the walls that run parallel to them. Those walls are tied in to the floor or ceiling construction using bent straps (see Figure 7 opposite), which extend from the wall across two or three joists at regular centres, usually every other stud.

Floor joist section size depends on the loading and the distance they must span. For longer spans, an engineered joist (see page 158) is normally used. Joists can sit on the wall plate and be fixed down into it from above, or be hung from the wall plate on metal joist hangers (see Figure 8 opposite). The first solution is generally preferred, since it leaves less metal exposed to the hempcrete, and in any case stainless-steel joist hangers are costly.

Framework for openings

Openings in the wall are created by horizontal and vertical timbers within the framework to define the opening and provide a fix for door and window frames. These timbers are also used at the shuttering stage, as the shuttering to form the opening is fixed to them.

Framework for openings in the wall may sit in the same plane as the structural frame or be offset from it, closer to either the internal or external surface, as required.

Sections of the timber framework around openings are shown in Figures 36 and 37 (pages 337 and 339).

Lintels

Lintels are the timbers that span the top of windows, doors and other openings in the wall. Their specification depends on the size of span across the opening and whether they are also supporting a floor joist, and thus how much load they are taking.

In its most simple form – over doors or windows that are not supporting upper floor loads – the lintel may simply be part of the framework for the door or window, and consist only of a

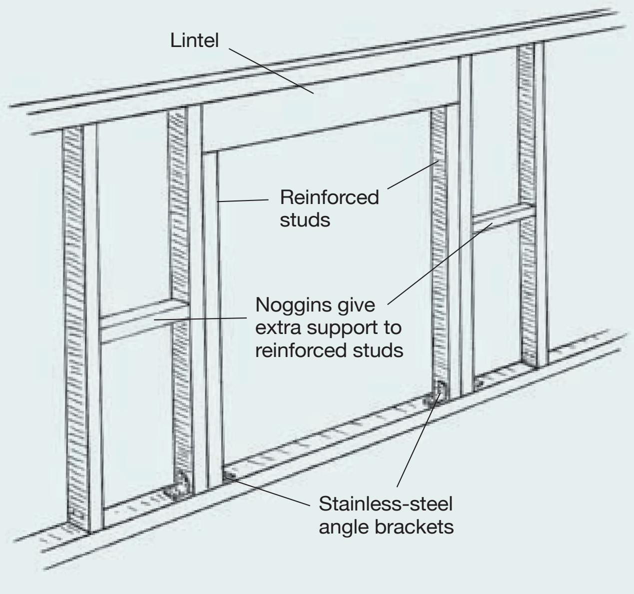


Figure 6. Reinforced studs under a lintel.

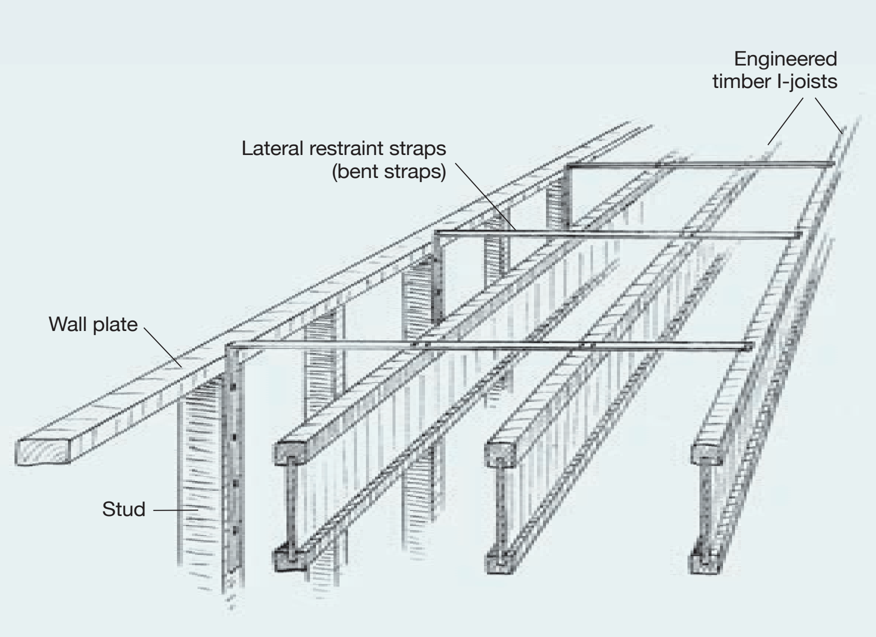


Figure 7. Floor joists are tied in to the floor or ceiling using metal straps.

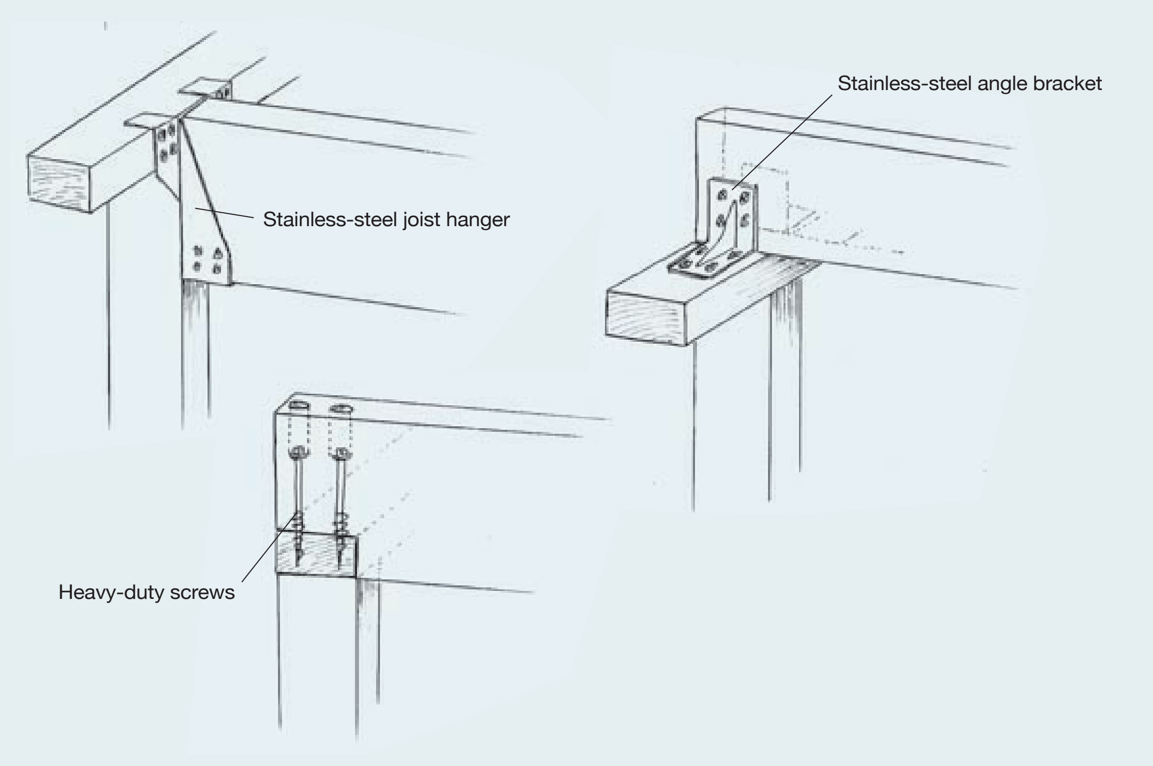


Figure 8. Floor joists may either bear on the wall plate or be hung from it using joist hangers. If bearing on the wall plate, fixings may be angle brackets or screws.

doubled-up timber to form a stable fix for its frame. When it is taking a load, a larger-section timber may be specified to form a 'structural lintel' as part of the structural frame. For very high loads, an engineered timber lintel might be used.

Window framework

The framework for windows is created by building a 'box' from two horizontal and two vertical timbers. This is then fixed into the frame in such a way that any load taken by the lintel is safely transferred down through the structural frame. Window frames do not necessarily sit perfectly between two vertical studs in the frame, and may need to be fixed to the nearest studs with noggins (see right) at each side.

Larger windows may span several vertical studs in the frame, which means that these studs need to be cut and re-fixed to both the lintel and the horizontal timber at the bottom of the window.

Larger windows often require doubled timbers for the framework, as specified by the frame designer based on the span of the opening and the structural load taken by the window frame.

Door framework

The framework for doors is created in the same way as for windows, although two vertical timbers and a lintel are usually all that is required to define the opening, unless there is to be a step up to the door.

If the door position doesn't fit exactly within existing vertical stud positions in the frame, then the position of an existing stud or studs can be moved back towards the previous stud(s) (i.e. decreasing the distance between them), and the repositioned stud can then form the side of the door opening. If, however, moving the stud to the correct position would mean an *increase* in the distance between the two studs, then an additional vertical timber should instead be used to create the edge of the door opening, tied back to the nearest stud with noggins as required to hold it securely in place.

The timbers for door framework are typically doubled up at the sides as well as for the lintel, since the sides must be solid enough to hold the door frame in place with no movement, even under the force of the door being slammed.

Noggins

Noggins are horizontal timbers connecting and supporting adjacent studs or joists. A normal timber-frame building has noggins in the walls to provide extra stiffness to the frame, but in a hempcrete building, the hempcrete provides this function once it has set around the studs. In a frame for hempcrete, horizontal timbers, including noggins, should be kept to a minimum, to make placing the hempcrete easier. However, noggins may be required for several reasons:

- to give extra support to reinforced studs that carry extra load in order to prevent them bending (see photo opposite, top)
- where permanent shuttering is used, to provide horizontal fixings for the joins in the board
- between floor or ceiling joists to stiffen that part of the structure.

Diagonal bracing (racking strength)

Although the hempcrete provides stiffness to the frame, in all but the smallest frames the engineer may insist that additional diagonal bracing is required to help the frame resist racking (movement of the structure as a result of lateral stresses, e.g. wind loading). This is usually provided by diagonal timbers of 150mm x 25mm section, or strips of 25mm plywood ripped down to 150mm, but can also be achieved by stainless-steel

A stud frame for hempcrete, showing many of the details described on the previous pages. Note the noggins; reinforced studs supporting the glulam beam; diagonal bracing and roof joists bearing on the wall plate (instead of being hung in joist hangers), where the junction between joist and wall plate will be inside the hempcrete wall.

strapping, or by permanent shuttering board if this is being used.

Diagonal bracing is fixed after the main frame has been erected, so that these timbers can be fixed across as many frame elements as possible to improve their effectiveness.

Roof structure

It is beyond the scope of this book to discuss roof structure in any detail, since this is a broad subject in its own right.[2] Suffice to say that in a pitched roof design, the roof timbers usually form a separate structure that rests on, and is fixed to, the wall plate. This can be achieved in a variety of ways depending on the roof detail. For example, roof structures might include prefabricated trusses delivered to site and hoisted into position, or single timbers used to build the roof structure from scratch on-site. Single-pitch or flat roofs are more likely to be constructed from engineered joists.

Framing for a very simple pitched roof structure of softwood, joined with L-shaped metal plates.

For the most part, roof design options for a hempcrete building are no different from those for conventional construction. The only difference in roof structure that often applies to hempcrete buildings is a long roof overhang at the eaves for additional rain protection, which is achieved using longer rafters or additional bolt-on rafter ends, as described in Chapter 22.

Practical considerations relating to the frame

At the frame design stage, it helps to think about the later stages of the build and to give some thought to practical issues that are likely to come up in the construction process. A few examples are outlined below.

When constructing a frame, consider the easiest way to go about it. Decide in advance how each section of the frame will be constructed and erected on-site, and whether temporary supports are needed for one section before the next can be put in place. Temporary braces can easily be screwed into the frame and removed again with no concern about marking the frame timbers, as these will be buried in the wall or covered with plaster, render or cladding.

It is possible to prefabricate large sections of the frame on the floor and lift them into place to be fixed in one go rather than lifting each individual timber into place, thus eliminating the need to both support and fix each timber at the same time.

Another approach that can make framing faster, if your design allows it, is to prefabricate the frame in sections in the workshop and bring it to site to be assembled. The main advantage of this is that the frame construction can be done more efficiently and quickly in a dedicated workshop, with machine tools, than among the relative chaos of a busy building site. It also means that the framers spend less time on-site, and it allows the frame to be quickly assembled as soon as the plinth is ready.

As noted earlier, it is important when designing the frame to consider the process of placing hempcrete evenly around the timbers, and how this will be affected by the frame design. As far as possible, the design should avoid creating areas that are hard to reach. This is why it is useful to minimize the use of horizontal timbers.

Think about other ways in which the frame design can be used to reduce work later in the build. For example, consider how the frame interacts with the erection of temporary shuttering around it. Shuttering boards are held off the frame at the correct distance by long screws and specially cut spacers made from plastic tube. So

Design the frame so that shuttering spacers are the same length on both sides.

you can save work by having your frame positioned *exactly* centrally within the wall – meaning that the spacers needed for the external and the internal shuttering will be exactly the same length, which greatly simplifies the job. Moreover, if the frame is offset from the centre only slightly, the different-sized spacers needed to set the shuttering on each side of the frame will differ only slightly in length. The problem with this is that two very similar-sized lengths of plastic tube can look almost identical when they are chucked in together in a bucket covered in dried lime. Given that on a large building you could easily need upwards of 50 or 60 spacers for each side of the frame, you can imagine the amount of time you can waste sorting out which ones you need – as well as undoing shuttering that is not held firmly, or is out of true, because the wrong spacer has been used.

Remember that even though the frame is not on display, it is important that it is constructed with the utmost accuracy (see Chapter 8). The shuttering that will form the faces of the final hempcrete walls is constructed off this frame, so timbers must be placed accurately within the frame so that it's easy to fix the shuttering in the right place, first time, without too much fiddling about adjusting spacers and fixing then re-fixing the boards.

The exact placement of the frame leads to the correct placement of the shuttering, which leads to flat, straight and plumb walls, which makes plastering easier. The plastered wall is the only thing you will eventually see, but in a hempcrete building the quality of the plaster finish starts with the frame, so take time from the very start to make sure everything is as good as it can be!

Accuracy at the framing stage makes applying render and plaster finishes easier, and allows the formation of very straight walls, as demonstrated in the clean lines of this garden office building.

CHAPTER FOURTEEN

Shuttering

In the cast-in-situ method, hempcrete is cast around a frame on-site, with the aid of shuttering boards, which keep the freshly mixed hempcrete in place while it sets. Shuttering may be either temporary or permanent.

Temporary shuttering boards

Temporary shuttering is erected to create the mould for the internal and external faces of a hempcrete wall. Once the hempcrete has been cast and has taken its initial set, the shuttering is removed and moved on around the frame so the next section can be cast. Temporary shuttering is usually either attached to the frame or built out from it using long screws and spacers.

Shuttering boards need to be stiff enough to hold their shape without lots of extra reinforcement, yet light enough to handle and carry easily in large sheets, and hard-wearing enough to be used again and again. There is no definitive rule about what type of board should be used, but the following criteria should be considered. No one board will meet all the criteria, but with a bit of thought a good compromise can be achieved. The board should be:

- hard-wearing
- cheap
- lightweight
- stiff/flexible as required (e.g. you may want to cast a curved section of wall or recess)
- easy to fix (to the frame and to neighbouring boards)
- easy to mark on and cut
- able to be recycled elsewhere in the building project once the hempcrete is cast (e.g. incorporated into the building as floor or roof boarding, or used to board out a shed or workshop).

You will probably also want to consider whether the board is:

- low in embodied energy
- made from natural materials or synthetic materials
- made from materials from a sustainable source.

Early on at Hemp-LimeConstruct we experimented with using chipboard flooring, which easily fits together with the next board as it comes with tongue-and-grooved edges, and this reduces the amount of fixings required and

Previous page: For this building the whole of the outside was shuttered in advance, then the hempcrete placed from inside.

speeds up the work. However, we have now moved over to using almost exclusively OSB, for the following reasons:

- While the interlocking nature of the chipboard flooring can be useful on long straight runs of a new-build wall, it can cause problems where there is any deviation from straight runs, as the boards become difficult to slot together.
- For any sections where the boards need to be cut into funny shapes, the tongues and grooves are guaranteed to be a hindrance rather than a help, as you will never get them to match up.
- Chipboard flooring uses more glue in its manufacture than OSB, which relies on both its binder and the compression of the interlocking strands of timber for its strength. This means that not only is OSB more ecologically sound, but the dust created when cutting it is less toxic.
- OSB is stronger than chipboard, as the pieces of wood in the board are bigger, and it is therefore much less prone to corners snapping off when it is cut into strange shapes.
- Due to this increased strength, a thinner board of OSB can be used, which makes it lighter and easier to handle, and more flexible where this is required.
- As the OSB contains bigger pieces of wood, it is more tolerant to fixings being screwed in and out repeatedly as the board is set up and struck many times through the course of the build. The chipboard, being made up of dust-sized particles, is prone to a hole being bored out very quickly so that the screw just turns round and round and won't come out.

Shuttering made from OSB (oriented strand board).

Temporary shuttering: basic principles

The method of fixing shuttering depends on the type of structural frame in the building. The description that follows is for the standard studwork softwood frame, which will not be visible in the finished wall. For temporary shuttering there is no need for fixings to be stainless steel, since they will be removed from the wall after the hempcrete is cast. In fact, stainless steel should most definitely *not* be used in this case, as it is much too brittle to take the repeated driving in and out: the head of the screw quickly snaps off, causing endless problems and delays.

In order to limit material costs, transport and wastage, the minimum amount of shuttering board should be purchased. For most binders (except Prompt Natural Cement, see opposite) this can be calculated in a variety of ways, depending on the requirements of the particular job. In the most simple terms, the amount of shuttering you need will be the amount needed to shutter up as much wall as your team can fill with hempcrete in a day and a half. This is because with most binders the shuttering must be left up overnight to allow the hempcrete to take its initial set, before being struck. Having enough for a day and a half allows your shuttering team to get a section set up for the morning, so that the casting can start immediately, while yesterday's shuttering is being struck and moved along to its next position. Remember also that if you are shuttering one side of the wall in whole boards to speed up the process (see box below), you will need to account for this as well.

In the case of Prompt Natural Cement, the shuttering can be struck after 30 minutes, so in theory you will need much less of it, although if you are using a central frame you will still need enough boards to shutter the whole of the longest run on both sides. This is because the fixing of each board to the next helps to give the shuttering its strength, and all the boards should be joined first to check the shuttering is straight before casting begins. Failure to do this will almost certainly result in uneven walls. This is not an issue with exposed frames on the side where the shuttering fixes to the face of timbers.

It is usual, on a clear run of wall, to set up the shuttering in lifts of 600mm at a time, since this is a comfortable depth of void to be filled by the person placing the hempcrete. This of course only applies to the side on which people are working when they are filling the void. Where appropriate, the other side can be boarded out in advance in full boards (see box). The mix is added gradually, one layer of approximately 100-150mm at a time, and a 600mm maximum depth allows someone to comfortably reach in, spread the mix around and pat it down before the next layer is added. For fiddly sections of wall, typically at the top under the eaves, or

Boarding out one side of the wall in advance

Erecting temporary shuttering over the whole of one face of the wall in advance may seem like an unnecessary expense, with more sheets of OSB needed, but there are several advantages to this method:

- A full board on one side of the wall acts as a 'backboard', making placing easier as hempcrete can be tipped quickly into the void, which speeds up the process dramatically. Without the board at the back, more care would have to be taken to avoid spilling the hempcrete.
- Having the whole wall boarded on the inside surface of the wall, when placing hempcrete from outside, effectively stops any spillage into the building, keeping the inside safe and tidy for other work to progress at the same time.
- The boarding out of the whole of one side of the wall can be done as soon as the frame is up, i.e. in advance of the rest of the shuttering and hempcrete-placing work. This speeds up the rate of hempcrete placing, as you are not held up by the shuttering.
- If you board one side of the wall in full boards, this reduces the amount of time spent cutting boards. It also leaves you with a lot of whole boards at the end of the job, which are easier than small pieces to reuse. (But when a central frame is used, shuttering with full boards also has its drawbacks – see page 177.)

when casting the 'triangle' of a gable end on a building with a double-pitched roof, it is common practice to use much smaller lifts of shuttering, so that they can still be filled consistently despite the restricted access.

Wherever possible, you should aim to fill the tops of walls from above (through the rafters), as this makes the job much quicker and more pleasant (without the risk of lime in your eyes), and keeps the cutting of shuttering boards to a minimum, as there is no need to cut smaller boards for the top of the wall. Where the hempcrete is being cast up to the level of the top of the rafters, as it usually would be, run the shuttering board up to the bottom of the rafters and then construct several 'lollipops' (we had to invent a word for them!), which attach to the top of the last board to shutter the spaces between the rafters – see photos below.

Once erected, each shuttering board should be checked with a straight edge to see that it is in line with neighbouring boards. It should also be checked for plumb with a level, and the distance between the inside face and frame should be double-checked at several places along the top of the board.

When removing the shuttering once the hempcrete has taken its initial set, remember that, until you reach the top of the wall, the top shuttering

'Lollipops' extend the shuttering into the eaves.

Hempcrete placed between rafters using 'lollipops'.

board – the one level with the top of the hempcrete – has to remain in place while another board is fixed above it and filled. This is essential to keep your plumb line true as you go up the wall, and also to give support to the last layer of hempcrete as the new layer is tamped down above it.

Keep screws and spacers organized as you move around the building.

Temporary shuttering: method

The exact process for fixing temporary shuttering depends on the frame design and of course the type of shuttering board used. The methods outlined here, which cover a range of frame details, assume that OSB is being used.

Fixing shuttering to central frames

Where the frame is buried inside the hempcrete wall, the shuttering boards are fixed to the frame with spacers and long screws. Spacers are usually made from strong 25mm plastic pipe (such as waste pipe for plumbing applications) cut into lengths. This is done accurately, with a chop saw, so that the spacers hold the shuttering away from the frame at the exact distance that will be the final position of the face of the wall. As discussed in the last chapter with regard to the positioning of a central frame (see page 166), careful design and accurate construction of the frame can make this job easier by avoiding the need for small variations in the size of spacers required at different points on the frame.

The screws used need to be available in a range of sizes from 150mm to 300mm (the usual length needed is 200-250mm, to take into account the width of the shuttering board and the proportion of the screw that should sit in the frame to support the boards), and should be strong enough to hold the boards in place without moving. The head of the screw needs to be heavy duty, and up to the job of being repeatedly driven in and out, time and time again. The best we have found are extra-long decking screws, which come in a range of sizes and are very heavy duty (which is lucky because they are not cheap!).

The length of screw required can be calculated by combining the thickness of the shuttering board + length of the spacer + 30mm (minimum) sunk into the frame. The optimum length sunk into the frame is probably about 40mm; anything over 50mm is too long, as it risks splitting the timber. It also makes the job harder, as you have to sink more of the screw than necessary into the timber frame – and get it out again when you strike the shuttering. This means that the job takes more time (and battery power) than it would do otherwise, so ideally the shortest possible screw should be used, while meeting the minimum length as outlined above. Don't forget that some screws include the head (which stays outside the shuttering) in the length of the screw.

Long heavy-duty screws are ideal for fixing temporary shuttering.

The heads of these heavy-duty screws are usually hexagonal nuts (supplied with a matching socket bit in every box), or they have a recessed torx or 'star' drive (and are supplied with the corresponding bit). In either case there is usually a flat at the bottom of the head, before the shaft of the screw starts, so the head sits on top of the face of the board instead of being pulled through into the board.

You may need to use impact drivers to put these screws in, and pull them out, especially if your screws are a bit over-long for the job. Normal cordless drill-drivers come in a huge range of specifications, and some of them will be up to the job, but even if they are they will be slower than an impact driver. A very low-torque drill (+/-500rpm) is sometimes useful for tackling screws that refuse to come out.

Be careful to periodically check the hex socket bits that are supplied with the screws, as these do get rounded out over time, and using a worn socket can round off the hex nut on the head of the screw, making it difficult to get in and out. It's a chicken and egg situation, but at a price of around £1 per screw, you will do better to keep an eye on it, and throw out any damaged socket driver heads, as well as any screws where the head has become too worn.

The shafts of heavy-duty screws are fairly thick and not particularly prone to bending, but they will be used over and over again, and take a fair battering, so they do occasionally bend. Because you are usually talking about a 200-250mm length, screws with a very light bend might actually still be usable, at least for a time, but a more significant bend will make the job really difficult. Screws should be checked for bends and head damage as they are collected up at the end of the day, or as you go along, and the damaged ones discarded.

The method of fixing is to start the screw so it emerges 20mm or so from the back of the

Fixing shuttering with screws and spacers.

shuttering board, and then hold the spacer tube over the end of the screw, shoulder the board towards the frame so that the spacer is holding them apart, and drive home the screw until the flat on the head is flush with the face of the board. When enough of these are put in (usually 8-10 per board, arranged in two rows) you will be surprised at how firmly the board is held in place.

The standard temporary shuttering board measures 2400mm x 600mm (a standard 'eight by four' OSB sheet ripped down the middle), and should be fixed as described in the method below right, with two fixings for every stud (three per stud if a full board is being fixed). Wooden 'straps' or 'ties' are used to connect a board to adjoining boards. These need to be around 150-200mm long, and are usually made from pieces of roofing batten. They must be sufficiently stiff that, when four screws are fixed through them into the board (one or two on each side of the join, as required to keep the boards true), they hold the two boards in the same plane (assisted by the heavy-duty screws and spacers that are fixing both boards back to the frame). It is important that these screws are long enough to go through the whole thickness of the strap plus nearly the whole thickness of the board, but *not* project through into the void. If the screw projects into the void, people cut their fingers on the end of the screw while placing hempcrete, or at least snag their glove, causing small holes through which lime enters to burn the hands.

Fixing wooden straps in place to join two shuttering boards.

For big jobs we pre-assemble OSB sheets, ripped down to 600mm with an OSB overlap panel screwed to one end, for easy fixing of one board to the next in the run.

Shuttering central frames: step by step

The following method describes the side of the shuttering that is moved up with each lift; the other side is likely to be already boarded out in full boards (see box on page 171).

- Rip down several 'eight by four' sheets of OSB, to create a pile of 'standard size' shuttering boards measuring 2400mm x 600mm.
- Fix the bottom board in place (see Figure 9 overleaf) using long screws and spacers (tubes cut to the appropriate length), with two of these per stud, positioned near the top and bottom of the board (the top one should be just below the top edge).
- If the plinth is exactly the width that the hempcrete wall is to be, then a screw alone can be used at the bottom, with the edge of the board pulled in against the face of the plinth, so the plinth acts as the 'spacer'.

- Fix the whole run around the building, with corners shuttered as described opposite. As each board is put up, join it to the previous one with wooden straps or ties, as described on the previous page.
- Once a few consecutive boards are up, check them for the line vertically and horizontally (with a long spirit level) and adjust the screws as necessary.
- Once the void is filled with hempcrete (see Chapters 15 and 16), remove each top screw in turn, taking out the spacer tube and replacing the screw. The face of the freshly cast hempcrete now becomes the 'spacer', forming a guide to how far the board needs to be pulled back in. Be careful not to over-tighten the screw, as the hempcrete is still wet and easily pushed out of shape.
- Fix three or four straps to the top of each board, projecting upwards, and place the next lift of shuttering above the first one, fixing each board with the straps at the bottom and a single spacer and screw on each stud at the top edge of the board.
- Continue the run, fixing and checking the line as described above.
- Aim to take the shuttering boards straight across any small openings in the wall (e.g. windows) that aren't needed for access to the building during the hempcrete-placing stage. This makes the process of keeping the wall straight much easier (see page 185).

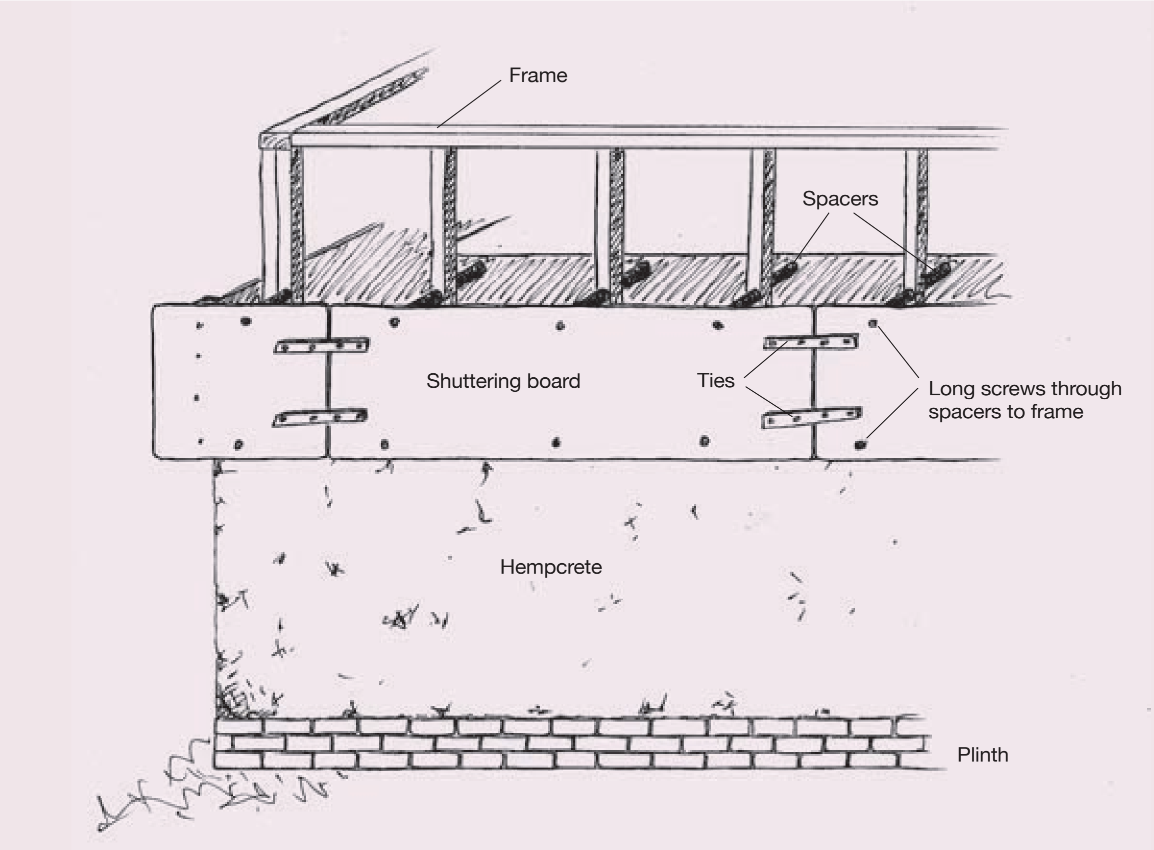


Figure 9. Shuttering boards are fixed to the frame and to each other.

As described earlier, the shuttering goes up in 600mm lifts on the side where people are working to fill it, but on the other side it can be created from full boards. In the case of a central frame, however, full boards are much harder to put up, since they are heavier and therefore more difficult to manhandle and to hold in place while the fixings are going in.

They have the added disadvantage that they require three rows of fixings, and – while this means fewer fixings overall, compared to two half-sized boards with two rows of fixings each – the bottom two rows of fixings are hard to fit, because it's impossible to reach around a full board to hold the spacers in place. Therefore one person needs to be positioned on the other side of the wall with the spacers, so that when the screw is started through the board, they can hold the spacer in place and guide the screw to the correct place on the frame as it is driven in.

Putting up shuttering on a central frame is always a two-person job, with one person to support the board in place (usually with the board resting on the section of shuttering below it, or on the ground) while the first two or three fixings are put in. Once there are enough fixings in to hold the board loosely in place, one person can put the others in, while the other person attaches two or three straps to tie the board to the end of the previous board in the line, and three or four to tie it to the board below, if these were not already added to the top of that board.

When a complete run of shuttering is fixed in place, take a long straight edge, and the longest level possible in the space, and check that the new shuttering is plumb vertically, and forming a straight continuous surface horizontally with the last board that you know to be true. If any adjustments need to be made this can usually just be done by loosening off the screws which go through the spacers or pulling them in slightly.

Shuttering at corners

The erection of shuttering at corners in a way that will create a straight, square, plumb corner is of course inherently more difficult than erecting straight runs of shuttering. It is also an area with very little tolerance for error, as any small mistake will result in a highly visible disturbance to the straight lines of the building. That said, straight lines in a building are not necessarily what everyone is aiming for – but if they *are* important to you, the following methods should help you to achieve them.

Corners externally:

- Cut the last board of the run so it over-sails the corner, fix it, check it for plumb and for straightness against neighbouring boards, and adjust as necessary.
- Start the next run of shuttering by placing the next board at right angles, butting up against the one that over-sails.
- With this board fixed loosely in place (with screws and spacers), use an appropriately sized square to check that the second board is at 90 degrees to the first, paying attention to top and bottom of the board (the middle should follow, in theory!).
- When you are happy with the position of both, the boards are held in place by one person while the other screws through the face of the over-sailing board into the end of the second board using 50mm screws. Screwing into the edge of an 11mm OSB sheet does not make for a very strong fixing, so use as many screws as are needed to keep it firmly in place.
- Tighten the fixings on the first board in the new run, and check it again for plumb and square at the corner (using a level on both faces, and a square outside and inside the corner formed by the boards), adjusting as necessary.
- Continue with the new run, working off this first board.

Shuttering for an external corner.

Fixing shuttering for an internal corner.

Corners internally (Method 1):

- Cut the two boards that run into the corner exactly to length, so that they butt up against each other to form a corner that sits exactly the right distance from the frame. Where possible, ensure that the factory-cut ends are used in the corner, as they will be easier to butt up square against each other.
- Obviously the boards cannot be screwed to one another as is done externally, as this would involve screws being put in from inside the void, which is later filled with hempcrete, making removal of the screws impossible. Instead, the normal fixings, i.e. screws and spacers, on each board should hold the two boards in the right place (this doesn't happen externally, as the external boards extend past the frame).
- If it is felt necessary to adjust the position of the boards where they meet at the corner, this can be done with a couple of heavy-duty screws diagonally from the corner of the shuttering into the corner post (see Figure 10 opposite). In this case, you might need slightly longer screws than normal (depending on the frame detail). Don't use spacers for these screws; just sink them into the frame wherever you can get a secure fix, and wind them in and out to adjust the position of the corner until you are happy with it.
- When fixed, measure all distances from the boards back into the frame, to check that the desired dimensions of cast hempcrete will be achieved. Double-check that the two boards meet at a 90-degree angle, using a set square on both sides of the boards, and check them for plumb with a level. Adjust as necessary.

Corners internally (Method 2):

- As an alternative to the above, a square-section timber can be screwed tight into the inside of the corner, with the screws sunk right through the timber from its exposed faces, to project slightly from the other side and catch the board (see Figure 10).
- Check that the timber used is completely straight and square, and double-check afterwards that the corner is where you want it to be.
- If using this method, don't do what one of our volunteers did and sink screws through the back of the board into the timber (see Figure 10). Once the hempcrete has been cast you cannot get at the head of the screw to remove it, and cutting the screws to get the shuttering apart without damaging the

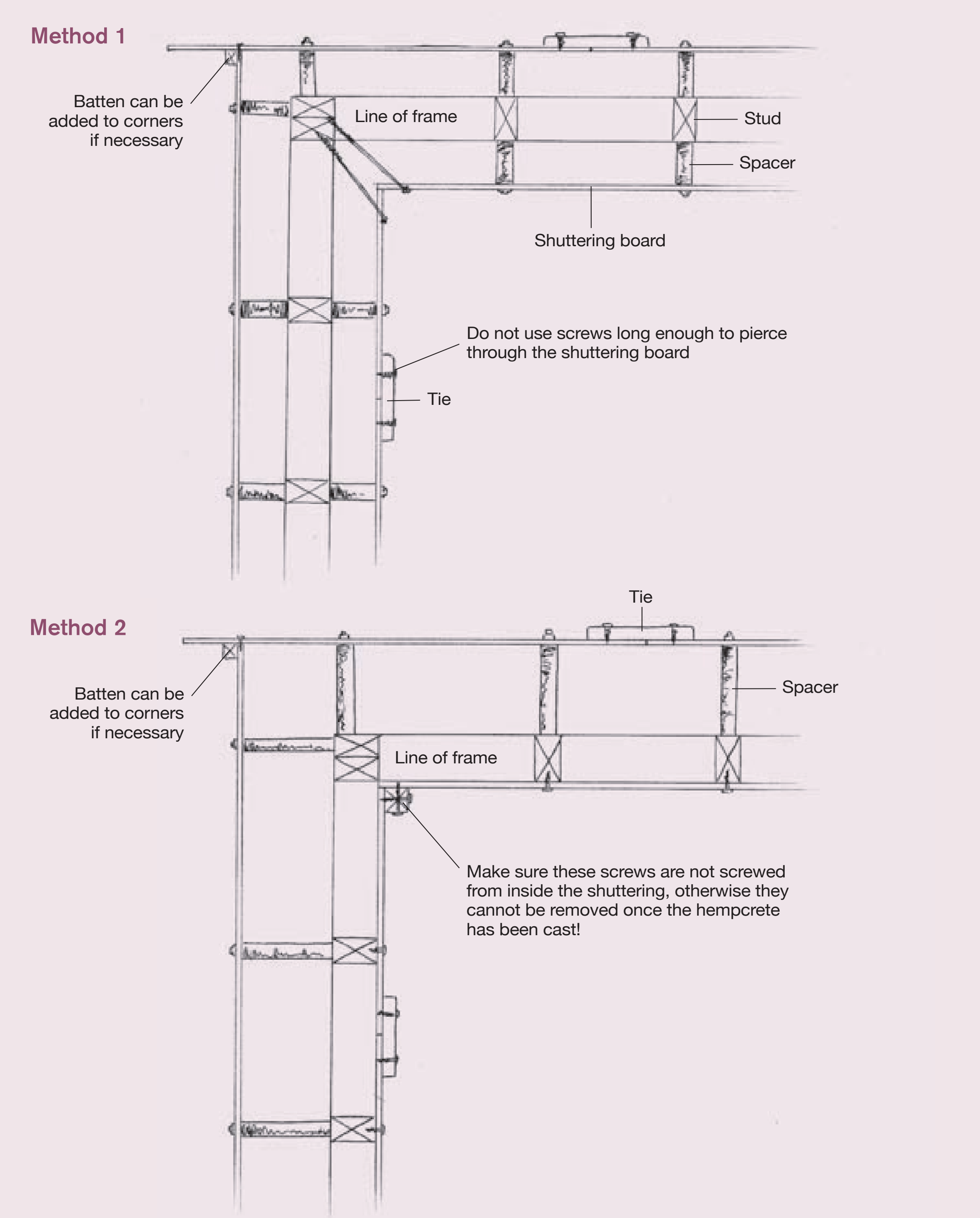


Figure 10. Constructing shuttering at corners, for a central frame and an internally exposed frame, showing Method 1 and Method 2 options for the internal corner.

freshly cast hempcrete is a heart-stopping and time-consuming business.

- Method 2 works better for shuttering on an exposed frame internally, where the boards are fixed straight to the timbers without spacers on the internal side of the board. With a central frame, Method 1 is the preferred option, as Method 2 can result in the corner being repositioned in relation to the (floating) timber, rather than being fixed in relation to the frame timbers as per the design.

Striking shuttering from central frames

To remove shuttering, the fixing process is basically reversed. The hempcrete is left shuttered until it has had time to take its initial set – about 30 minutes with Prompt Natural Cement; overnight with most other binders. In any case, always ensure that the time allowed is in accordance with the guidelines from the binder manufacturer. It is good practice to remove the shuttering as soon as possible after this time, even if you don't need the boards, because with the boards still in place the wall cannot start the process of drying out.

The first step is to undo the straps that tie the board to its neighbours, although where convenient these can be left on one of the two boards, as they will be put back on again when the board is reused further along the wall. Having the straps sticking off the boards sometimes makes them easier to handle.

Removing the long decking screws is a two-handed job, because the screw is threaded only for the last 50mm, i.e. most of the shaft is smooth. The easiest way to get them out is to start unwinding the screw, so the head sits off the face of the board, and then hook a mini claw bar, or similar, around the head so you can pull it away as well as unscrewing it. Once the threaded piece is pulled back as far as the board, it will unscrew by itself.

Shuttering partially removed from a wall with a central softwood frame.

Top tip for removing shuttering

When all of the screws have been removed, slide the board across the face of the hempcrete before pulling it away from the face of the wall. This reduces the risk of bits of hempcrete sticking to the board and being pulled out of the wall as the board is taken down.

Remove spacers gently before the wall hardens.

Spacer holes are filled in later with a little hemp-crete mix.

Because of this, two people are needed to remove the boards, just as they were to fix them. One person needs to support the bottom edge of the board, in the centre, while the other person removes the last two or three screws. If it isn't supported in this way then the falling board risks catching the face of the freshly cast (and still delicate) hempcrete, and damaging it. Also, dropped boards are heavy and at high risk of falling through gaps in the scaffolding and landing on people below.

When a full shuttering board is removed, the plastic spacers around the screws are effectively cast in place in the hempcrete wall. These can be removed straight away with pliers, but very carefully, as the hempcrete is still wet and fragile. The best method is to first gently turn the tube left and right (without pulling) to loosen it from the hempcrete around it. It can then be withdrawn from the wall without pulling lots of hempcrete out with it. The resulting void can be filled by hand with a bit of loose mix. Add a little at a time, to make sure the void is completely filled.

Fixing and striking shuttering to/from exposed frames

Fixing shuttering to, and removing it from, exposed frames is a much easier and quicker business than with central frames, as spacers are not required on the side of the frame that is flush with the face of the finished wall. Boards are screwed straight on to the face of the frame timbers, using 40mm screws, unless the frame is to be left exposed as part of the finish (see Chapter 20, pages 275 and 276). Boards should be fixed to every post, with screws at no wider than 600mm centres going up the post, with a screw placed within 100mm of the top and bottom of the board to ensure that the edges are not pushed out.

The boards will still be going up in 600mm lifts on the side from which the wall will be filled, but if you are filling from the side opposite the exposed frame (or if it is a double-frame design), then you can of course use full boards, and it is much easier to fix these flat to the timbers than it is to attach them with long screws and spacers.

Fixing shuttering to an exposed frame is much easier than with a central frame.

Shuttering partially removed from a section of wall with an exposed frame.

As long as you have built the frame accurately, with all the facing timbers in the same plane, then there will also be no work to do in terms of keeping the boards that are fixed to the timbers vertical and in the same plane. Indeed, if out-of-place timbers are noticed at this stage, there's not much you can do to correct that with the boards. Any frame timbers that are not correct should be replaced or planed down before boarding continues, otherwise the whole wall will be out.

Straps to tie across the top and bottom of boards are not needed on this side, given the increased strength from screwing the boards directly to the timbers, although they are still needed for adjoining boards where the two boards don't meet on a timber. Having an exposed frame on one side can speed up the shuttering process significantly, and also makes it possible for just one person to do the job on that side, as with a magnetic screwdriver bit you can sink or extract screws one-handed while holding the board in place against the timbers with the other hand. Even when using full boards, this is just about possible with care.

The ease and speed of applying shuttering to an exposed frame makes the idea of the double frame (exposed frame on both sides) very attractive. This should, however, be considered with caution, since the increased proportion of wall thickness that ends up being filled with wood will reduce the level of insulation.

Having an external exposed frame is, in any case, to be avoided unless it is needed for a specific purpose, for example to help with tying wood or masonry cladding back to the face of the wall, because of the potential for damp to affect the frame. Internal exposed frames are a different matter, and the speed of shuttering is also a convincing argument for using a permanent shuttering board internally.

Permanent shuttering

As described in earlier chapters, permanent shuttering can replace temporary shuttering on one side of the wall. It cannot be applied to both sides, since at least one side of the wall must be left open for a number of weeks after casting to allow drying of the hempcrete (see Chapter 16, page 215). Permanent shuttering has to be fixed to an exposed frame, flush with the wall's face, and is generally used internally.

In order for the hempcrete wall to retain its vapour permeability, permanent shuttering boards should, of course, be breathable themselves. These boards need to be able to carry whatever finish is desired, and the more open-structured boards on the market actually provide the ideal key for a lime plaster or render. It is unusual for permanent shuttering to be used externally, since a render finish can be applied quite easily to a normal hempcrete wall, without the added risk associated with having the structural timbers so close to the external face of the wall. At the time of writing, two choices of permanent shuttering are available: wood wool board – made from compressed and bound wood fibres, which is very breathable due to its open structure; and magnesium silicate board – a dense, smooth board that resembles gypsum plasterboard, but is white in colour.

The open structure and the strength of wood wool board makes it an ideal surface to carry lime and clay plasters. At the time of writing, several choices of wood wool board are available on the UK market, for example Heraklith, Troldtekt and Anutone, which are comparable products in terms of their physical properties. However, different brands may vary in terms of the binders used, the process and site of production (usually in Europe) and the level of certification provided with regard to the board's embodied energy, including whether proper lifecycle analyses have been carried out.

Clearly the use of materials manufactured in Europe as opposed to the UK can be said to have a greater environmental impact in terms of transport to the UK, but this can be offset by the fact that there is a higher requirement on companies operating in Continental Europe to provide full disclosure about embodied carbon than exists in the UK currently. However, it should be remembered that, despite being made from natural materials, *all* of these products are highly processed manufactured materials, which can only add to the carbon emissions represented by the build. Permanent shuttering, unless using spray-applied hempcrete, is an 'optional extra' within a hempcrete building design. The most

Wood wool board's open structure provides good breathability and an excellent key for lime plaster, just like hempcrete.

Magnesium silicate permanent shuttering, from inside the building.

Permanent shuttering using magnesium silicate board, viewed from outside the building.

sustainable way of building with hempcrete is to cast a simple hempcrete wall and apply finishes direct to the hempcrete.

Magnesium silicate board is a synthetic, high-embodied-energy product. It is a much more expensive option than wood wool board and, in our opinion, brings fewer benefits, since its very dense structure appears in practice to be much less breathable than wood wool. The very smooth surface also precludes the application of traditional lime plaster, and is probably best finished with a (more expensive) proprietary lime-based plaster, which adds further costs to the build.

To our knowledge, at the time of writing magnesium silicate boards are all produced in India or China, and therefore may use more energy in their transportation to the UK than those made in Europe. There is also a lack of clear information available about the environmental impacts of the manufacturing processes or the working conditions of those involved in their production.

The fixing of permanent shuttering boards is exactly the same as for temporary shuttering to exposed frames (see page 181). Follow the manufacturer's guidelines as to the number and type of fixings, but remember that all fixings should be alkali-resistant (stainless steel or plastic), as they need to resist corrosion by the lime in the hempcrete and the lime plaster that will be applied over the top of the board. In the case of wood wool boards, a plastic disc washer of 60mm diameter is fitted to the screw, so that the screw holds the board effectively and does not pull through the face of the board. These discs are designed to be plastered over in the basecoat.

The usual reason for permanent shuttering is to save on labour costs: the exposed frame design

Wood wool board used as permanent shuttering is fixed using screws and plastic washers, as shown here on a window reveal.

means that spacers are not needed to fix the shuttering on that side of the wall, and of course no time has to be spent removing the shuttering. Weighed against this, however, is the cost of the boards, as well as the inherent reduction in sustainability of the build when using additional, highly processed materials that are transported long distances.

Different solutions will fit the priorities on different builds. Self-builders, for instance, who may be in a position to supply their own labour, might prefer to go with the labour-heavy option of temporary shuttering rather than have a significant increase in material costs. All these factors need thinking about at the design stage, so that the frame design can encompass them.

Lastly, it is worth saying that while permanent shuttering can be a useful strategy in lots of situations, something of the elegant simplicity of a cast hempcrete wall is lost by adding another layer to it.

Shuttering around openings in the wall

To create openings in the wall for windows and doors, shuttering boards need to be fixed around the inside of the framework defining the opening. Since the frame timbers either side of the opening, and for the lintel, are double timbers, this makes a secure support for the boards, which are screwed straight through into the face of the timbers. However, unless the frame is a double frame (exposed on both sides), the corners of the boards inside the opening, on both sides in the case of a central frame, will be at risk of moving about when the hempcrete is being placed. This can be solved by blocks of timber placed up into the corners where these boards meet each other (as in shuttering corners Method 2, see page 178), or sections of batten running across the whole width of the board inside the opening (i.e. spanning the width of the wall), with screws going right through the timber (from inside the doorway or window) to fix into the boards.

Straight reveals can easily be constructed with the shuttering in this way, while straight-sided angled reveals are probably also best formed by casting, using more complex shuttering. To achieve delicate rounded reveals where the wall curves gently into the reveal in a continuous surface, cast them square or angled, and then shape them by hand with a nail float as the hempcrete is hardening (see Chapter 18, page 244).

The shuttering method described above for creating openings for doors and windows can be

Shuttering for openings in the wall.

adapted to create openings that go part-way through the wall. These might include, for example, alcoves, shelves or cupboards that are inset into the finished wall and are partly or completely formed by the casting of the hempcrete itself, in whatever form pleases you. Obviously there is a limit to the depth to which the alcove can extend without significantly reducing the insulation provided by, and the strength of, the hempcrete that remains.

Hempcrete freshly cast around a window opening.

A small-section frame detail around the alcove opening can be useful in this situation, not only for fixing the temporary shuttering but also for ease of fixing the finished lining, for example wooden shelves, a lining around the recess or a cupboard door, into the opening.

Window openings with shuttering partially removed.

Curved walls

It is possible to cast curved hempcrete walls, by constructing a curved frame and holding shuttering boards off the frame with spacers in the usual way. In this situation, experimentation is needed to find boards that bend enough to create the desired curve without breaking, while remaining stiff enough to hold their shape in a smooth, continuous curve. The obvious choice for this is a thin ply, but a 15mm wood wool board curves pretty well too.

A curved hempcrete wall enclosing a shower. (The inside face is finished with tadelakt – lime-based and waterproof – see page 249). *Image: Margot Voase*

A note on shuttering historic frames

Shuttering for casting hempcrete in the context of historic restoration work is potentially more complex than on a new build, and has to be designed on a job-by-job basis according to the particular needs of the application. The shuttering design itself is not necessarily difficult, but

Hempcrete can be shaped with a nail or grid float after casting.

the materials used for straight walls in new-build applications may not be suitable.

As anyone who has lived in a house that was built before the late nineteenth century knows, walls in old buildings are never straight. For this reason, when setting up shuttering, especially on ancient timber frames, a more pliable bendy material is often required, so that the shuttering can easily follow the line of the wall. However, bendy shuttering is only so bendy; where necessary, a 'best fit' shuttering solution is constructed and the rough or unwanted edges of the cast material can be scratched back and shaped with a nail or grid float after the shuttering is struck.

Remember that historic timber frames are often left visible in the face of the hempcrete wall, and therefore it might not be appropriate to screw shuttering boards directly into the face of the timbers. This problem can be overcome by screwing battens centrally to the inside faces of

Shuttering and casting around ancient timber frames, such as in this Tudor barn, can be a slow business.

the timbers (i.e. the side of each timber that faces in towards the hempcrete panel) and screwing through the shuttering boards into the batten (without spacers so the shuttering is pulled in tight to the shape of the frame). The battens are buried below the surface of the cast hempcrete, and the screws are easily removed when striking the shuttering.

Bear in mind that in historic work the casting of hempcrete is likely to be a slower and more intricate process, with lots of existing wall structures that get in the way of casting and very much need to be 'worked around' rather than removed. The final wall thickness, if determined by the historic frame, is often a lot thinner than in a new build, which makes it a more fiddly business to spread hempcrete evenly in the void. For this reason the wall may be cast in smaller lifts, and the height of each shuttering board needs to be adapted accordingly.

For more information on the use of hempcrete in historic buildings, see Chapter 20.

Plastic shuttering

Contractors may be tempted to invest in one of the modular reusable formwork systems that are used for casting concrete. These are often made from recycled plastic, and are available in a range of designs, including rounded pieces for casting columns.

This option might at first seem a sensible route to go down, as the modules are very easy and quick to assemble, keep the wall very straight and reduce wastage (if you are throwing away your OSB when it gets too tatty, or has been cut up too small).

On the other hand, they are expensive to buy – so much so that you would only begin to see a saving if you were doing a lot of large builds. They also need cleaning well after each build, so that any bits of dried hempcrete on their surface will not stop them producing a clean, straight wall on the next build, which is an extra job. Lastly, they are much bulkier than thin wooden boards, and you would need to have lots of them, and therefore would have to think about where to store them and how to transport them.

As described earlier in this chapter, at HempLimeConstruct we have concluded that the most practical and economical solution is to use OSB, since the finished wall it makes is no worse or better than one formed with plastic shuttering. OSB is cheap, readily available and easy to store, it's made (mostly) from natural materials, and you can reuse it many times over as shuttering, and then use it in the building or build a shed with it afterwards.

Plastic reusable shuttering. *Image: The Limecrete Company*


MULTI MARQUE
HemShiv
100% Hemp Core
HemShiv
100% Hemp Core

CHAPTER FIFTEEN

Mixing hempcrete

This and the next chapter are arguably the most important of the whole book. We would very much like you to read them more than once – indeed, as many times as necessary in order to absorb all the information well. For a 'belt and braces' approach you could write down the key steps, and have them handy the first few times you make a hemp–lime mix.

Mixing hempcrete is easy to get wrong when you are not practised at it, and there is not much margin for error. Getting the mix even slightly wrong can have serious negative effects on the finished wall. For this reason we recommend that you not only follow the binder product manufacturer's guidelines to the letter, but also pay close attention to the principles and method described here. It goes without saying that if you have not done it before, you need to make up and cast some test mixes of hempcrete before starting on a real project. The construction of a section of test wall enables you check and adjust both your mixing and placing techniques.

Basic principles

The first thing to say is that personal protective equipment (PPE) is extremely important when mixing hempcrete. If you attempt to do it without the correct equipment you *will* get chemical burns from the lime in the binder. Lime burns are painful, and can cause serious health problems in the case of getting it in your eyes (permanent loss of vision), or airway (acute irritation and/or chronic respiratory problems).

Read Chapter 9 (Health and safety) very carefully, and make sure you put it into practice. You are *not* the exception to the rule. Even if you are a bloke. What's more, if you are employing people to do this work, you (and also they) have a duty to ensure that safe working practices are followed, that the correct PPE is worn or used, and that proper training and instruction is given to anyone carrying out this work. You also need to keep a first aid kit handy with the correct items in it, the most crucial of which is eye wash.

Previous page: Hemp-LimeConstruct's pan mixer has been specially designed for mixing hempcrete.

The key principle to remember when mixing hempcrete is the importance of the mix including all the constituent materials – hemp shiv, binder and water – in the right proportions. For those used to working with cement mortars and concrete, this may seem strange: with these, there is much more leeway for the mix having slightly too much, or too little, cement in it. The gauging of the cement binder to the required sand and/or gravel is usually done quite roughly with a spade or shovel. And the worst consequence of a cement mix that is too wet or too dry is likely to be your boss grumbling about its workability, rather than it having a serious effect on the building's structural integrity. Not so with hempcrete. Because the aggregate in hempcrete is a plant material, and because the desired consistency is a light and fluffy (low-density) mix, with every piece of hemp shiv coated in binder, exactly the correct proportions must be added.

Just the right amount of water

Water can be measured into the mix in different ways, and in some cases small adjustments may have to be made, usually by eye, to account for variations in the weather conditions or the hemp shiv being wet. However, as a general principle, precision about the proportions of ingredients is especially important in terms of the amount of water added. The consequences of either too much or too little water can be serious.

The right consistency is not too wet and not too dry.

Not enough water

The hemp shiv arrives at the site in a dry state, and is carefully stored on-site to ensure that it does not get wet. Failure to do this can result in it getting damp and mouldy and beginning to rot before it can be protected by being mixed with the binder. The lime-based binder is hydraulic, meaning that it requires water for the chemical reaction by which it sets (see Chapter 3). A certain amount of binder requires a certain amount of water to allow it to set fully. However, because the hemp is dry, it naturally absorbs water when it comes into contact with it, and so when the hemp and the binder are combined with water, the two ingredients are actually in competition for the water in the mix.

The effect of not enough water in the mix is that the water-hungry dry hemp soaks up water needed by the binder, leaving some of the binder in a powdery or semi-powdery state. Result: your wall fails to achieve full strength and is at risk of collapse.

Too much water

Well that's easy then, you might say – simply over-compensate and make sure there's plenty of water in the mix: a little bit over won't hurt – better safe than sorry? Well . . . no. Unfortunately, because we are using a natural plant aggregate, one of the risks is that excessive or extended exposure to water can cause the hemp to rot inside the wall. This is in fact an unlikely result, because the hemp's natural properties allow it to absorb water and release it again without any damage – that's why it is so suitable for a breathable wall system. However, any prolonged period of exposure to excess water is to be avoided.

In addition, we need to be sure that the water we introduce at the mixing stage is able to dry out of the wall within a reasonable time period, so that finishes can be applied. Although the wet finishes used will be vapour permeable, they restrict the speed at which moisture leaves the wall, because compared with the bare hempcrete they have a less open structure and therefore a smaller surface area from which water can evaporate.

This second effect of having too much water in the mix is probably the more serious. In our experience this is often a major bone of contention on building sites, as any perceived delay in applying finishes is assumed to be costing time and money. In practice, this is not always true, and it would make sense in most cases to leave at least one side of the hempcrete walls without finishes for the longest possible period, to be certain that they have dried out to their optimum 'resting moisture content' as quickly as possible. (see Chapter 16, page 215). Frequently, however, there is pressure to complete the wall as quickly as possible, and assuming this to be the case, you really don't want to be introducing any more water into the mix than is absolutely necessary.

Another effect of too much water is that the weight of the mix increases, causing the placed hempcrete to compact more closely, resulting in a denser material and a reduced insulation value. When excess water in the mix reaches a critical level, the wall could collapse when the shuttering is removed, because the weight of the wall is too great for the strength of the initial set of the binder to hold. For this reason, as well as those already described, we really cannot overemphasize the importance of using the correct amount of water.

Pan mixer opened to show paddles and hempcrete mix. (Note: *never* use a pan mixer with the lid open!)

Who is doing your mixing?

It goes without saying that the best way of ensuring correct proportions in the mix is by accurate measurement every time. This is partly addressed in the mixing method (described on the following pages), but you can't avoid the fact that some people in your team are going to be more suited to this job than others, and getting the right person (or people) on the mixer will be the best way of ensuring consistency of mix on the build.

The people best suited to the job will have the following qualities:

- They are physically up to it – this is less of an issue when using a smaller mixer, but feeding larger mixers over a long period is a physically demanding task.
- They don't mind doing a repetitive task over and over, and understand the importance of, and take on the responsibility for, getting it right every time. Your worst-case scenario is someone who isn't really bothered whether they get it right.
- They are well organized, and have a natural tendency towards keeping things clean and tidy – the work area, the mixer itself, and the buckets and tubs.
- They can count (it sounds basic, but you'd be surprised!) and remember how many buckets they've already put in.
- They don't mind being on the sharp end when it comes to handling the lime binder, and getting splashed with water at the same time (not a great combination).
- They have a responsible attitude to health and safety and PPE.
- They don't go to pieces under pressure, and have the confidence and communication skills to get other team members to keep them supplied with raw materials.

If you haven't found a person you can rely on to consistently do the mixing properly, then it's best to do it yourself, as it *must* be done correctly.

Tools, equipment and method

The exact method for mixing hempcrete (including the specific amounts of water, hemp and binder in mix) is dictated by the type of binder you are using. As has been said several times already – it is an important point – you should

Mixing hempcrete is not a pleasant job, but it needs to be done correctly.

always follow *exactly* the instructions given by the manufacturer or supplier of the binder product you are using. Suppliers are generally very helpful in passing on guidance issued by the manufacturer (and if yours is not, find another supplier!). It is your responsibility as the builder to ensure that the finished building has full structural integrity. This is achieved by the correct use of materials, which, as discussed, largely relates to the level of accuracy, and the method used, when mixing the hempcrete.

On every build, someone needs to take overall responsibility for the training and supervision of everyone involved in this process, and monitor quality and consistency over the whole build.

The exact proportions of hemp:binder:water vary slightly depending on the type of binder used and the application (floors, walls, roof, etc.) in which you are using it. For this reason, in discussing the mixing method on page 199 we are going to use an 'Example Mix' – a made-up product using our very own, purely imaginary 'HLC (Hemp-LimeConstruct) Binder' and our own specified proportions of hemp and water.

We cannot stress enough that you *should not* use our Example Mix in your real building. If you do, it will not work, because our HLC Binder *does not exist*! In the real world you *must* follow the exact proportions specified by the manufacturer of the binder you are using.

Mixing in a pan mixer

Hempcrete is usually mixed in a large (800-litre capacity) forced-action pan mixer. These are available to hire (see Resources), or you can often buy a second-hand one from a farmer (try *Farmers Trader* or *Agricultural Trader* magazines).

Forced-action pan mixers should not be confused with roller pan mixers, which are used for lime putty plasters. Instead of rotating blades, roller pan mixers have heavy rollers which roll

A pan mixer on a telehandler is convenient, as it can be used at different heights.

round the pan, crushing the mix against the bottom of the pan. Roller pan mixers are *not* suitable for mixing hempcrete.

Hired 800-litre pan mixers are supplied from the hire shop in one of the following set-ups:

- A stand-alone mixer that can be lifted on a telehandler – handy for combining the stuff up on the scaffolding where you need it, instead of down on the ground and carrying it up in tubs. This combination is really the most flexible, and having a telehandler on-site has other advantages too (see opposite). In this set-up, the mixer is powered by the hydraulics from the telehandler.
- A mixer on a specially designed stand – to give height for the hempcrete mix to fall out of the machine under gravity, and room for it to be caught in a tub without someone having to bend down all the time. In this set-up the mixer is powered by a separate generator.
- A mixer on a trailer – to raise it off the ground and to make it possible to move it around the site. In this set-up it is powered by an engine, which also sits on the trailer.

If using a mixer that has been specifically adapted for hempcrete, it may have an integrated water tank that automatically fills up to the desired level and then empties the correct amount of water into the mixer when a tap is opened. This simplifies and speeds up the process, and the mixing area stays much dryer than if you are measuring the water in tubs, which tend to slop everywhere.

As well as the mixer, the other items of essential equipment are:

- **Gloves, masks, goggles, waterproof clothing** and **waterproof boots** for the person doing the mixing.
- **Gorilla Tubs** (at least 10-12).
- A **plastic measuring jug** and **permanent marker** for accurate marking of desired fill levels in buckets or tubs (unless the mixer has an integrated water tank).
- A **knife** to open the bales of hemp and bags of binder.
- A **broom** for the top of the mixer.
- A **hose** for the water supply.
- A **block and pulley with rope and carabiner clip**, if tubs are to be hoisted up the scaffolding.

Method

First, think about where you are going to put your mixer. These are heavy things, best moved as little as possible around the site. The mixer is loaded through the grille at the top and, when ready, the mix is allowed to fall through the chute at the bottom of the machine, filling tubs which are then carried to where the mix is needed. This part of the job is done by hand and is obviously much easier and quicker if the machine is close to the wall being filled.

You also need to consider how you will supply the bales of hemp and bags of binder to the person operating the mixer. How much effort will have to be expended in getting the hemp and binder close to the mixer, and up to the level where they can be fed into the *top* of it? Both hemp and binder come on pallets, so if you have a telehandler on-site, this part of the work could be made easier by using the forks to lift supplies to the required level.

The mixer area should ideally be slightly away from where people are working, because of the dust that inevitably escapes into the surrounding air. It should have space for a good supply of materials to be stored next to the person doing the mixing, so these can be easily reached. Materials need to be stored dry, and wherever possible the mixer itself should be somewhere under cover, so that rain is kept off while it is in use. The under-cover area should be well ventilated.

Do whatever it takes to prevent excess water entering the mix.

If it rains into the mixer, of course, you run the risk of adding excess water to the mix. If it is not possible to keep the rain off (and it's not always easy to find a covered and well-ventilated space for such a large mixer) then in heavy rain, either stop mixing or reduce the amount of water *you* are adding to the mix to compensate, checking the consistency as you go along and adjusting it as necessary (see page 200). Always aim to add the *minimum* amount of water needed to achieve the correct consistency.

On a large build, it may be appropriate to change the site of the mixer as the work moves around the building, although in practice this can be complicated as it involves balancing all of the factors described, as well as finding a place that is not disrupting the work of other trades. Obviously if you have the mixer on a stand rather than on a trailer, you need a forklift or telehandler to move it around the site, instead of just towing it.

If you have the mixer-on-its-own type then you need a telehandler anyway, as the mixer sits on the forks while in use and is powered by the hydraulics on the telehandler. With this arrangement, as well as the convenience of being able to collect the hempcrete from the mixer at scaffolding level, you have the advantage of the telehandler on-site for moving materials on pallets, which saves a lot of time and physical labour. However, do bear in mind that a) if you are hiring, you have the additional cost of the telehandler hire as well as the mixer hire; and b) you have to be quite organized with your shifting of materials around the site, otherwise you are constantly having to take the mixer on and off the forks because someone needs the telehandler, and this really cuts into your mixing time throughout the day, and brings the whole hempcrete-placing operation to a stop each time.

Despite all this forethought, as often as not, the site of the mixer is determined by the location of the water supply, and/or the length of your hose! However, it is worth taking the above into consideration, as it can make a big difference to your productivity and costs over the course of a build.

Mixing in a pan mixer: step by step

1. Add the hemp shiv.
2. Add the binder and start the mixer.
3. Add water.
4. Mix until well combined.
5. Adjust the amount of water by spraying down.
6. Empty the hempcrete into tubs.

The mixing process is described in more detail below right, but these are the basic principles:

- The binder should be well mixed with water first (to ensure sufficient water is taken up by the binder).
- The hemp shiv is then added, then, after more mixing, the rest of the water, and all materials are evenly combined to achieve a consistent finished mix. However, depending on the individual mixer you are using, it may not be possible to add the materials in this order. Sometimes the pan is not completely watertight (though it should be), so, if combining water and binder first, some may escape. Also, when the hemp is added last it sometimes clogs together as it goes in and doesn't mix easily. In either of these situations, it is acceptable to mix the hemp and dry binder thoroughly first and then add the water (as shown in the photos opposite), although care should be taken to distribute the water evenly through the mix.
- The mixing should be long enough to achieve an evenly blended material and no longer. This time can vary with the materials, but is easily judged by eye, since it is quite easy to see into the mixer.
- Once mixed, the wet hempcrete should be placed immediately, or within the time recommended by the manufacturer (depending on which binder you are using), and this time limit should be strictly observed.
- If you are not able to use the mix straight away, the hempcrete should be stored in a tub in *clean* and *dry* conditions so that no contaminants and, most importantly, *no extra water* gets introduced to the mix.

For our Hemp-LimeConstruct Example Mix, with our imaginary HLC Binder (see page 195 – do *not* use these proportions in your real building), we need to make a mix of the proportions 4:1:1 (hemp:binder:water). In terms of what will easily fit in our large pan mixer, this equates to (per mix):

360 litres of hemp (2 x 180-litre bales) + 90kg of 'HLC Binder' (3 x 30kg bags) + 90 litres of water

Mixing process

The method will be prescribed by the binder manufacturer and/or supplier, but in general the process of mixing is as follows:

- Put on goggles and mask (or full-face mask), waterproof clothing, gloves and waterproof boots.
- Pre-fill either marked tubs or buckets, or a gravity-release tank with the required amount of water, so that the precise amount is already measured out before mixing begins.
- Add approximately half of the water to the mixer and let its paddle move the water around to collect any leftover residue from the last mix.
- Add the binder, opening the bags and emptying them through the centre of the mixer grille in such a way as to minimize the dust released into the air above the mixer. Ensure that *all* the binder has been removed from each bag.
- Allow the water and binder to mix to a smooth slurry, and meanwhile use a broom to knock in any binder that got caught on the grille of the mixer. Dispose of binder bags safely in a way that limits the amount of binder dust spreading around the working area.
- Open the bales and dump the hemp (a bale at a time) in the centre of the grille. Use a broom to work the hemp down through the grille into the mixer, being careful not to brush it off the side of the mixer. Again – although it is less of an irritant than the binder dust – take care to ensure that minimal hemp dust is released into the air.
- Allow the hemp to mix into the slurry, until a dry but fairly consistent blend is achieved. At this point, or if no further mixing can occur due to a lack of water, add the remaining

water. As far as possible, try to add the water in such a way that it is evenly spread around the mixer rather than being concentrated in one part of the mix.

- Note: if using the alternative method described in the 'basic principles' on the previous page, in which the hemp and binder are mixed dry before water is added, follow these steps: With the mixer off, put the hemp in, then add the binder, distributing it as evenly as possible. Start the mixer and run it until the hemp and binder have integrated to become a consistent blend. With the mixer still turning, add the water, ensuring it is distributed as evenly as possible throughout the mix as it goes in.
- Allow the mixer to do its job, until the mix seems to have the right consistency and looks completely even. You are trying to achieve a light, fluffy mix and to avoid it 'balling up' (small balled lumps in the mix, which mostly consist of binder).
- If you see balled lumps appearing, stop mixing immediately. There is not much you can do to get rid of them again, but make the placing team aware of it and ask them to discard any balls they see in the tub as they are placing the hempcrete.
- To test the consistency, drop a little of the mix out into a tub, pull out a handful, and squeeze it into a ball with both gloved hands. No liquid should drip out. Hold the ball in the palm of one hand and push a finger in. If the ball crumbles, it is too dry; if your finger just 'squidges' into the ball, it is too wet. If it splits in two, it is just right (see photos below).
- If it is not right, throw the pile in the tub back into the mixer and adjust the consistency by adding a little more water or hemp as required, and adjust the amount of water going into the next mix if necessary.
- When the proper consistency is achieved, leave the mixer turning, place a Gorilla Tub under the chute and fill it by opening and closing the chute door with the lever. Repeat until the mixer is completely emptied. It's easiest to have one person mixing and one working the chute (see opposite).
- Try to avoid any delay in emptying the mixer. If delay is unavoidable, stop it turning, as over-mixing will cause the mix to start balling up.

Testing the mix

1. Squeeze some hempcrete into a ball.
2. Push a gloved finger into it.
3. If it breaks cleanly, then it is ready.

- When the mixer is empty, ensure that the chute is properly closed (watch out for pieces of hemp getting stuck in the chute door), and use some of the next mix's allowance of water to wash any bits from the sides. Then you are ready to either start a new mix or turn off the machine if another mix is not needed immediately.
- Any spilt bits of hempcrete by the mixer, or bits dropped outside the shuttering, can be swept up – as long as they are uncontaminated by other materials – and added to the next mix to replace fresh hemp shiv. However, this must not make up more than 10 per cent of a whole batch. You are more likely to be able to reuse dropped hempcrete mix if you deploy clean OSB sheets or similar at the bottom of the shuttering where people are placing, and underneath the mixer chute.

With a pan mixer, the mixing team typically includes two people: one organizing the materials and feeding the mixer, and another below operating the chute, i.e. filling tubs and handing them to a team of people ferrying them to the 'tampers', who are placing the mix into the shuttering. Once each tub has been emptied into the shuttering, the ferrying team returns the empty tubs to the mixer to be refilled and brought back, or to wait for the next mix. However, it may be possible for one experienced person to operate the mixer alone, and this is certainly possible if it has a built-in water tank, automating the process of measuring and adding water.

The quantity produced with an 800-litre pan mixer will be (depending on the exact quantities used) around 0.4m^3 per mix. This of course takes a while to produce, given the mixing time, the physical work involved in feeding the mixer, and the time taken to empty it into 30-litre or 45-litre Gorilla Tubs (the 30-litre type is more useful, as everyone can carry them) before a new batch can be started. It is important at first to give your mixing team time to get used to the process, so start slowly: with hempcrete, getting it right is always more important than getting it done quickly.

Once you are used to the process, you will work out a general rule of thumb for the quantity of mix you can knock out in a normal working day, but remember that the mixing speed depends on a lot of other factors as well, such as other people needing to use the telehandler, and the distance that the ferrying team have to walk to empty the tubs. Ultimately, of course, the mixing speed has to match the speed that the placing team can work at, which can vary around different parts of the frame (placing slows down around corners and openings, and also relies on the shuttering being moved on ahead), as you don't want tubs of mix sitting around drying out or getting rained on. In any case, you need the tubs back to keep emptying the mixer, unless you want to invest in more than 25 tubs.

We return to this subject in Chapter 19, but for now, the point to remember is that finding the balance between the speed of mixing, ferrying and placing hempcrete is important. The balance needs to be constantly monitored and readjusted as necessary, in order that the operation is run efficiently and maximum productivity is achieved.

Mixing in a bell mixer

For applications where placement of the hempcrete will be slower (e.g. fiddly historic building work, or work with complicated or narrow shuttering), or where the total amount placed is smaller (e.g. a small building or extension), it is possible to mix hempcrete in a standard bell (or 'drum') concrete mixer. This is not recommended for large new-build applications, as you will not be able to produce enough to keep up with the speed of placement work.

A bell mixer is more difficult to use than a pan mixer, and requires even more attention to technique in order to produce a working hempcrete mix. This is another good reason to use a large pan mixer whenever possible.

If you do decide to use a bell mixer, get the larger type, designed for mixing concrete. These usually have a wheel at the side to alter and set the tilt of the bell, so you can run it closer to horizontal (bell mouth at the front rather than pointing up at 45 degrees). This is much easier on your back than the type that just has handles at the back to lift and tip the bell: to use these with the bell close to horizontal you have to stand there and hold it in the right position while it mixes.

Bear in mind that to make the job as easy as possible you also need to get the largest bell size available, and you will probably want to hire two, as with a bit of practice it's possible to have two mixers running at the same time.

As well as the mixer, you need the essential equipment outlined for use with a pan mixer (see page 196). In addition, you need:

- **Buckets** (half a dozen or so at least).
- **Shovels** for the hemp.
- A **broom** for tidying the mixing area.
- A **bulk bag** or two.
- An **old trowel** to scrape the mixer.

When mixing in a bell mixer, you need first to mark your buckets with fill levels for quick and accurate measuring of the required amounts of hemp, binder and water (see box below). As we keep reminding you, the required amounts vary depending on which binder you are using, so it's important to check with the supplier, and to mark fresh buckets for each job – don't just assume that old buckets are marked correctly: check them

Tips for measuring using buckets

First, measure the amounts using a plastic measuring jug and experiment with converting those values into equal amounts within a bucket – for example, rather than saying 'a bucket and a half' of binder in each mix, split the amount equally between two buckets, mark the level on each as the 'binder line' and say you need two of these.

You might find that the required amount fits neatly with the bucket size, for example 'three full (level) buckets of hemp' – in which case you don't need to mark the line.

Any colour of marker is hard to see on a black plastic bucket, so use buckets of a light colour, such as yellow or orange, and mark the lines in black pen. Remember to re-draw your lines if they are starting to wear off.

You can use the same buckets for the dry loose hemp and binder powder, with two different lines drawn, but keep separate buckets for water. Measuring binder and hemp in wet buckets results in lots of it sticking to the inside of the bucket, thus reducing accuracy.

Plastic buckets have a limited life: check them regularly for cracks and leaks, especially the water buckets. If they spring a leak, either bin them straight away or make them into a 'hemp-only' bucket, as hemp doesn't spill out through a crack or tiny hole. Write HEMP on them in big letters so there's no confusion!

for yourself, unless you *know* that exactly the same materials are being used.

To mix hempcrete properly in a bell mixer, it needs to be slightly wetter than for a pan mixer. Inform your binder supplier that you are using a bell mixer and tell them its capacity, and they will give you the exact ratios/amounts of ingredients required.

For our Hemp-LimeConstruct's imaginary 'HLC Binder' Example Mix (see page 199), the proportions are 4:1:1 (hemp:binder:water). But for a bell mixer the proportion of water needs to be slightly higher. When we adjust this for the size of the mixer we are using, for each mix we need:

50 litres of hemp + 12.5kg of 'HLC Binder'
+ 13 litres of water

Work out what your quantities equate to in terms of the particular buckets you have by using the measuring jug, and on the inside of buckets labelled clearly 'hemp', 'binder' and 'water', make a line in permanent marker.

In the case of our Hemp-LimeConstruct Example Mix we are using 15-litre buckets, so our 50 litres of hemp fits nicely into four buckets marked at 12.5 litres.

Method and mixing process

Choose your mixing site according to the factors already described for using a pan mixer (see page 196). Keep the mixing area clean and tidy, disposing of binder bags in such a way that they are not spreading binder dust around the site.

Ensure you have a good supply of materials close to the mixer. Empty several bales of hemp into the bulk bags for ease of access. Stick your hands in and shake the hemp about to loosen it up, as it is packed very tightly into the bales.

It's useful to have a large Gorilla Tub full of water set aside that you can quickly dip into when you need a bit of water for both wetting and cleaning the mixer.

Follow the supplier's instructions for mixing exactly, but in general the process of mixing is as follows (see also photos overleaf):

- Put on goggles and mask, waterproof clothing, gloves and waterproof boots.
- Pre-fill all your marked buckets with water, binder and hemp so that the precise amounts you need are already measured out before mixing begins.
- First, you need to wet the mixer, otherwise the (rather dry) mix has a tendency to cling to the sides and make thorough combining difficult. Dipping into your 'spare' tub, throw a bucket of water into the mixer, let it run a bit, and then empty it out.
- Carefully add all the measured-out water, and then all the binder, to the mixer, with it switched off to minimize the amount of dust that is released into the air. With the wheeled type of mixer you can set the mouth of the bell to face up to near-vertical to make adding the binder easier.
- Turn on the mixer, watching out for dust that escapes before the binder and water have mixed together (although *you* will have your mask on, warn any other people working nearby, who may wish to retreat to a safe distance).
- Once the water and binder have mixed to a consistent slurry, add the first bucket of hemp (about a quarter of the total), then the second, in fairly quick succession. Half of the total hemp is now in the mix, and your wet slurry will now be thickening, but is still quite liquid.
- Next, add the third bucket of hemp, and set the wheel on the mixer to the angle closest to horizontal at which it will mix without the contents falling out.

Mixing in a bell mixer: step by step

1. Measure out the ingredients.
2. Add the binder.
3. Add the hemp shiv.
4. Mix until well combined, but no longer.
5. Turn half-turns and clean the sides.
6. When the mix is ready, empty it into tubs.

- At this point, watch the mix as it turns, because it now becomes important not to leave the hempcrete mixing any longer than is necessary, otherwise it starts to form into balls, preventing an even mixing of the hemp and binder (see below).
- When the third quarter of hemp is evenly distributed, stop the mixer and reach in with a gloved hand to pull off any mix that is stuck to the back of the drum. Then start-stop it once to turn the bell through 180 degrees, and repeat the process.
- Start the mixer and add the last bucket of hemp. Watch it closely and don't let the mixer turn any more than it needs for all the hemp to blend in and become a consistent colour (approximately 1 minute).
- Stop the mixer and pull any mix off the back as before, then let it turn for a further 10 seconds.
- Stop the mixer. Your mix should now be ready.
- To test whether it is the correct consistency, use the ball-and-finger test described on page 200. You are trying to achieve a light fluffy mix, whilst avoiding the mix balling up (see also page 200). Balling up is best avoided by keeping the mixing time to the absolute minimum necessary. In a bell mixer a perfectly good mix will turn to balls if you leave it going too long. Keeping the mixer in the most horizontal position possible after you add the second half of the hemp also helps to prevent balling.
- If the consistency is not right, adjust it by adding a tiny bit more water or hemp *and* binder accordingly, turning the mixer only the absolute minimum for all the hemp to mix in consistently, as described above. If necessary, adjust the amount of water you will use for subsequent mixes (never adjust the ratios of binder to hemp).
- You may find that on hot dry days the loose hemp shiv is exceptionally dry and a little bit more water is required, but always stay conscious of the fact that you want to add only the very minimum of extra water to the mix, as every unnecessary litre you put in will increase the drying time of the finished wall.
- Sometimes, for no apparent reason, you get a mix that isn't combining as well as it should. If this happens, stop the mixer and thrash the hempcrete around with your hand a bit. Turn the mixer 180 degrees and do the same again. Let it turn a bit more, and repeat this step until the mix looks correct.
- When you have tipped your mix into Gorilla Tubs, throw some water in and clean the mixer out, so that you don't get bits drying on the side of the bell and affecting the success of the next batch.
- Any spilt bits of mix that are still 'clean' (uncontaminated) can be swept up and put back into the next mix, as long as the guidelines described on page 199 for using a pan mixer are followed.

The bell mixer method may sound a very long-winded and time-consuming way of mixing, but once you get the hang of it it's possible for one person to keep two mixers constantly running – as long as the materials are close to hand and you have a good pressure on your water supply. You can get into a rhythm so that while the mixer is turning you're filling buckets ready for the next batch. One mix takes about 5-10 minutes, and it is possible to mix around 2-2.5m^3 of hempcrete in a day.

The point noted on page 201 about finding a balance between the speed of mixing, ferrying and placing hempcrete, applies here. But suffice to say that if you have chosen to use a bell mixer, you have already decided that you are doing a job where large quantities of mix are not required quickly.

CHAPTER SIXTEEN

Placing hempcrete

The process of placing hempcrete is a deceptively simple one: while it is true that the basic method is straightforward, it does require some skill and an understanding of the important qualities of the finished cast hempcrete material. Moreover, it demands knowledge of the effects that differences in placing technique can have on these key qualities.

Before we look at the method itself, it is worth briefly discussing the principles involved, as a good understanding of these underpins successful technique.

Basic principles

When placing hempcrete, the aim should be:

- to fill the whole of each shuttered void evenly and consistently with hempcrete, with no gaps, and achieve a good proximity of the placed hempcrete to the frame timbers
- to achieve a consistent, low-density cast material: strong enough to hold its own shape, but trapping the maximum amount of air inside it to provide as much insulation as possible.

In order to achieve a consistent, low-density material *it is important to avoid over-compacting*. At Hemp-LimeConstruct we very rarely use a 'tamping stick' (or any other tool) to compact the hempcrete in the void, as we have found that this encourages people to over-compact it. This is because if your hand is not in contact with the hempcrete itself, you cannot feel how much it has been compacted.

There are two exceptions to this rule. A stick can be used if needed to extend your reach into an area of the void that is difficult or too far away to reach by hand. In this situation the stick should be used, as far as is possible, in a way that replicates the motion of your gloved hand. A stick is also used when tamping *is* required – which is usually in areas of thin coverage over frame timbers, where more compaction is needed to

Previous page: Placing freshly mixed hempcrete into shuttering.

The (in)famous tamping stick: never used unless *absolutely* necessary.

give increased structural integrity, at the cost of a little loss of insulation. A short length of roofing batten is generally used for this purpose, but occasionally a plate is screwed on to the bottom to create a tamping stick with a slightly wider area.

The density of the cast hempcrete is the key quality of the finished material, and can be thought of as a continuum, as illustrated in Figure 11 below.

The finished material should be closer to the 'low density' end of the continuum – achieving a high enough density that it will support its own weight, resist damage from things knocking against it, and carry the render and plaster finishes, while remaining as low density as possible in order to maximize insulation and minimize material cost.

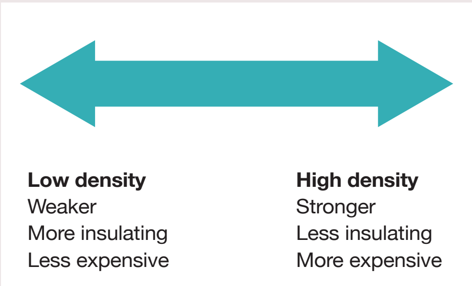


Figure 11. The density of cast hempcrete.

The density of the finished material is partly defined by the amount of binder in the mix, which varies depending on the application, for example floors, walls or roof insulation, with different ratios specified to achieve different densities for specific applications. Another factor that can affect the density is the amount of water: as described in the previous chapter, excess moisture in the mix can increase the density of the finished cast material.

Assuming the correct ratio of binder to hemp is used, and the mixing technique is good and hasn't allowed excess water to enter the mix, then the only thing that can affect the density of the finished material is placing technique.

Apart from density, the other important quality of the finished material is the open structure of the surface of the hempcrete wall. The flat surface formed by the shuttering board is covered with small pockets or openings formed by the individual interlocking pieces of hemp shiv in the mix. This open texture is useful for three reasons: it provides the ideal key for lime renders and plasters, it improves the breathability of the finished wall, and it speeds up the drying of the freshly cast hempcrete by connecting the outside air with the many small air-filled channels inside the cast material.

The degree to which the surface is open (lots of relatively large holes) or closed (fewer and smaller holes) depends on how much the hempcrete that lies against the shuttering is compacted during the placement process. More compaction at the edges means a less open structure.

The significance of this is that there is a balance to be struck: a very open surface, while desirable for quicker drying times and better breathability of the finished wall, will also swallow up a lot of basecoat when you come to apply the finishes. This can significantly increase the material and labour costs in the application of finishes.

In general, it is probably best to err on the side of the surface being more open than closed, since the benefits of shorter drying times and good breathability probably outweigh the extra expense in the finishes. However, it is important to keep this balance in mind when perfecting your technique, and to demonstrate to all members of the placing team what level of compaction is required at the edges, and explain the thinking behind it.

Occasionally a more closed finish is desirable, for example where you know in advance that the hempcrete is to be left bare internally as a feature wall. In this case a more closed-up surface is required to consolidate the surface of the wall, as this will not be achieved with plaster. In such cases the longer drying time resulting from the closed surface is not a problem, as there is no pressure for the wall to dry quickly so that finishes can be applied.

When consolidating the surface of a hempcrete wall, look for a good balance between an open and closed structure. This close-up shows a good consistent surface: not too open and not too closed.

To some extent, however carefully we describe it here, finding the correct placing technique necessary to achieve the correct density throughout the wall and the desired surface texture is a process of trial and error, and first-hand practical experience is essential.

When building with hempcrete for the first time, or with materials you have not used before, it is normal practice to construct a test panel to try out your placing technique and to review its success (see page 213). In this way any problems can be identified, and adjustments to technique made, before starting on the build proper.

Method

The placing of hempcrete is not an exact science, owing to the non-standardized nature of the plant-based aggregate and its low-tech method of application. Although it is by no means a difficult task, the success of the finished cast material depends on the level of experience of those placing the hempcrete.

Always keep in mind the relationship between compaction of the placed material and eventual density and insulation value. There is a risk, with inexperienced or over-enthusiastic workers, of over-tamping the hempcrete, resulting in a higher density. Not only does this mean a lower insulation value of the finished material but it also means increased material costs, as more hempcrete than necessary has been crammed into the void.

The challenge, especially with a large team, is to keep the density consistent across the build. A

Hempcrete is tipped into the shuttering in layers of 100-150mm.

The loose hempcrete is spread around evenly, and patted down.

Hempcrete when first tipped into the void.

finished wall that includes sections of differing densities is not as stable as a wall with a consistent density throughout. For this reason it is recommended that one person, or a very few experienced people, retain responsibility for training new workers and monitoring the consistency of the placing as the build progresses.

Basic method

While placing hempcrete is not as hazardous as mixing it, it is important to wear the appropriate personal protective equipment (PPE) – see Chapter 9. Ensure that, as a minimum, everyone is wearing long sleeves with a pair of chemical-resistant PVC gloves and a pair of latex gloves underneath to protect from any stray particles of lime-covered hemp finding their way inside the PVC gloves. Especially when placing for several days, encourage people to use barrier cream and moisturizer to avoid lime drying their skin out and then working its way into the cracks.

Before beginning to place hempcrete, check around to ensure that everything that needs to be fixed before the placing starts has been completed, for example natural drip details at the plinth (see Figure 14(b), page 246).

The basic method for placing hempcrete is as follows:

- Tip the contents of a tub of hempcrete into the shuttered void so that it forms a layer of loose hempcrete around 100-150mm deep but no more. Any deeper than this and it will be difficult to compact evenly and consistently, leading to loose or dense areas in the finished material.
- With a gloved hand, spread the mix out evenly to make sure it fills the whole void to the same level.
- Pay particular attention to any hard-to-reach areas, such as small corners around doors and windows and around horizontal frame timbers (see page 213).
- Consolidate areas around the frame timbers and against the shuttering using the tips of your gloved fingers, always bearing in mind the desired finish on the surface of the wall (see page 209). If using permanent shuttering, there is no need to consolidate the hempcrete next to these boards.
- Spread it evenly once more to ensure that the compaction is consistent, and check that the above areas are still well consolidated.
- For hard-to-reach areas you can use a stick, e.g. a length of roofing batten, as an extension of your hand, using the same method as with your hand. Apart from this instance, avoid using ‘tamping sticks’ generally, as this tends to encourage over-compaction.
- At external corners, and at window reveals, a little extra compaction of the hempcrete as you place it is a good idea, to give these vulnerable areas a little more strength in the set material, and thus maximum resistance to knocks and bumps.
- For certain applications – usually in solid-wall insulation or historic work – where a thinner section of cast material is being placed (e.g. 150-200mm), it may need to be tamped more firmly than usual to increase the strength of the material, but this should still be kept to a minimum. If you are casting that thin then you don’t really have much leeway for a reduction in thermal performance. If in doubt, experiment by casting a test panel at a low density, letting it dry for a week or two, and testing the strength of it.
- When placing hempcrete over any opening in the wall, the section immediately above the opening up to at least 300mm above it, and extending at least 300mm either side, needs casting in one go, so that a single cast-in-situ ‘lintel’ of hempcrete is formed. Where the opening is not formed by permanent shuttering then some sort of reinforcement needs casting into the hempcrete to support it while it dries, e.g. battens spanning the opening (see Figure 37, page 339).
- When you reach the top of a shuttering section where no hempcrete will be placed directly on top of it, e.g. a windowsill, over-fill this section so that the hempcrete sticks out of the top of the shuttering. This is necessary because the exposed section at the top can dry too quickly and become loose and friable. Over-filling allows the loose hempcrete to be cut off after it has dried (using an old saw or multi-tool), back to the solid stuff at the required level (see photo overleaf, bottom left).
- Ensure that the wet hempcrete mix is placed well before it has started to take its initial set. This is not usually a problem, unless using Prompt Natural Cement, which has quite a short window of workability – though this can be increased a certain amount through

the judicious use of Vicat's Tempo (citric acid) retardant (see page 46). If you use Prompt after it has started to go off, strong bonds are not formed in the cast material, leading to loose mix which can disintegrate when the shuttering is removed. (Thankfully such patches can be remedied if they don't extend too far: see page 214.)

- Although no manufacturer specifically recommends a maximum daily lift in their literature, it is much better as a general principle to move around the whole building to the same level before moving up again. This is so that the placed hempcrete has the maximum possible amount of time to begin setting before extra weight is placed on top of it. Unless your walls are very short, meaning that you would complete each lift very quickly, you are unlikely to have any difficulties in this regard. We have occasionally done lifts of 2 metres in a day without experiencing any problems.
- When a day's work does not take you to the end of a run of shuttering, it is important not to come to a 'sudden' stop. Vertical day joints are to be avoided, because they have the potential to weaken the cast material. Instead, slope the end of the placed hempcrete down gradually over several metres, so that a gentle slope is formed as the day joint, and build up from this the next day.

A section of shuttering filled with hempcrete.

Hempcrete is over-filled at windows and then cut back with a saw so there is solid hempcrete immediately under the window.

Hempcrete wall showing lines left by shuttering lifts, and a gently sloping day joint.

Bonding between lifts

The act of creating a bond or 'key' between lifts may be a necessary part of placing the hempcrete, or it may not be necessary at all. This depends partly on the design of the wall and partly on the materials being used. The procedure recommended by your material manufacturer or supplier should always be followed.

In the case of a central frame design, additional bonding measures are usually unnecessary, since the frame itself extends through the centre of all the individual lifts of hempcrete, tying them together.

With other frame designs, extra measures to ensure a good bond between lifts might include, for example, casting sections of batten sticking out of the top of a lift centrally at regular intervals, so that when the next lift is cast the batten ties the two together.

Other measures might include (especially with a fast-setting binder) wetting down the top of the previous lift with a spray, or painting it with a slurry of binder and water to control suction (the action by which a very dry surface can pull too much water out of a lime binder), and thus encourage good adhesion between the two layers.

Placing around horizontal frame sections

Where horizontal timbers form part of the frame, extra care needs to be taken to ensure complete and even placement of the hempcrete at a consistent density around and especially *under* these frame members. Because it is so hard to reach into the shuttering and shove the last bits of hempcrete under a horizontal timber, the tendency is for small sections to get missed, or for the hempcrete in these areas to be either too loose or over-compacted.

For this reason, wherever possible, horizontal timbers should be kept out of the frame design, but in certain circumstances, including the frame around windows, timbers for electricity sockets to fix to, and the extra horizontal battens used in an exposed frame design, it is unavoidable.

With an exposed frame design, horizontal battens as 'rails' are fixed to the upright studs at 600mm centres going up the frame. To make things easier, some hempcrete contractors recommend fixing these rails as the build progresses. Since the standard shuttering lift is also 600mm, the shuttering can be filled to the top, and a rail laid along the even flat top of the filled shuttering and fixed, then a new shuttering board is fixed and more hempcrete placed on top of and either side of the batten. This is a great idea, as it allows the easy placement of even density hempcrete all around the batten, and the horizontal batten doesn't get in the way as you are tipping the hempcrete into the shuttered void. However, on a large, busy build this may not be compatible with the way that the hempcrete casting has to fit in around other works. Whole-building runs of shuttering before another lift is started are not always possible in practice, and on a busy site the job of fixing the rail before the next lift of shuttering goes up sometimes gets forgotten. Since these rails provide such a vital function, you might decide it is safer to fix them all to the frame at the outset, before placing any of the hempcrete.

Reviewing the success of hempcrete placing

It is essential to review the success of your team's hempcrete placing, so that mistakes can be picked up early and adjustments made to the placing technique. This needs to be done after building a test panel, at the end of the first day's placing, and then again as necessary throughout the build.

When the first shuttering comes down, go along the wall and check for consistency and any tamping mistakes evident in the face of the wall. When training up a placing team, it can be helpful to have each person responsible for placing in a specific section of wall on the first day, so that when reviewing the success (or otherwise) the next day, you know who did which bit. Needless to say, this should be less about 'naming and shaming' than about knowing where to target your teaching and supervision on the second day of placing.

Look for the following errors visible on the surface of the wall:

- If the whole wall is too open, loose and crumbling, then it wasn't tamped enough.
- If it is too closed and dense everywhere then it has been over-tamped.
- If some layers are well tamped, but interspersed with loose layers, then too much mix has been poured in at one time. This means that when it was tamped down, the top of the layer was compressed but not the stuff underneath.
- If there are empty pockets, or unfilled hollows visible, then the mix has not been spread around evenly before tamping.

Gather your team around and show them the difference between different results, and make it clear what you are aiming to achieve. Ensure that everyone understands the issues relating to the closed versus open surface, render costs versus drying times, and breathability.

Occasionally, and especially with an inexperienced team, you may take the shuttering down to find that there are a few small areas where you can see empty holes on the surface that haven't been filled properly, or which are filled with very loose hempcrete. These areas have not been tamped properly, creating a very low density of finished material that will not be strong enough to support the render or plaster.

Any unfilled voids in the wall such as this, under the back boxes, can be filled in afterwards.

If this happens, resist the temptation to start picking at it straight away to remove the loose bits, otherwise there is a tendency to go on and on and end up scraping out a massive section of the freshly cast wall, as none of it is set hard at this point! (It's a bit like picking at a thread and unravelling the whole jumper.) Instead, it is best to do nothing for a week to ten days, to give the surrounding areas time to harden sufficiently that the loose stuff can be removed without taking out more than absolutely necessary. Fresh mix can then be placed into the hole and shuttered with a small section of board with something propped against it to hold it in place.

If there is only a small localized area of low-density hempcrete it may not actually need replacing, as it might eventually set firm enough to carry the plaster or render. It only needs taking out if it's so friable that it won't hold a finish. Test this, after ten days or so, by pushing firmly against it with the palm of your gloved hand. If it feels firm it's probably OK; if bits of it fall out, or come away stuck to the glove when you take your hand away, you need to scrape out the loose stuff and re-cast it.

Drying times

The moisture content in any natural breathable wall containing plant materials (timber, straw, hemp, etc.) will never be 'zero'. A certain amount of moisture is always present in natural materials as part of their cell structure, and this will vary slightly as the materials react to the relative humidity of the air inside and outside the building. We would expect a 'resting moisture content' (a natural equilibrium level, see below right) in a hempcrete wall, after drying, of around 14-16 per cent. This will vary slightly with changing levels of humidity next to the wall (caused by weather externally and human activity internally) – the fact that the moisture content changes dynamically demonstrates that you have a functioning breathable wall.

However, any significant and sustained increases in the moisture content, to levels of 20 per cent or above, brings the risk of deterioration of the hemp, despite the action of the lime as an anti-rotting agent. For this reason it is important to ensure the drying out of the water that was added to the hempcrete on being mixed.

The drying of a hempcrete wall is a separate process from the setting of the binder, which is a chemical reaction that happens in slightly different ways, and at different rates, depending on the constituents of the particular binder being used (as described in Chapters 3 and 6, binders might include air lime, hydraulic lime, natural cement or Portland cement in varying quantities).

The whole process has three distinct phases:

1. The binder achieves its 'initial set' in a relatively short time (usually overnight, but with Prompt Natural Cement this can be as little as 30 minutes), at which point the hempcrete is able to support its own weight, allowing the removal of temporary shuttering. The removal of the shuttering at the earliest opportunity opens up the surface of the wall so that drying can start (and allows the shuttering to be reused for the next section of wall).
2. The hardening of the binder's set continues over the next few days and weeks, rapidly at first and gradually slowing, until it has achieved its maximum compressive strength. The time taken to reach maximum strength depends on the type of binder used, and this information is supplied by individual manufacturers. In practice, though, this time is not critical since hempcrete is not a load-bearing material. It simply needs to be strong enough to hold its own weight, support finishes and resist damage.
3. Separately, but alongside this setting process, the water introduced to the mix needs to dry out of the cast wall.

It is important to note that this does not mean the wall becoming *completely* dry. Drying is 'complete' when the hempcrete wall reaches its natural equilibrium in terms of moisture content – around 15 per cent water content, but this will vary slightly with local humidity levels. The 'complete' drying out of a hempcrete wall usually takes several months, but the breathability of the wall and finishes means that this is a process that can be left to continue without any particular attention from the builder.

The type of binder used will affect the speed at which the wall dries out. Very hydraulic binders, such as natural cement, will quickly use up more of the water introduced in the mixing process as the binder sets, whereas binders that contain a combination of air lime and Portland cement rely on the slower process of carbonation to set the lime, and therefore there is potentially more water in the wall that needs to dry out.

The more important factor to consider, from a builder's point of view, is how much drying needs to happen before finishes can be applied.

Before it sets hard, hempcrete can easily be shaped using a nail float. Here the sharp corners are rounded off to give softer lines to the building.

The surface of hempcrete quite quickly forms a dry crust, and there is often scheduling pressure to apply finishes as soon as the wall 'looks' dry. This is especially the case with external renders, stemming from a wish to take down scaffolding at the earliest opportunity to reduce costs.

Although finishes for hempcrete are always breathable coatings, and must remain so in order for the wall to work properly, they do slow down the drying of water out of the wall once applied. This is because the finish covers up the open structure of the bare hempcrete, reducing ventilation to the surface. In the case of plasters and renders, the open structure of the hempcrete surface is closed up by the finish, reducing the overall surface area from which the water can evaporate. A cladding finish with a well-ventilated cavity allows faster drying of the hempcrete than does a standard render finish.

It is important that finishes are not applied too early, for two reasons:

- First, because the drying out process can be slowed significantly when there is still a very high water content in the wall, there is an increased risk of the hemp shiv rotting, although in reality this is probably a fairly unlikely outcome.
- Second, and much more likely, is the risk of staining on the plaster or render finishes (see Chapter 5, page 74). The reason for this is that tannins present in the hemp shiv can be carried through in water droplets and deposited on the surface of the render as the water in the wall evaporates. These unsightly stains can be painted out when the wall has dried sufficiently, but if the reason for rendering early was to reduce scaffolding costs, you will be disappointed to find that it is even more expensive to have scaffolding reinstalled so the walls can be painted again.

Render applied too early: dark patches show where liquid water is drying through the render.

When the surface has dried sufficiently, finishes can be applied.

The way to tell whether the wall is sufficiently dry for the application of finishes is to ensure that there is a consistent dry crust on the surface of the wall, to a depth of around 40mm. This indicates that the wall has dried to the extent that water is now reaching the surface of the wall only as moisture vapour, rather than liquid water droplets. Tannins only dissolve in liquid water; they are not carried by moisture vapour, so once this stage is reached you are safe to apply renders and plasters without the risk of staining.

The time taken for hempcrete walls to dry to this point varies depending on a number of factors: the type of binder used, the thickness of the wall cast, local weather conditions, good mixing technique (limiting the amount of water that goes into the mix) and good drying management once walls have been cast. The 'normal' time before finishes can be applied is around 6-8 weeks, depending on the binder used and of course on the thickness of the wall.

When planning the build schedule, 6-8 weeks after casting should be considered the earliest time at which finishes (especially wet finishes) can be applied to a wall of 300-350mm, *and only if local conditions are favourable and the correct mixing and placing techniques are followed*. Additional factors, such as the time of year and on-site management of drying (see Chapter 19, page 264), will also have a significant effect on drying times. For example, in particularly wet climates or at colder and wetter times of year, drying can take significantly longer. Sustained wet weather brings the double problem of it being harder to prevent excess water entering the wall during mixing and placing, and less-than-ideal drying conditions.

It is important to get accurate estimates of drying times for the specific binder you are using from your material manufacturer or supplier, based on the *exact thickness* of wall you are proposing to cast, since a quoted time of, say, 6-8 weeks for a 300mm wall does not automatically mean that a 400mm wall will take 8-11 weeks. In other words, increasing the thickness of a wall by a given amount can have a disproportionate effect on drying times; you can't assume that there is a linear relationship between the two.

Given the importance of drying times and their potential effect on the schedule of works, you really need to get as firm an idea as possible of the drying parameters right at the start of planning your build. In this way, sensible decisions can be made about material choice, and even about the thickness of walls, in the knowledge of how these will affect the project schedule. It is worth keeping in mind that drying times are not so critical with a cladding or rain screen finish, as the vented cavity will continue to bring air across the face of the hempcrete, and staining does not in any case affect a cladding finish.

Moisture readings

Judging the readiness of a hempcrete wall to take a finish is a decision best left to an experienced person, and if in any doubt, material manufacturers or suppliers will be able to offer guidance.

The judgement of readiness involves taking a number of dynamic factors into account, but to assist with this, the progress of hempcrete drying can be monitored using an electronic moisture meter of the type commonly used to test the moisture content of wood. This is appropriate for the material because, like hemp, timber is a

100mm probes allow testing at depth within the wall.

hard cellulose-based material. However, these devices are calibrated for timber, and are supplied with a table showing variances in the expected reading for different species of timber. This means the readings given don't necessarily bear a direct relation to the *actual* moisture content of

Moisture reading for a pretty dry hempcrete wall.

hemp, but they do provide a useful relative scale with which to monitor drying. The experimental calibration of such a moisture meter for hempcrete would be a valuable focus for future research.

The GE Sensing Protimeter shown in the photos opposite is particularly useful for hempcrete, having the option of longer sensing probes (bought separately) to extend the reach of the testing inside the surface of the wall (to a maximum depth of 100mm). It gives readings in WME (wood moisture equivalent), expressed as a percentage moisture content, and readings are also shown with a coloured light following a 'traffic light' system: red (up to 90 per cent WME), to amber to green. Green values are less than 16 per cent WME, which is the ideal moisture content for hempcrete. (While this may not show the exact percentage moisture content for hempcrete, for the reason described above, it is a good starting point from which to judge dryness – a skill that comes with experience.)

When taking a moisture reading, press the 100mm metal probes carefully into the wall to avoid snapping them, as they are quite narrow and fragile. Once inserted to the desired depth, leave the probes still for 5-10 seconds to allow the reading to 'settle'. Ensure that many readings are taken around the building, at varying depths below the surface and at different heights on the wall. Remember also to take several readings in each locality and compare them, since hempcrete is not a homogeneous material, and with the probe tips inside the wall you are not able to see whether they are in contact with hemp or binder, or sitting in an air pocket.

Unsurprisingly, it is common for walls with better exposure to prevailing winds to dry more quickly, and for the tops of walls to be drier, as the water will naturally run downwards within the hempcrete to a certain extent. Walls that have had recent driven rain may show an inaccurate reading on, or close to, the surface. However, even quite prolonged driven rain shouldn't penetrate far under the surface, and should evaporate quickly in dry weather, so sub-surface readings should still be accurate.

In the information provided to the authors on the use of their Tradical® HB binder,[1] Lime Technology suggest that the 'dry' crust needed before plasters or renders are applied is represented by achieving readings of 23 per cent WME or lower on the surface and up to 35-40mm below the surface, and we have found this to be a useful rule of thumb.

Finally, it is common practice, where both sides of a hempcrete wall are to have a wet finish applied, and if the contractor is not happy that the wall is sufficiently dried, to finish one side after 6-8 weeks and leave the other side 'open' for as long as possible. This can be a compromise in situations where there is pressure on the contractor to apply the render finish so that scaffolding can be removed. The render can be applied, and the inside face left open as long as necessary before plastering internally.

Conversely, on a single-storey build, it might make sense to apply the internal finishes and to start using (and heating) the building, then come back several weeks or even months later to apply the renders, as long as the bare hempcrete walls were not left exposed to extremes of weather (though a bit of rain won't matter). As a general principle, leaving hempcrete for as long as possible to dry out before finishes are applied can only be a good thing.

CHAPTER SEVENTEEN

Floors, ceilings and roof insulation

The previous two chapters describe the procedure for mixing and placing hempcrete for its 'normal' use: within the walls of a building. However, it is also possible to use cast-in-situ hempcrete in other applications: as insulation in a vapour-permeable or 'breathable' floor, in a ceiling, and as roof insulation. These applications are discussed here, with particular reference to how the methods differ from that for the standard walling application.

Floors

Hempcrete can be used as an insulating, vapour-permeable floor slab. Note, however, that breathable floor slabs are not suitable for areas in which a radon barrier is required in the floor slab.

Conventional floor construction involves the use of synthetic insulation products, such as stiff polyurethane boards, together with concrete, a plastic damp-proof membrane (DPM) and a cement screed to create a non-vapour-permeable floor. Synthetic insulations have high embodied energy, and carry the risk of off-gassing of toxic chemicals from the floor. Additionally, since it is not breathable, this type of floor can cause problems with the management of moisture in the ground immediately below the building. In particular, when retrofitted to old buildings that were originally built with a breathable floor and walls with no DPC, this modern floor construction can cause rising damp problems, as moisture which cannot rise through the floor is instead forced up the walls in more concentrated amounts. Often, the use of cement render externally and gypsum internally exacerbates the problem.

Previous page: Hempcrete floor, walls and ceiling make it easy to achieve airtightness around the whole thermal

In contrast, hempcrete floor insulation is a natural non-toxic material that acts as a carbon sink. Hempcrete insulation alone is not sufficient for a floor (without casting a prohibitively thick layer), but it is combined with other vapour-permeable materials to create a 'breathing' floor, which prevents moisture from building up in the ground immediately below the building. The advantage of combining hempcrete with another breathable insulation, as described below, is that it adds thermal mass, and so helps the floor act as a heat store. Additionally, a well-detailed hempcrete layer in a floor can form a continuous layer with the hempcrete walls, reducing potential areas for thermal bridging.

The vapour permeability of such a floor must always be maintained, through the continued use of breathable finishes. Otherwise there is a risk of moisture building up in the hempcrete layer, which in turn would carry a risk of eventual deterioration or failure.

Insulating sub-base layer

The hempcrete layer is cast on top of a free-draining, insulating sub-base layer. This replaces the use of a DPM, as it provides a layer through which water can only drain out, not rise up. It also provides a firm base on which to build. In addition, it provides extra insulation, which compensates for the reduced insulation value of the hempcrete. The hempcrete in a floor is less insulating because it needs to be of higher density (made with a more binder-rich mix) in order to be capable of supporting typical floor loads. The cast material is also thinner in a floor slab than is typical for walls, as there is not room for 300mm of hempcrete within the usual floor build-up. Furthermore, a reduced thickness of hempcrete is more practical for a floor, in that it minimizes the time needed for drying – since you are not waiting for excessive amounts of hempcrete to set.

The sub-base should be a material that allows no capillary movement between its particles, so that water can't 'wick up' through it. Of the products on the UK market currently, the most sustainable options available are coated expanded clay aggregate or a recycled glass foam aggregate. The thickness of the sub-base depends on the size and design of the floor, but is usually between 120mm and 200mm.

Hempcrete slab

The hempcrete slab provides the floor structure on top of the sub-base level. This is a higher-density mix than the hempcrete mix used for walls, for additional structural strength. The higher-density hempcrete is easier to mix, as the increased binder means it doesn't tend to ball up in the mixer as much as the standard wall mix (see Chapter 15, page 200). The process of placing the hempcrete is easier and quicker too, as you are spreading it on to the floor rather than placing it carefully in shuttering.

Because both the sub-base and the main structural layer are insulating materials, the total depth of the floor build-up for a hempcrete floor is usually less than is necessary for concrete floors, meaning that less excavation is required, which has the potential to reduce costs, energy consumption and material to be removed from site.

The thickness of the layers depends on the area of the floor (a larger floor may need a thicker slab) and the U-value you want to achieve, which depends on the type of ground you are on and whether you have perimeter insulation or not. A small extension floor, for example, might comprise 120mm sub-base and 80mm slab. A large new build might be made up of 150mm sub-base and 150mm slab.

Due to the potential problems associated with using an organic insulation material at ground level, suppliers and manufacturers usually specify their own details for a floor build-up, and these should be followed faithfully. All the available binders in the UK – Tradical®, Batichanvre® and Prompt Natural Cement – can be used to create insulating floor slabs, but Prompt has the advantage that you can walk on it after 20-30 minutes.

Our recommendation is that, when detailing a floor that includes a hempcrete slab, the hempcrete should be designed so that it is 'out of the ground', i.e. with the bottom of the hempcrete slab sitting above the outside ground level. In practice the self-draining sub-base layer will prevent water from building up in the slab, but if the design allows for it, placing the hempcrete above ground level is the most robust detail.

As much, if not more, than when casting walls, good drying management (see page 264) is essential when casting a hempcrete floor slab. It is important not to leave *anything* sitting on the floor while the hempcrete is drying. In contrast to walls, the hempcrete in a floor slab has open air on only one side of it, so most of the moisture has to dry out of the top of the slab, and it is therefore important that nothing impedes this. As with walls, it is useful to keep the windows and doors open as much as possible to maximize venting of the air outside the building. The use of a low-level fan to encourage movement of the air just above the floor can help. Once the hempcrete is strong enough, you can walk on it while it continues to dry, but remember not to leave things sitting on it that might slow the drying.

You will get some idea about when a hempcrete floor will be strong enough to walk on from the type of binder used, and the advice of the manufacturer, but each case should be considered in its own right. Ultimately, the best way of testing a floor is to gingerly try putting your weight on it. Expect this period of time to be longer than is normally required for the initial set, since a) a floor only has one side to dry to; and b) taking down shuttering on a wall and having it hold its own shape is very different from a floor taking the load of people walking on it.

Although good planning should aim to prevent this, inevitably it will sometimes be necessary to carry out further works in the room while the floor slab is drying, or before a protective floor finish has been applied. In this situation, it is advisable to temporarily cover the whole floor with a solid sheet material such as plywood or OSB to protect it effectively from dust, dropped tools and the like. However, if the floor is still in the drying stage, remember to remove the protective sheets again *as soon as the work is finished*, so that it can continue drying out.

A freshly cast hempcrete floor.

Underfloor heating can be included above the hempcrete slab, in the screed or mortar, depending on the desired floor finish. Again, all finishes for a hempcrete floor must be, and must *remain*, breathable (see next chapter).

Method

The basic steps for creating a breathable hempcrete floor are as follows:

- Excavate the floor area to the necessary depth, add hard core and level this out.
- Use a suitable-sized gravel to level out any significant dips in the hard core surface, to avoid having to fill them at the next stage with the (more expensive) insulating sub-base aggregate.
- Pour in the sub-base layer. This should be free-draining, non-capillary and insulating. It usually consists of loose particles of coated expanded clay aggregate, or recycled glass foam aggregate. This stage is easy work, as the aggregate is very lightweight.
- Ensuring that the appropriate PPE is worn, mix the hempcrete according to the manufacturer's specification for a floor, and place the hempcrete slab. The difficulty here is getting it level. Hempcrete doesn't spread out easily like concrete, as the particles of shiv give it a dry consistency. Draw a level line around the perimeter walls at the required height and use long levels or a laser level to guide you, as you work backwards towards an exit.
- For the hempcrete layer you are aiming for a 'generally flat' surface, not a completely smooth one. Any small bits sticking up are covered in the screed or mortar that is usually applied over it.
- Once the hempcrete has taken its initial set (overnight for most binders, or 30 minutes for Prompt), you can walk on it, but try to limit this as far as possible to light traffic for the first few days.
- Give the hempcrete plenty of time to dry out fully (see Chapter 16, page 215), and follow good drying management throughout this period to speed up the drying process as much as possible. Be particularly careful to not leave anything on the floor.
- Cover the floor temporarily to protect it if other works are being carried out.
- When the hempcrete is dry you can apply your chosen breathable finish (with integral underfloor heating if required). These include, for example, natural stone or clay tiles set in a breathable lime mortar, a limecrete polished screed, a compacted earth floor, loose-fitting timber boards, or an engineered timber floor with a vented air gap underneath (see next chapter).
- If the final finish will be a timber floor, then battens can be cast in the floor, flush with the surface, for the timber floor to fix into (as pictured on page 85). The inclusion of battens makes levelling the hempcrete slab a much simpler process: you can level the battens first, and then fill in around them with hempcrete. Since these battens provide the main fix for the floor above, they need to be wide rather than deep in order to spread the load (although in practice the floorboards will also bear directly on to the hempcrete). In the past we have used 80mm x 25mm garden decking boards to good effect, with the grooved side facing down to help with key against the hempcrete.

Ceilings and roof insulation

When cast around a reinforcing timber frame, hempcrete can be used to form ceilings and provide insulation at roof level. Although not widely used in this way in the UK, these applications are perfectly possible, and all of the binder products currently on the market are suitable for them, according to their manufacturers' technical specifications.

At Hemp-LimeConstruct we have successfully used cast-in-situ hempcrete for both roofs and ceilings, usually in situations where it was important to the client to keep the use of processed, high-embodied-energy materials to a minimum.

Ceilings

Cast hempcrete is suitable for ceilings inside either flat or pitched roofs, or between floors where there is cast-in-situ hempcrete insulation directly above the ceiling. Hempcrete ceilings are never cast independently of hempcrete insulation. Cast-in-situ hempcrete is rarely used for downstairs internal ceilings and insulation between floors, since the extra expense is prohibitive, unless increased acoustic or thermal insulation is required between different parts of the building.

In comparison with conventional ceiling boards, a cast-in-situ hempcrete ceiling has a number of advantages:

- It provides insulation.
- It reduces material costs.
- It reduces the number of different materials used in the building, thereby reducing the complexity of achieving airtightness.
- It has the same environmental advantages of hempcrete in other applications – being made from renewable materials with low embodied energy and relatively low transport costs. In contrast, conventional ceiling boards consist of highly processed materials, often come from abroad, and may include glues and sealants that contain VOCs.

Another advantage of using cast hempcrete in ceilings, as with other applications, is that it is an ideal background to plaster on to with lime or clay plasters, and provides a breathable ceiling which can help regulate humidity in the room. This is especially useful in bedrooms, where the

Erecting shuttering for a hempcrete ceiling.

Placing hempcrete in a ceiling.

majority of human-generated moisture is produced during the night, by the occupants breathing in their sleep.

The method for casting a ceiling out of hempcrete takes its inspiration from the mechanical structure of lath and plaster, with small-section timber battens acting as the 'laths', providing a key, and the hempcrete being in place of the basecoat plaster. This is illustrated in Figure 33, page 330. The basic method is as follows:

- Timber battens of 20mm x 35mm section or similar are fixed to the underside of the rafters or joists, running perpendicular to them at 150mm centres. These act as the key for the hempcrete and provide the structure and reinforcement of the ceiling.
- There are two options for shuttering the underside of the ceiling: you can fix OSB sheets directly to the battens, which leaves the battens showing in the surface when the shuttering is removed, or you can hang them underneath the battens by about 20-25mm, so that continuous hempcrete makes up the surface of the ceiling. Fixing shuttering direct to the battens makes placing the hempcrete easier, as you don't have to get it underneath the battens, but plastering is harder owing to the varying background. Conversely, if you hang the shuttering underneath the battens, it is harder to hempcrete but easier to plaster.
- Whether your battens are showing or not, it is recommended to use a fibre reinforcement mesh in your basecoat plaster, or a haired lime basecoat.
- If hanging the shuttering below the battens, rather than messing about with 25mm spacer tubes, use 50mm screws and a tape measure to hang the boards at the right distance below the battens, and double-check across the ceiling using a spirit level.
- Wearing the appropriate PPE, mix the hempcrete using the normal wall-mix ratio, according to the manufacturer's specification, and place it around the battens, working from above. Tamp it down fairly hard to ensure the total filling of all the small corners around the battens. This hard tamping is very important, since gravity makes it difficult to repair patches of loose or missing hemp in a ceiling once the shutters are removed.
- The well-tamped layer of hempcrete should be placed in one go across the whole ceiling, and should provide at least 25mm coverage above the battens.
- As soon as this layer is completed, mix the low-density roof insulation mix that will go above it, and place this all in one go across the whole ceiling as soon as possible, to encourage good bonding between the two layers.

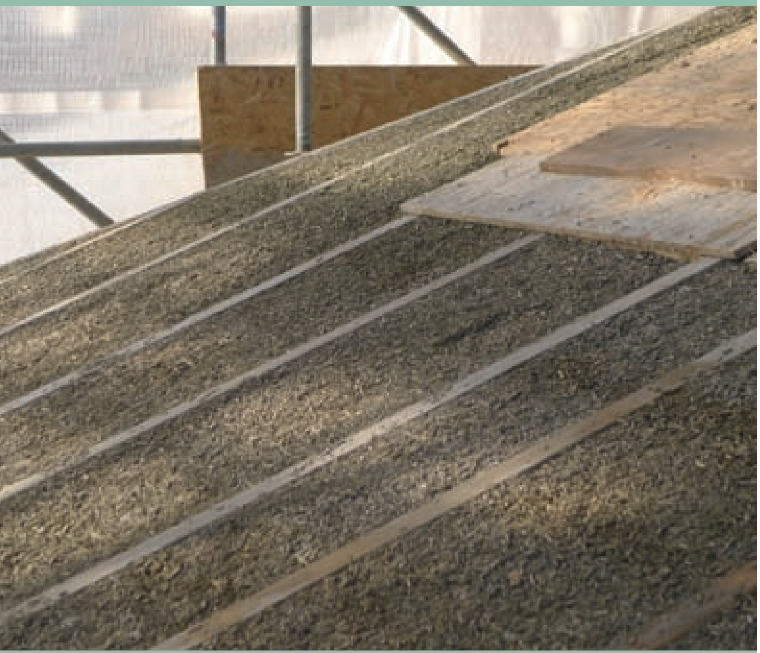
A freshly cast hempcrete ceiling with exposed battens.

- Leave the hempcrete for 50 per cent longer than normal to take its initial set (refer to the individual manufacturer's guidance) to make sure it has really gone off properly before the shuttering is removed.
- Remove the shuttering boards very gently. Remember to move the boards horizontally first before letting them drop, to break the contact with the hempcrete, which was tamped down hard on to them. By doing this you avoid pulling away any of the freshly cast hempcrete that might be sticking to the top of the boards.
- You now have your cast-in-situ ceiling. Follow good drying management (see page 264), and when the hempcrete has dried sufficiently, plaster finishes can be applied.

Roof insulation

Hempcrete roof insulation is cast between the rafters and is equally suitable for flat and pitched roofs. It is often used in new build but is not usually retrofitted to old buildings, as the thickness of hempcrete required necessitates deep rafters, and to increase the depth of the total roof build-up in an old building causes complications with either changing the roof height externally or losing height from the inside of the room, not to mention the increased load put on the original structure by extra roof timbers. Roof insulation hempcrete can be cast straight on top of a freshly cast hempcrete ceiling, creating a homogeneous ceiling–roof insulation slab. If you are not going to have a

Low-density hempcrete used as roof insulation.



Hempcrete roof insulation between rafters. 80mm wood-fibre sarking boards will be fixed on top of the rafters to provide airtightness and extra insulation and to stop cold bridging down the rafters.

cast hempcrete ceiling, then roof insulation is usually cast on top of permanent shuttering formed from a breathable carrier board, for example wood wool board. The depth of the cast slab will be defined by the thickness of the rafters – the hempcrete simply fills the space between them.

Cold bridging can be minimized by careful detailing of the rafters, such as by using battens and counter-battens, and airtightness over the top of the hempcrete insulation can be provided either by a vapour-permeable membrane or by the use of tongue-and-groove water-resistant vapour-permeable sarking boards, which have the advantage of adding extra insulation.

The hempcrete used for roof insulation is a very low-density mix, in order to minimize weight and maximize insulation. The mix has just enough binder to enable it to support its own weight and to protect it from rotting and insect infestation. It is not in any way load-bearing, so ensure that all loads, for example the weight of the roof covering, are placed on to timberwork.

The mix is prepared in exactly the same way as for normal walling hempcrete, but using less binder (refer to the individual manufacturer's guidelines).

The hempcrete is placed from above, before the roof covering is put on. When placing hempcrete for roof insulation you literally just need to *place* it into the space between the rafters. Make sure it fills the whole space, but don't pat it down or tamp it at all. This is because you are aiming to achieve a high air content (for better insulation), and since it is not carrying a finish it only needs enough structure to support itself.

For more information on cast-in-situ roof insulation, see Chapter 22, page 322.

A cascade of hempcrete roofs. Note the visible difference in density between the roofing hempcrete and the walling hempcrete.

CHAPTER EIGHTEEN

Finishes for hempcrete

Finishes applied to hempcrete floors, walls and ceilings, as to any other substrate, perform the function of consolidating the surface, protecting it from damage and preventing excessive moisture ingress. In addition, as readers who have not turned straight to this chapter will be aware by now, they must also remain 'breathable' – vapour permeable. In most cases the finish for hempcrete will be a lime-based render, plaster or screed, but there is also a range of other options, including a variety of natural cladding materials for the exterior or, less commonly, the interior.

In choosing exactly which finishes to use, and how to apply them, people without experience in using natural finishes are advised to stick to the advice of the hempcrete manufacturer or supplier when it comes to specifying and applying a finish. For those who are well versed in the use and performance of natural finishes, however, a wider choice exists. Hempcrete provides an ideal background over which to apply many different natural finishes. This chapter explores the peculiarities of hempcrete as a substrate compared with other common backgrounds, and describes how to apply an example finish appropriate to each building element.

The application of plaster and render finishes, especially when using lime and clay, is a skilled trade, and it is beyond the scope of this book to provide instruction in all the techniques necessary to achieve a fine finish with these materials. Nor is it possible here to give in-depth information about all the other possible finishes for hempcrete and how to apply them; instead, we aim to list appropriate finishes and describe any specific adjustments required by the hempcrete substrate. We strongly advise further research in this area for anyone building, specifying or designing with hempcrete.

For those who wish to learn more about a range of natural finishes, including lime and clay, we heartily recommend *Using Natural Finishes: A step-by-step guide* by Adam Weismann and Katy

Previous page: This oak staircase, made from reclaimed beams, complements the soft lines of the hempcrete walls.

Bryce, and for a more in-depth introduction to the techniques involved in building with lime, including plasters and renders, we suggest *Building with Lime: A practical introduction* by Stafford Holmes and Michael Wingate. Information on a range of natural paints and other finishes, including some DIY recipes, is given in *The Natural Paint Book* by Lynn Edwards and Julia Lawless (see Bibliography for details of all three publications). This is by no means an exhaustive list of the literature on natural finishes, and many other useful sources can be found, both in print and online.

As noted in Chapter 5, the application techniques and knowledge required for lime plasters differ significantly from those used in gypsum plastering, which is the more commonly used finish in conventional construction. Employing a gypsum plasterer to apply lime finishes to your building is advisable only if they have specifically gained skills in both techniques. If you are not sure, ask to see examples of their lime work.

Self-builders may be interested to note that:

- Training courses in the basics of lime plastering are now to be found all over the UK. These are usually taught by local craftsmen, and often hosted by local colleges or organizations, as part of a programme of sustainable or heritage building skills.
- People who have never done any gypsum plastering work often find it easier to pick up the techniques involved in lime plastering, as they are not having to 'unlearn' gypsum techniques.
- Although the application of fine finishes using lime is a skilled business, a 'rougher' finish can also be attractive, and performs just the same function. Self-builders may decide that they are happy enough with such a finish and prefer to teach themselves the necessary skills rather than going to the expense of hiring a specialist lime plasterer.

A 'rough' lime plaster applied by a novice can still be an attractive finish.

Finishes for hempcrete walls can be divided into two broad categories: wet-applied finishes and cladding. The majority of this chapter is devoted to wet-applied finishes, while cladding and also floor finishes are outlined at the end.

For simplicity, and since the application methods are more or less identical, the term 'plaster' is used throughout this chapter to describe both plaster and render finishes. The exceptions are 'clay plaster', which is not usually suitable for an external finish, and specific references to render.

Wet-applied finishes

You might think that the choice of finishes for hempcrete walls would be restricted by the requirement that they be vapour permeable, but in fact there are many lime, clay and earth finishes available. Many exist as proprietary products, and some of these are specified for use on hempcrete by binder manufacturers.

For the more experienced, or more adventurous, there are also many different types of lime, clay and earth available as 'raw' materials, which can be used as a base from which to create your own plasters. Extra strength can be added to plaster finishes in the form of hemp shiv, fines (small pieces of shiv and bast fibre), chopped straw or commercially available meshes. Different-sized aggregate can be used to create different textures. You can colour your finish using carefully selected aggregates or by adding natural pigments.

Finishes can be applied using different tools to create different aesthetic effects and to change their performance in the management of rainwater. They can be applied by hand, or spray applied and finished by hand. Once on the wall they can be scraped with metal trowels, rubbed with floats (sponge, rubber or wooden) or polished with steel trowels or stones to give different surfaces and effects. There are many different options.

Proprietary products come in a range of colours, finishes and textures. They tend to be a lot more expensive to buy than the raw ingredients, but they do offer one distinct advantage for self-builders and contractors new to lime: in contrast to natural finishes in general, many of them have been designed to be relatively simple to apply, and come with precise instructions. When these instructions are followed, they usually behave quite predictably with regard to application method, performance and drying time. There is also no requirement for specialist knowledge in specifying and mixing the raw ingredients – you usually just need to add the specified amount of water, and mix.

If using permanent shuttering, which is constructed from a breathable plaster carrier board, the finish required for these will be different from that for direct application to hempcrete, as the boards have joints and fixings to cover. You will probably be able to purchase suitable carrier boards from your lime supplier, especially if using a wood wool board or similar. The supplier will recommend a preferred breathable plaster

Coloured breathable render at The Triangle, Swindon.

system for use on these boards, usually including a basecoat with reinforcing mesh, and a topcoat. Where specified, these systems should be followed; for boards where no system is specified, the example basic plaster system shown in the table on page 237 can be used, with the addition of reinforcing mesh (see page 242).

Becoming adept in the use of wet natural finishes, to the point where you are able to specify and apply them and adapt their use for all types of substrates and in different circumstances, requires specialist training and years of practice. However, gaining enough knowledge to mix and use your own basic lime or clay plasters is not difficult, and there is lots of help available, not least from your lime supplier.

Never underestimate the value of a good relationship with your supplier of lime and other natural building products. If you plan to do a lot of this type of work, it's worth putting some time and effort into this relationship. Don't just buy your materials from whoever is cheapest that week; choose your supplier in terms of their locality, the types of materials in which they specialize, and above all their knowledge of what they are selling – and then stick with them. If you help them, they will help you, and you are likely to need their support. Some suppliers offer training courses. In some cases they may produce their own proprietary plasters and will be able to advise you on specification, taking into account your level of experience and skill, and the job at hand.

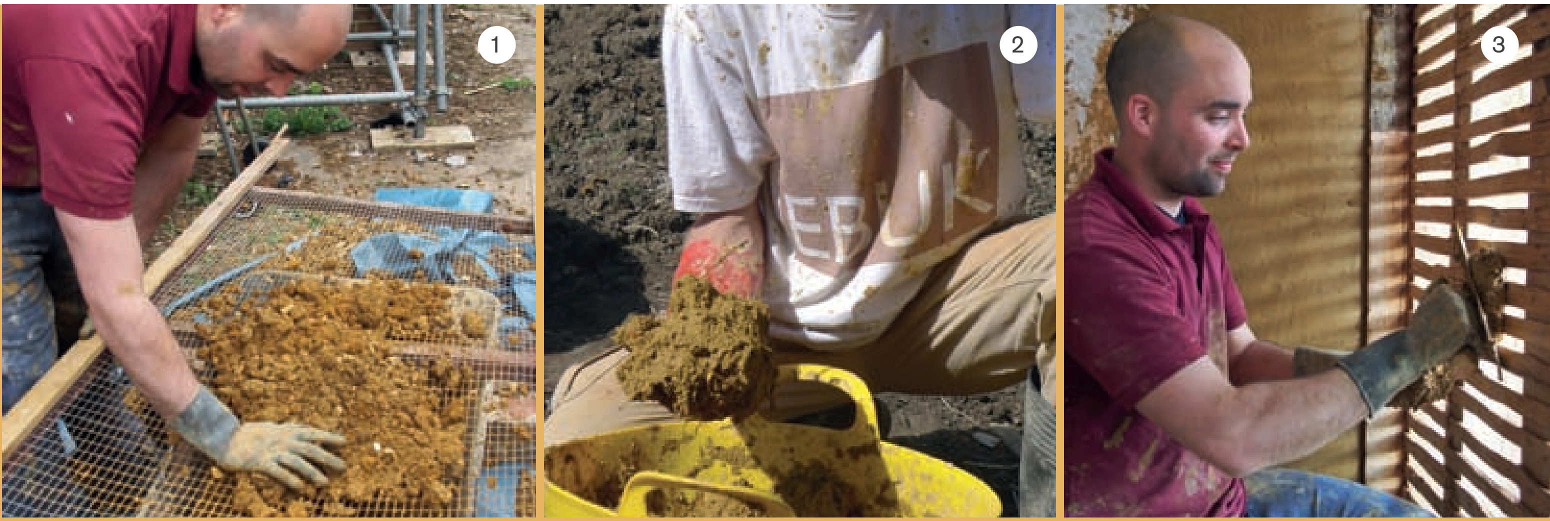
Whether you choose to mix your own plasters or buy proprietary products, it is important that your supplier knows that hempcrete is the substrate, and understands what it is. If using a proprietary mix, check that it is suitable for use on hempcrete; if mixing your own, ensure that you are using a well-graded aggregate (with a range of particle sizes) for maximum vapour permeability, and, in the case of a lime finish, that it is of suitable type for the application. The easiest way to ensure the quality of the aggregate is to buy it direct from specialist heritage or natural building suppliers, who normally stock a range of types of sand and other aggregates and can discuss your specific requirements with you. Bags of lime (usually only NHL 3.5) can sometimes be found in, or at least ordered through, your local builders' merchants, but the staff team in these shops are unlikely to have personal experience of using lime or be able to give advice, or at least reliable advice, about it.

Thankfully, lime plasters and mortars and other breathable building materials are available from a growing number of specialist suppliers around the UK (see Resources for some examples). The market for these suppliers was initially builders involved in specialist heritage building restoration, but over recent years the market has expanded to include customers interested in low-impact, sustainable construction.

Many new suppliers have emerged to supply this market, and existing suppliers have developed their business in this direction. As a result, today you will find some suppliers who focus more on traditional building; some on sustainable building; and, increasingly, some who straddle both markets. Which type of supplier you choose may depend on the focus of your particular project, since hempcrete is as likely to be used in historic refurbishment as sustainable new build. The important thing is that you find a supplier with whom you get along, and that you feel confident that they know their stuff when it comes to the materials you want to use in your project.

Clay finishes

With its excellent moisture buffering qualities and high thermal mass, clay is the natural choice (excuse the pun) as a finish to complement a hempcrete wall internally. Usually clay is not



Self-made earth plasters are the ultimate sustainable finish

1. Clay dug from the garden is sieved to remove stones.
2. It is then mixed with water, straw and a little lime.
3. Here the finished clay plaster is applied in the restoration of a listed building.

suitable for external wall applications, since it deteriorates quickly on exposure to the elements. Occasionally, people have used clay to finish a very sheltered outside wall, but this is very much the exception rather than the norm.

Clay may potentially have a much lower carbon footprint than finishes based on lime, since building limes are produced by burning limestone in a kiln (a high-energy process). Clay is a common, easily accessible, naturally occurring subsoil found all over the UK and indeed the world, and has been used for a finish for the walls of earth, timber and stone buildings for centuries. Clay plasters made on-site from raw materials dug from clay deposits nearby (as illustrated in the photos above) boast virtually unbeatable sustainability criteria. If a suitable clay is found on your plot, your finishes could even be made from the subsoil excavated when foundations are dug. Weismann and Bryce give more information on how to make and use clay plasters in *Using Natural Finishes.*

Clay is a material that takes up a lot of moisture in conditions of high relative humidity, releasing it again when the humidity level drops. This makes clay plasters eminently suitable for a finish over hempcrete or timber on internal walls, since the clay will also help to suck any excess moisture out of the hempcrete wall and release it into the atmosphere.

Lime finishes

Lime finishes can be used internally and externally, and share the ability of clay, although to a lesser extent, to buffer moisture in response to changes in the indoor humidity. They have advantages over clay in terms of cost and convenience of application. Lime finishes are particularly suitable for use externally, since the re-carbonation of the building lime gives them a hard finish that withstands weathering while retaining the all-important property of being vapour permeable.

Lime plaster in a new-build hempcrete house.

Lime finishes, especially those based on air limes or feebly hydraulic limes, have a unique ability to reseal small cracks in their surface, should any appear. This is due to the presence of free lime (lime within the render that has not fully carbonated – see Chapter 3). These particles of lime are free to move around in the render, and when it rains, are deposited in the crack and then carbonate on exposure to air, sealing up the surface again.

More detailed information on lime plasters and renders is given in *Building with Lime: A practical introduction* and *Using Natural Finishes.*

Plastering on to hempcrete

Cast hempcrete formed with shuttering is the perfect background on which to apply plaster, since, if constructed properly, it has the following attributes:

- It is very flat, making the process of applying finishes easier, and keeping costs of (potentially expensive) finishes to a minimum.
- It provides a very consistent surface across the whole of the wall, which again makes the application of finishes much simpler.
- Its open-textured surface provides an excellent key.

This last reason makes cast hempcrete a particularly suitable base for lime finishes, as these require a good strong key. The most commonly used finish for a hempcrete wall is therefore a simple two-coat lime plaster. As described earlier, advice on the most suitable finish to use should be sought from your hempcrete binder and/or natural building materials supplier (depending on whether you are plastering direct on to hempcrete or on to a carrier board), but the following example describes the general method for applying a basic lime plaster to hempcrete and wood wool board.

If plastering on to a cast hempcrete ceiling, a glass-fibre reinforcing mesh is required (see page 243).

When plastering with lime, the absolute minimum ambient temperature required is 5°C, but effectively the working temperature range is between 8°C and 22°C; below (or above) which the plaster dries too slowly (or too quickly).

You will need the following tools and equipment:

- A standard **bell cement mixer.**
- Clean buckets in a range of sizes: **standard buckets** for measuring materials; **large buckets** or **Gorilla Tubs** for transporting and storing mixed plaster.
- A **plasterer's bath** may be useful for storing large amounts of mixed material.
- Plastering trowels: **steel laying-on trowel** of a size you are comfortable with, and a variety of **margin trowels, corner trowels** as required, and a **bucket trowel.**
- **Foam rubber floats**, of coarse and fine grades, and a **wooden float** or **metal grid float.**
- **Plasterer's hawk.**
- **Water sprayer:** the standard pump-action


Tools for plastering.

pressurized garden type. The more expensive heavy-duty ones are best. They all break, but heavy-duty ones last a lot longer, and spare parts are available, so you don't always have to throw the whole thing away because the trigger mechanism has stopped working.

- **Large car-cleaning sponge.**
- **PPE:** waterproof gloves, dust masks to the relevant standard, goggles and a first aid kit with eye wash and a mirror (see Chapter 9).

The mix ratios, aggregate sizes and coat thicknesses for basic lime plaster and render are set out in the tables below.

The mixing method is as follows:

- Wear appropriate PPE and follow safe working practices for mixing lime plasters (see Chapter 9).
- Mix only a small amount of plaster to start with, until you get used to how quickly you are using it up. As your technique improves and you use it up faster, you can double the amount you mix at a time.

Plaster

	Mix ratio	Aggregate size	Thickness of coat
Basecoat	5:2	0-2mm sand	Up to 6mm (or less, as necessary to achieve an even surface)
Topcoat	2:1	Silver sand or silica sand	1-2mm

Render

	Mix ratio	Aggregate size	Thickness of coat
Basecoat	5:2	0-4mm sand	10-12mm
Topcoat	5:2 (use 3:1 if you want to see more of the sand colour in the topcoat)	0-4mm sand (or 0-2mm for a smoother finish)	8-10mm (for 0-4mm sand) 4-6mm (for 0-2mm sand)

- Measure out the lime and aggregate into buckets, e.g. 1 bucket of lime and 2.5 buckets of coarse sand for the basecoat.
- Tip both dry ingredients into the mixer and start it turning.
- Leave it mixing for 5-10 minutes, as this gives the mix a more even consistency.
- Add water little by little until the mix is rolling around the mixer nicely and resembles a very thick cream. When you pull some out on your trowel it should stick to the trowel blade when held vertically. The water takes a while to dissipate through the mix, so adding it slowly prevents you ending up with a very wet mix.
- Leave it mixing for at least 20 minutes, and leave it to rest in the mixer for 10-20 minutes before use. Double-check the consistency when you come to use it, as it may have dried out a little and you might need to add a bit more water.
- When it is ready, tip the mix into a bucket, making sure you have your goggles on, as it can splash.

Pick a 'learning wall' to start off with, for example the garage or toilet, where a perfect finish might be less important. Before you start mixing, make sure your wall and immediate area are prepared for plastering:

- Remove any debris or clutter from the floor in the vicinity around the wall, to make sure you have room to work.
- Make sure there are no raised areas of hempcrete, such as where it has stuck out through a join in the shuttering, or at the corners of the wall or where it butts up to exposed timbers. If there are, cut or scratch them back flat to the wall with a multi-tool or nail float.
- Likewise, make sure that any repairs (filling in) to the hempcrete are flush with the wall; if not, cut or scratch them back flat.
- Wet the wall down with clean water using the pressure sprayer (see box on page 242).

'Knocking up' a manageable amount of plaster on the hawk (by pushing it back and forth with a trowel until it forms a single consistent lump).

Using a laying-on trowel to apply the plaster.

For applying the basecoat:

- Wear the correct PPE for application of plaster (see Chapter 9).
- Load your hawk with a comfortable amount of plaster, and knock this into a consistent lump of plaster using your laying-on trowel.
- Transfer the amount you need on to your trowel, and apply the plaster to the wall with an upward motion. The trowel should be held at about a 45-degree angle to the wall at the

start of the stroke; as the stroke continues, turn the trowel in towards the wall (with the blade closer to vertical) to dispense the plaster.

- Every so often, intersperse upward strokes with horizontal ones but without any plaster on the trowel. This allows the stiff edge of your trowel to check for flatness in both planes. Any lines or dips in the plaster become apparent after the horizontal stroke. You may need to trowel out high points, or fill in dips, but don't play around with it too much as you will make it worse. You are better off practising your laying-on technique than playing around with plaster once it is on the wall.
- To fill in a dip, take a small amount of plaster on the corner of your trowel and apply it to the low area before smoothing it over with a trowel stroke.
- The aim should be to achieve a generally flat surface. However, any small lines or ridges in the plaster created by the edges of the trowel are irrelevant at this stage, as are any minor dips and high points, as these will be taken out later with the float.
- Once you have applied the plaster over the whole wall, leave it to firm up before coming back to float the surface.
- Leave a small amount of plaster in your bucket covered with a damp cloth, which you will use when you come to float the surface.
- You are waiting for the surface to set just hard enough to rub back with a foam rubber float to give a grainy texture. You don't want the plaster to set so hard that this becomes difficult to do. The time taken for plaster to firm up depends on the ambient temperature, and how dry the hempcrete was when you applied the plaster. At 8ºC on quite a 'green' (not fully dry) wall this could take 24 hours; at 16ºC on a dry wall it could be 30 minutes.
- To test its readiness for floating, return to the wall intermittently and press the plaster with a finger: if this doesn't leave a print, the wall might be ready. Try rubbing your float (a coarse rubber float for basecoat) tentatively on the surface in circular motions. If it begins to give the surface a texture like coarse sandpaper, without moving the plaster on its background or leaving deep lines, then it is ready.
- You will find that floating the surface is all in the timing. If it takes a lot of effort to create the desired surface, then you have left it too long. If this happens, you can wet the wall down with the sprayer and try again, or use a hard plastic or wooden float. Once you have 'got to' one wall at the ideal time, then you should be able to gauge the drying time for the rest of the walls, as it should be similar.
- Continue rubbing the surface in a circular motion, keep your float vertical and parallel to the wall at all times (i.e. don't dig the corners in).
- You are trying to achieve an even and rough texture across the whole wall.
- Where there are any high points or lines left by your laying-on trowel, you should be able to take these off using the float.
- Any low points (dips) will become apparent, as the rubber float will not come into contact with them and so won't roughen the surface. You can easily fill these dips by adding some of the plaster you kept in the bucket to your rubber float and applying it to the dip, continuing your circular motion.
- Leave the wall for around six days before attempting the topcoat.

When applying a *render* basecoat, the rough surface alone is not sufficient to provide a key for the topcoat, which is thicker and heavier than a plaster topcoat. Therefore, after rubbing back with the float, the surface of the basecoat is scratched with either a three-pronged scratcher made from pieces of lath, a comb scratcher or a devil float, to provide a better key.

For mixing and applying the topcoat:

- Use the same mixing method as for the

Gradually angle the trowel towards the wall to apply all of the plaster.

The right timing is crucial when rubbing back the plaster to achieve a finish.

Rubbing back lime plaster

There are important reasons for rubbing the plaster back with a float. When the plaster is laid on the wall, the action of the trowel pushes the aggregate into the plaster, leaving a fine, smooth layer of set lime and water, which is less vapour permeable as it contains very little aggregate. The rubbing action removes this thin layer, 'opening up' the surface and exposing the aggregate just below it, leaving a surface with lots of tiny bumps caused by the particles of sand.

In the basecoat, this has the effect of:

- increasing the total surface area for quicker and more consistent drying of the plaster
- providing a better key for the topcoat
- improving vapour permeability between the coats.

Also, in the topcoat, the rubbing action gives an attractive and consistent texture to the plaster.

Depending on the aesthetic effect desired, floats made from different materials and/or different techniques can be used.

basecoat, but using the correct ratio and aggregate for topcoat.

- Wet the wall down with the sprayer until it stops taking water in (see box on page 242).
- Apply the topcoat using the method described as for the basecoat, and rub it back with a fine rubber float instead of a coarse one.
- Once it is rubbed back, go over it with a damp sponge (the big yellow car-cleaning type) in the same circular motion you used with the rubber float. This removes loose aggregate and gives a smoother surface.

When applying a *render* topcoat, a smooth surface is less desirable, since the increased surface area given by a rougher finish allows quicker evaporation of any water that soaks into the render after heavy rain. This can be achieved by floating the surface with a wooden float or a metal grid float, or scraping the edge of a metal trowel across the surface. These techniques will also give a more consistent colour to the surface of the render, as the aggregate is more evenly distributed on the surface.

Basecoat render scratched up ready for the topcoat to be applied.

Lime plaster and an oak frame in a new-build hempcrete house.

Wetting down hempcrete to ensure the correct level of suction (see box overleaf) before applying a basecoat plaster.

Suction

Any surface on to which a wet finish is applied (the substrate) will have a certain amount of 'suction', i.e. it will suck water out of the wet finish. Suction varies with different types of substrate, and also with different levels of moisture content present in the substrate.

This sucking action is a key factor in how the plaster adheres to the wall, and it is important to have control over it, since either too much or too little can cause problems for the lime plasterer. Very high suction (from a dry substrate) can draw too much water from the plaster and not leave enough to set it, causing the plaster to fail. Too little suction (from an over-wet substrate) can result in the plaster not adhering to the background, and slumping or falling off the wall.

To control the suction, you must spray the wall with water before plastering. Knowing how much water to apply comes with experience, but the following approach is a good rule of thumb.

Before plastering a panel, give the whole area (several square metres) a thorough wetting with a fine-pressure spray, until water starts to run off the surface. As you apply the plaster, watch out for any areas drying out again and give them a quick spray as required.

The amount of spraying a hempcrete wall will need depends on how dry the hempcrete is, which is affected by the length of time since it was cast and by current environmental conditions. A fresh, or 'green', wall that is only just ready for finishes may only need wetting down once, since there is a relatively high moisture content still under the dry crust. A wall that has been left for several months will be very dry, and likely to need more wetting as you go along.

Sometimes, despite wetting down the basecoat, a very high level of suction is experienced when applying the topcoat (this happens on basecoats that have a very dry substrate behind them). A technique for controlling suction in this situation is to apply the topcoat in two passes. The first skim of half the topcoat serves to control the suction, and then the top half can be more easily applied. This is easier than wrestling with a high-suction background and trying to apply the finish in one pass.

Plastering on to wood wool board

The open structure of wood wool board provides the ideal key for lime and clay plasters. Basecoat and topcoat plasters are applied in the same way as to hempcrete; the only difference is that an alkali-resistant reinforcing mesh is required within the basecoat (see opposite).

If there are any movements or other stresses in the timber frame, these always have the potential to cause movement cracks at weak points in the plastering. When using a permanent shuttering board, the joins where two boards meet creates just such a weak spot. The inclusion of the mesh mitigates the risk of cracking along these joins.

If using a proprietary, or other specific, lime plaster which a supplier recommends as being suitable for the particular board you are using, you need to make sure that it is sufficiently vapour permeable to act as the finish on a hempcrete wall. In practical terms, this usually means that the lime in the plaster should be no stronger than a feebly hydraulic lime such as NHL 2.

Reinforcing mesh

Alkali-resistant glass-fibre mesh can be bought in rolls, usually 1m wide by 50m long, and is available in various mesh sizes. The size of the openings should be larger than the largest aggregate in your plaster by at least 2mm. For example, if using a 0-4mm aggregate in the basecoat, you will need a mesh with openings of minimum 6mm.

Rubbing glass-fibre mesh into the basecoat.

Mesh sunk into basecoat plaster.

To apply the reinforcing mesh:

- Cut pieces of mesh of the required size off the roll – enough to cover the whole surface being plastered – before you begin plastering.
- Apply the basecoat plaster to approximately half the total desired thickness.
- Stick the mesh to the wall by holding it in place (often easier with two people) and smoothing it with your gloved hand into the wet plaster.
- The mesh should readily stick to the plaster, but if it looks a bit loose, rub it with a gloved hand so that it sinks into the basecoat a little.
- When all the mesh is in place, apply the rest of the basecoat over it.
- If the total area of the panel needs more than a single piece of mesh to cover it, overlap the mesh pieces by at least 50mm to avoid creating a weak point where the two meet.

Pieces of mesh can also be used in the plaster at the usual stress points, for example at the corners of window openings (see Figure 12), and where different substrates meet, such as at a cross-over between hempcrete and wood wool board. The

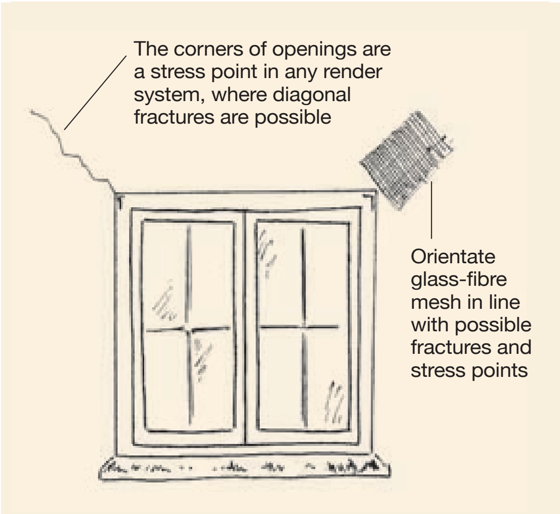


Figure 12. The correct orientation of mesh at stress points.

orientation of the mesh is important and should follow the line of the expected stress fracture.

Beads and other details

Plastering beads or alternative details are used for various reasons: to reinforce the plaster or render finish where required, to seal the finish to other surfaces, and to create 'drips' to shed water away from the building.

Natural plasters and renders are softer and more flexible than modern cement-based renders and gypsum plasters, and are able to move slightly with the substrate. For this reason, anything that is included within them should also be able to tolerate movement. If very stiff beads were used, this could cause local stresses and potentially lead to cracking of the plaster. Highly flexible glass-fibre mesh beads are widely available, and these are suitable for use within natural finishes. As with reinforcing mesh, it is important when using these to make sure the openings in the mesh are larger than your aggregate (see previous page). There are also some natural alternatives to synthetic beads, which work just as well (see Figures 13 and 14, opposite and on page 246).

Corner reinforcement

Protruding corners (both internal and external) require reinforcement, since they are vulnerable to knocks. This can be achieved with purpose-made corner beads, usually of stainless steel or PVC with 'wings' of glass-fibre mesh to locate the bead and attach it into the plaster. Some of these are designed to be completely concealed under the topcoat, which means you don't see the plastic or steel running down the corner. Mesh wing corner beads are sometimes supplied on a roll, folded down the middle. This reduces waste, as you can cut it to the length you require, and the pre-folded corner means you can open this out to any angle you want. This kind of flexible bead is useful for hempcrete, as you are likely to have angled window reveals, requiring corner beads at an angle greater than 90 degrees.

A simple alternative to including these synthetic or highly processed products is to design out sharp corners. Hempcrete, once cast, can easily have its corners rounded off with a nail float. You can create curves with radiuses ranging from small right up to half the width of a wall (keeping in mind where the frame sits, and making sure you don't accidently expose it). The wider the curve, the stronger it will be, but even a small curve of, for example, 25mm radius will withstand knocks. It is also possible to create curves at the corner when using wood wool board as permanent internal shuttering. The board is 25mm thick, so a 25mm radius can easily be achieved using a multi-tool with an oscillating cutting blade.

Another solution is to use an exposed timber at the corner: if done decoratively in a nice hard-wood, this could provide an attractive feature. This approach could be employed in high-use areas such as corridors (where more frequent knocks are expected) or in commercial premises where heavy knocks are expected.

Curved corners and window reveals eliminate the need for corner beads in the plaster.

Sealing beads

Seals are required to tightly connect the render to window frames and other elements in order to prevent water ingress and improve airtightness.

This can be achieved with a render stop bead, again made from stainless steel or PVC and glass-fibre mesh, and a sealant. The mesh is rendered into the basecoat and stops the render shrinking away from the PVC bead. The bead is then sealed to the window frame and the underside of the windowsill with an appropriate sealant.

Window frame seal beads come with expandable sticky tape ready attached, and also a guard to stop you scratching the frame with your trowel. The bead is stuck to the frame prior to rendering, which makes it very easy to accurately line it up with the window. The guard is either ripped off and taped to the frame (it too has sticky tape attached) or left attached to the bead and ripped off after the render has set. You may also require a sealant at the corners where the beads meet.

When choosing a sealant, bear in mind that synthetic mastics have high embodied energy and contain toxic chemicals. You may therefore wish to consider using a traditional burnt sand or linseed oil mastic, both of which are made from natural materials and do not contain toxic substances.

Just as effective as a stainless steel or PVC or glass-fibre bead is a hardwood bead detail. Rather than being incorporated into the render, this is applied afterwards to cover the join between render and frame, and held in place with burnt sand mastic or linseed oil mastic sealant (see Figure 13(a)). Alternatively, the bead detail can be designed out by adapting the shape of the hempcrete wall (see Figure 13(b)). If using this

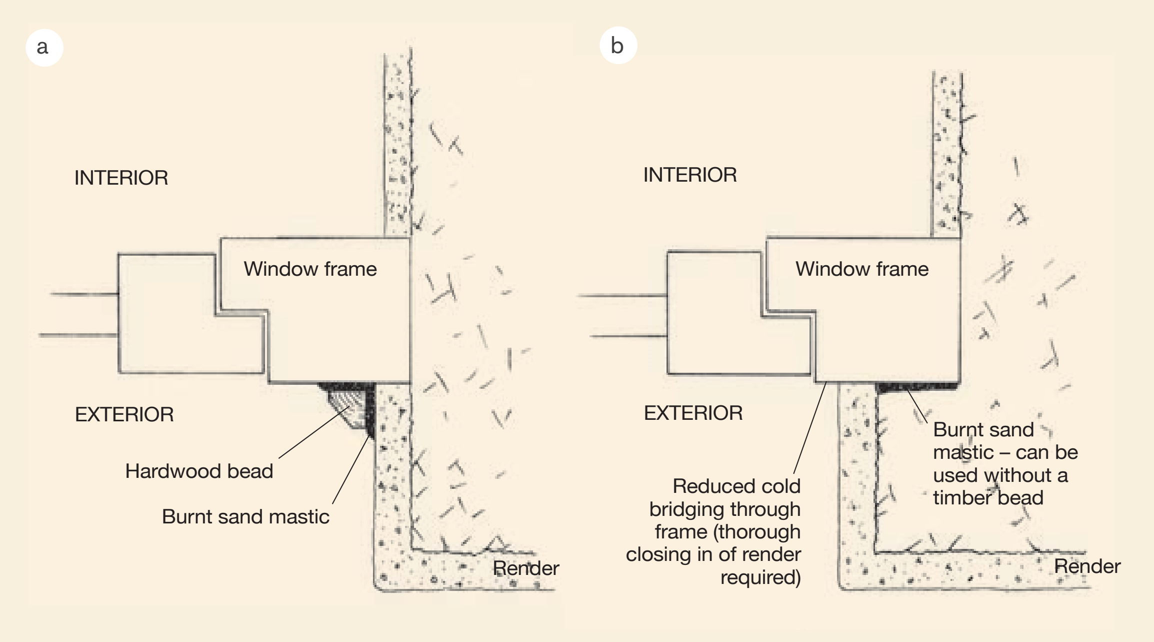


Figure 13. Plan views of window jamb. (a) A hardwood bead detail with burnt sand mastic provides a natural alternative to stainless-steel or PVC frame-seal beads. (b) Here the bead has been designed out by extending the hempcrete over the window frame.

approach, care must be taken not to knock the hempcrete too hard with the window when fitting, as this can result in damage (just where you don't want it).

Weismann and Bryce describe how to make burnt sand mastic in *Using Natural Finishes*.

Drip details

A range of beads made from stainless steel or glass-fibre mesh and PVC are available in varying widths to create a drip (to shed water away from the wall) above windows or at the bottom of the rendered face of the wall above the plinth.

Natural alternatives include a hardwood timber drip to the window head, and a drip detail created from slates or tiles bedded on lime mortar over the plinth (see Figure 14(b)). Note that if using slate or tile drip details at the top of the plinth, these need to be fixed in place before the hempcrete is placed.

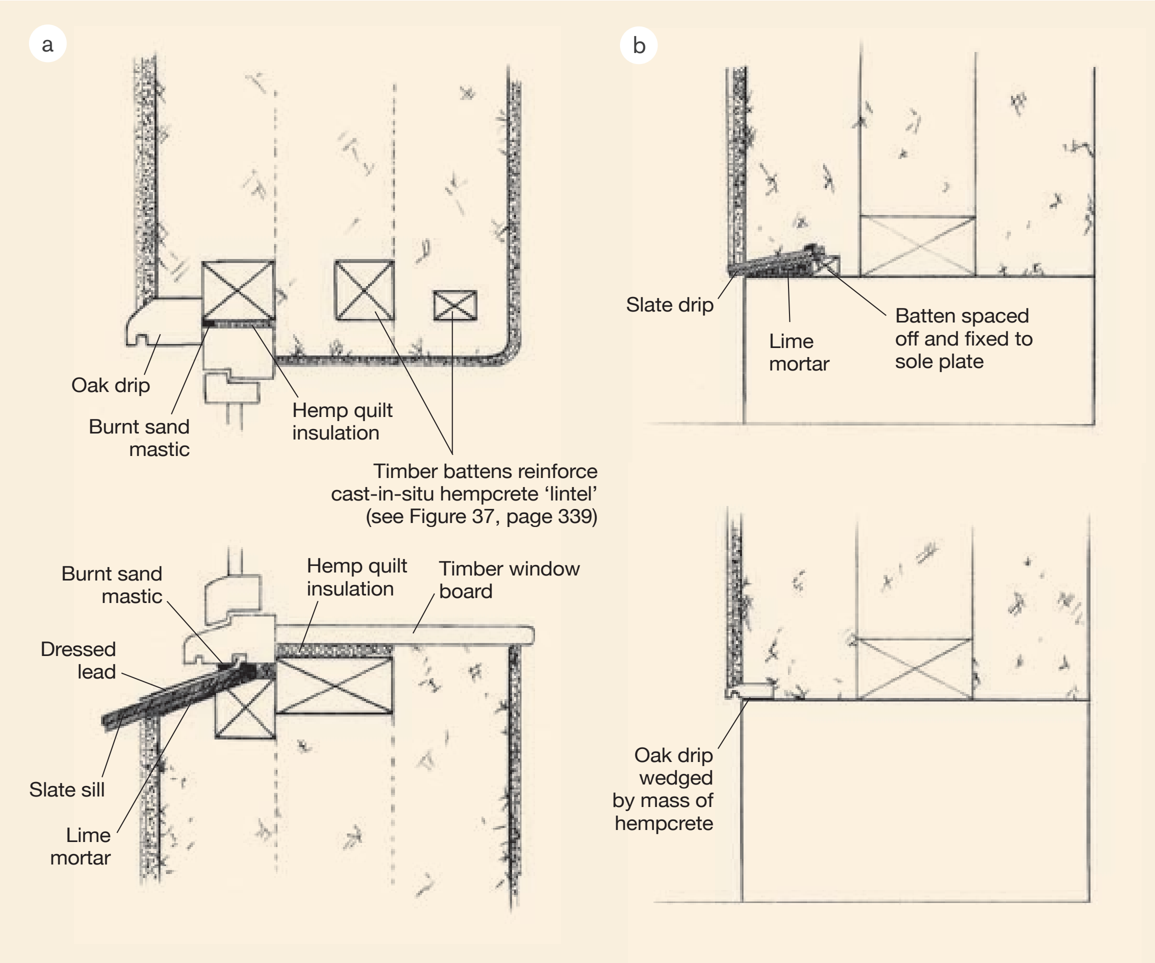


Figure 14. Natural drip details can easily be incorporated, as in these examples: (a) at the window head and sill; (b) at the plinth.

Paints and limewash

Many paints that claim to be 'eco-friendly', low in harmful VOCs or 'breathable' are available on the UK market. It often involves a little digging to find out the facts behind these claims, although manufacturers should provide vapour-permeability figures and a list of chemical ingredients in the product data. As more and more synthetic paint manufacturers try to jump on the 'breathability' bandwagon, the picture has become increasingly confusing. In many conventional paints described as 'micro-porous' the levels of VOCs and other chemicals mean they fall a long way short of being natural, healthy or 'eco-friendly'. Likewise, paints are often described as 'eco-paints' to indicate the fact that they meet current EU requirements for low VOCs, but these paints are not necessarily breathable, or may be breathable only to a certain degree.

Unfortunately, at present it is up to the consumer to ask the right questions to find out if a particular paint really is what it says it is. If you are confused, there are various websites, independent eco-building suppliers and books that can help you negotiate through the maze (see Resources). A good test is to see whether the manufacturer prints a comprehensive list of ingredients on the tin, and also states where these ingredients came from.

Clearly, lower embodied energy and low (or zero) VOC content are desirable attributes in paints, but for use with hempcrete the most desirable attribute is breathability – permeability to moisture vapour – so it is worth finding a paint that confirms the exact level of permeability on the tin rather than one that the supplier just claims verbally to be breathable. After all the trouble of creating your breathable wall, it is important not to get it wrong at this stage and seal up the surface with a paint. Again, natural/heritage building materials suppliers should be able to provide appropriate information on their own stock of breathable paints. Most sell such paints as suitable for painting over lime plasters, and many also stock a ready-made limewash, which can be supplied pre-coloured with natural pigments or you can add these on-site.

Limewash is a very cost-effective option, but it is more temperamental than paint, and for a successful limewash that will not dust when dried you need to be surprisingly accurate about the proportions and obsessive about mixing it well before every use. Our preference is to use paint inside and limewash outside.

Limewash can be bought from traditional building suppliers, but is very easy to make by diluting 2kg of lime putty in 2 litres of water. Varying amounts and mixtures of lime-tolerant natural pigments (e.g. ochre, burnt umber or sienna) can be added to the limewash to colour it, or it can be used in its natural milky-white state. Limewash keeps very well, but it is important to

Natural breathable paints complement hempcrete perfectly.

stir it well before each use as the constituent parts tend to separate out quickly.

Limewash on the external walls of a building is first applied as at least three to five thin coats, and probably more if a pigmented limewash is being used. The finish is then maintained with the application of further coats as necessary over subsequent years. How often this is required depends on the skill with which the initial coats were applied, as well as on how it is weathering, which in turn depends on the orientation and exposure of the building. Much research has highlighted the role of limewash in the repair of heritage buildings, not just in colouring but also in protecting and preserving masonry and render.

Truly breathable paints will usually be mineral-based, often lime or clay. It is worth doing your own research on what works best for you and your build, and indeed your pocket, as more and more products are coming on to the market. Our favourite paint currently for indoor use is a clay paint called Earthborn, which we find to be cost-effective, attractive and breathable. In contrast to other clay paints on the market, Earthborn is a truly natural, breathable clay paint which contains no acrylic. We find that this paint is so thick that it can be watered down by 20 per cent and still provide a super-matt thick clay finish, which seems more like a very thin coat of clay plaster than a paint. Another option is silicate paints, which can provide a very hard-wearing and breathable solution for both internal and external applications. In particular these can be a comparatively low-maintenance alternative to limewash for large buildings, where the initial outlay of using these paints is outweighed by avoiding the costs of access to re-apply limewash on a more frequent basis.

As well as the very important issue of breathability, it is worth keeping in mind that paint is one of the main ways in which toxic chemicals are introduced into our living environments. Because of the proximity of paints to us, i.e. being on the surface of the wall rather than buried deep inside it, any chemicals present within paint pose a much greater risk than other synthetic building materials of contaminating our immediate environment or coming into direct contact with us. The choice of which paint you will use is therefore a very important one – for the health of you and your family as well as the health of your hempcrete walls.

As many people will be aware, it is perfectly possible to make your own natural breathable paints, in some cases using ingredients so easily available that you may already have them in the house. This option can often be cheaper than buying manufactured paint, and of course enables you to be 100 per cent sure about exactly what has gone into your paint. For those interested in exploring this idea further, there are many books containing natural paint 'recipes', including *Using Natural Finishes* and *The Natural Paint Book*. There are also courses available on the basic techniques.

The most basic, and minimalist, form of internal finish for hempcrete is a limewash or breathable paint applied directly to the face of the cast wall. This simple technique is appropriate for those who like the look of hempcrete, and who see value in the simplicity and 'honesty' of leaving materials exposed within the building. In theory the hempcrete could be left as originally cast, but a couple of coats of natural paint, for example a nice thick clay paint, will help to protect the surface and consolidate any loose particles of shiv or dusty areas.

Painted hempcrete can provide an attractive textured wall surface, but remember that when casting hempcrete there is a skill in achieving a surface with a consistent appearance across the whole wall. This relies heavily on the hempcrete being placed carefully, and with particular attention given to achieving an even density on the internal face of the wall. If using a limewash painted directly on to the hempcrete, at least four coats would be required to give a solid textured background and cover all the substrate.

Finishes for bathrooms and kitchens

At Hemp-LimeConstruct we are often asked about the issue of maintaining the breathability of hempcrete walls in rooms such as kitchens and bathrooms, which conventionally have non-porous finishes such as tiles and waterproof 'bathroom and kitchen' paints.

There are two reasons why the internal wall surface needs to be breathable. The first is so that the cast hempcrete can dry out properly to both sides of the wall, ensuring that excessive moisture is not retained in the wall. For this reason it is important that hempcrete walls should be given time to dry out fully before any non-porous surface finishes are applied, however limited in area (see Chapter 19, page 264).

The second reason why internal surface breathability is desirable is to do with indoor air quality and human health. As discussed in earlier chapters, a breathable wall buffers moisture, absorbing and desorbing it from the air in response to changes in internal humidity, thereby maintaining a healthy indoor air quality. If non-porous surface finishes are applied, this function is reduced, and it is in the kitchen and bathroom where it is especially needed, since it is here that excessive moisture is created by human activity, leading to significant changes in the relative humidity of the internal air.

For this reason, we recommend that tiled surfaces should be kept to an absolute minimum,

Modern lime-based render systems, such as the breathable external render used here, are easy to apply but more costly than a simple lime–sand render.

for example for splashbacks behind sinks, and waterproof paints should never be used. Instead of trying to make the surface of the wall water-resistant, the answer is to increase surface breathability through the use of finishes that are especially good at regulating humidity, such as clay plasters and certain paints. Where large areas of tiling is necessary, for example in showers and wet rooms, think about this at the design stage and try to site these against internal walls (that are not constructed from hempcrete) so that the external hempcrete wall remains breathable.

Tadelakt is an attractive natural lime-based waterproof finish, made from a particular type of limestone found in the foothills around Marrakech. The technique of applying and finishing tadelakt, including polishing the surface with stone, creates a beautiful waterproof plaster that can be used to finish baths, showers, sinks and wet rooms. Being a lime-based material, it sits well alongside the other natural materials within a hempcrete house.

The application of tadelakt is highly specialist, and we would recommend seeking advice from a professional experienced in its use. It is also possible to take a course in its application. When applying tadelakt to hempcrete walls or floors, we advise first finishing the hempcrete with a normal lime plaster or screed, to ensure a firm background, and then applying the tadelakt over this.

Cladding

The first choice for the external finish on a hempcrete wall is usually a lime render, for reasons of simplicity and low material cost, but there are times when a different finish is required. For example, the orientation or exposure of a particular wall may make a simple lime render insufficient to protect the hempcrete from the prevailing weather, or planning restrictions may demand that the outside of the building is clad in a certain material to ensure it is 'in keeping' with other buildings in the vicinity, for example in a conservation area.

Timber cladding and render are the two most frequently used finishes for hempcrete.

Cladding on a hempcrete wall is much the same as that on any other building, and can take the form of timber boarding, stone or brick masonry, or hung tiles and slates. The cladding is tied back on to a section of the frame that is flush with or just below the surface of the hempcrete wall (see Chapter 13). In the case of masonry cladding this is done with wall ties, but timber cladding and hung tiles or slates are attached to cladding battens, which are in turn fixed to the frame.

With many different cladding options available and many different details possible, it is beyond the scope of this book to give substantive information on the construction of cladding. The important issues relating to the use of cladding on a hempcrete building as opposed to any other are discussed in greater detail in Chapter 22, but the main principles are as follows:

- A vented air gap should be included between the cladding and the face of the hempcrete.
- Wherever possible, cladding should be of natural, breathable materials.
- Steps must be taken to ensure airtightness on the face of the hempcrete, if it is not rendered underneath the cladding.
- Since part of the frame needs to be near the surface of the hempcrete wall to make fixing the cladding possible, it therefore has increased vulnerability to moisture ingress, and steps should be taken at the design stage to mitigate this.

A system that has been used successfully on straw-bale buildings but not so far, to our knowledge, on a hempcrete wall, is a combination of timber cladding and render. A protective lime render is applied to the wall and a timber rain screen cladding is fixed over this. A rain screen is a less robust form of cladding, which is constructed by butting up timbers against each other. It is not as protective as a shiplap or tongue-and-groove cladding, but since the hempcrete wall below is rendered, the rain screen is not the only protection for the hempcrete, and a more basic and cheap timber – even recycled timber – can be used, as long as it is durable enough to withstand external conditions.

Similarly, because the rain screen is acting as the main barrier, the render does not need to be as strong, durable or decorative as it would be if it were acting alone. This might mean, for example, that a single very roughly applied basecoat of lime render could be used, or even an earth render – perhaps made from clay-rich subsoil excavated during ground works.

In other words, the combination of materials means that both the render and the cladding can be 'lower spec' than they would be normally, and this therefore offers a cost-effective solution that may appeal to self-builders, who may not necessarily have the skill to create a beautiful render finish or the money to pay for purpose-cut, profiled cladding.

Floor finishes

Finishes applied to a breathable hempcrete floor slab must be not only vapour permeable but also hard-wearing. Whatever finish is used, it is extremely important that the floor is completely dry before laying the finish, since only the top is open to the air and this is therefore the only side to which the hempcrete can dry.

Binder manufacturers may give their own details for the application of finishes to hempcrete floor slabs constructed using their binder, and where they do, these should always be observed. Available finish options include the following.

Timber:

- This should be solid timber, not laminate.
- Timber boards can be fixed to battens sunk flush into the hempcrete floor.
- Timber should be protected with natural waxes or resins, not varnish, in order to preserve the breathability.
- Underfloor heating can be set in a lime screed between the hempcrete slab and the floorboards using counter-battens above the screed. Make sure that the floorboards are suitable for use with underfloor heating.

Natural flagstones set on lime mortar:

- Flagstones are laid in much the same way as for a patio, on a continuous bed of mortar, of a suitable thickness, bearing in mind that underfloor heating pipes can be included within this mortar.
- Mortar-filled joints between the flagstones can be slightly wider than normal to increase breathability.
- Where the type of stone used requires it, the floor can be finished with natural oils.

A lime screed (of around 75mm depth), topped with one of a range of finishes:

- The lime screed is used to level the hempcrete and provide a surface for the chosen finish.
- Finishes include thin natural floor tiles, a natural carpet, or simply another layer of screed, polished to a finish.
- Advice on the application of lime screeds can be obtained from natural and traditional building suppliers, who may even have their own proprietary system.


Kilworth
Wood

CHAPTER NINETEEN

Practicalities on a hempcrete build

Having set out the 'nuts and bolts' of hempcrete construction, we now consider the wider practical issues on a hempcrete building site. The main roles are discussed here, together with factors affecting the success of a hempcrete build. Many of the issues raised in this chapter will be especially important to those who are building with hempcrete on a busy commercial site, alongside a range of other contractors. If you are going to be doing a lot of hempcrete work, or your project is a large one, then this chapter is for you. If you are a self-builder with only a one-off project to think about, you won't need to worry about *everything* contained in this chapter, but a broad understanding of the concepts set out here can only improve the efficiency of your build.

Roles on a hempcrete build

As we have seen in previous chapters, there are three distinct stages to a hempcrete build. Often these are actually separated by a period of time, as well as conceptually. The roles at each stage are summarized below.

Stage One: framing

A supervisor is required to take responsibility for the frame being constructed to the structural engineer's specifications, and for the requirements of the hempcrete that is to be cast around it.

A team of joiners either builds the frame on-site from plans, or assembles a frame that has been

Previous page: A pan mixer for hempcrete running off a telehandler on a large building site.

prefabricated elsewhere and delivered to site in easy-to-transport sections.

There may be a need for a labourer or semi-skilled role to assist every one or two joiners on-site, depending on the requirements of the job.

Stage Two: mixing and placing hempcrete

A supervisor, with an oversight of the whole process, is required to ensure that a consistent standard of work is achieved by everyone involved in casting the hempcrete. Particular attention needs to be paid to the accuracy of the shuttering work; the quality and consistency of the mixing; and the consistency of tamping of the hempcrete mix, to avoid over-tamping.

The remaining workers can be divided by their role into four teams:

The mixing team. This usually consists of two people, assigned to operate the mixer and supply the ferrying team with Gorilla Tubs of hempcrete. At least one of these needs to be a person skilled in mixing hempcrete (see Chapter 15). Extra people are needed from time to time to supply materials to the mixer, and it is not uncommon to swap people on and off the mixer to give them a break, as this can be hot and unpleasant work.

The ferrying team. This comprises a number of people employed in ferrying tubs of hempcrete from the mixer to where it is needed by the placing team. On smaller builds, where smaller amounts of hempcrete are being mixed at one time, this role might be carried out, as required, by members of the placing team.

On larger builds this work is usually carried out by the unskilled members of the team. This is the main lifting and carrying work, so people on the ferrying team need to be strong; that said, hempcrete is a lot lighter than freshly mixed plaster, mortar or concrete, and is certainly not heavy enough to make it worth moving in a wheelbarrow.

The placing team (also known as the 'tamping team' or 'tampers'). This team does the work of actually placing the hempcrete mix into the shuttering, and ensuring it is evenly distributed. It is essential that at least one person on this team is skilled in the placing of hempcrete, and it should really include one skilled person for every three unskilled or semi-skilled people. This enables the skilled one to effectively supervise the work of the other three, and to be responsible for maintaining a consistent quality of work.

The tamping team at work.

The shuttering team. This usually consists of two skilled joiners, sometimes supported by a semi-skilled person. The shuttering team is of course responsible for setting up shuttering around the timber frame ahead of the placing team. But, as work progresses, this role also involves taking down shuttering from cast walls that have taken their initial set, and moving it on to the place where they are next required. It is crucial that this team does its work accurately if the finished hempcrete walls are to be straight and plumb, as any errors will incur costs later, in extra work at the plastering stage.

Note that some members of each of the four teams outlined here need to be flexible, able to shift between the different roles as required (see right).

Stage Three: finishes

Depending on the final finish, a range of roles might be called for:

A **supervisor role**, again, is needed to ensure that a consistently high standard of work is achieved by everyone involved in applying the finishes.

Lime plasterers apply render and plaster finishes, either direct to the hempcrete wall or to permanent shuttering boards where these have been used. Note that applying lime plaster or render is a distinctly different skill from the application of gypsum plasters and cement renders (see Chapter 18).

Where timber cladding is used, **joiners** are needed to construct and apply the cladding.

Where brick or stone cladding is used, **bricklayers** or **stonemasons** who are used to working with lime mortars are needed, to build the cladding and apply pointing mortar.

Painters are required to apply breathable paints or limewash on to lime plaster and render finishes, and, in the case of timber cladding, to apply protective oils or other finishes.

Depending on the scale of the build, an appropriate number of **labourers** or **semi-skilled workers**, for mixing, fetching and carrying, is really useful at this stage.

The balancing act at Stage Two

When placing hempcrete, adjusting the 'balance' of the number of workers in each of the four teams is an important concept. You will gradually develop and fine-tune this skill over the course of managing your first hempcrete build, but it's worth considering it beforehand, as to some extent it will have an effect on your choice of people in each team.

The balance is constantly shifting, because the level of difficulty of each team's job fluctuates throughout the day, and the team's work rate slows accordingly. This is illustrated by the following scenarios.

Mixing team

Scenario: The supply of materials close to the mixer runs out, so more materials need to be brought over (sometimes this might also require the mixer being disengaged from the telehandler so that it can be used to transport materials).

Problem: If there is a delay in getting the next mix on, this might stop the whole operation and leave the ferrying team and placing team with nothing to do.

Solution: People from the other teams are assigned to the mixing team, so that materials

The person mixing must be kept supplied with binder and hemp.

can be brought up while mixing continues. If a telehandler is needed to move materials and this will stop the mixer, a temporary solution is for the extra team members to move (by hand) enough materials to keep the mixer going until the next scheduled break, when the telehandler (and the whole build team) is used to replenish materials, since the placing work has stopped anyway.

Ferrying team

Scenario: As the day has gone on, the part of the shuttering that was being filled in the morning (10 metres or so from the mixer) has been finished, and work has moved to a part of the building that is 35 metres from where the hempcrete is being mixed.

Problem: The extra time taken to ferry the mix to the shuttering might slow the placing team down, as they have already placed what they have got, and are waiting for more to arrive. It might also slow the mixing team down, since they are waiting for the tubs to come back so that they can empty the mixer and begin the next batch.

Solution: A couple of people from the placing team, or one from the mixing team and one from the placing team, are reassigned to help the ferrying team temporarily before returning to their duties.

Placing team

Scenario: After finishing a long ‘clear’ run of wall, the tampers reach a section where there are several windows close together, making it a fiddly business to place the hempcrete in, under and around the more complicated frame structure without leaving unfilled gaps.

Problem: Slowing of the rate of placing may result in a queue forming of tubs full of mix sitting on the scaffolding waiting to be placed. This can slow the mixing team down, as empty tubs don't get sent back with the ferrying team, so the mixer takes longer to empty. In bad weather it can also allow tubs to get rained on, meaning that extra, and very much unwanted, water is introduced into the mix. Likewise, in hot, dry weather, the hempcrete in tubs risks drying out too much before it is placed.

Solution: Either a couple of people from the ferrying team can be assigned to work with the placing team, or the ferrying team, instead of just dropping full tubs and picking up the empties, can begin pouring the mix into the shuttering ahead of the tampers, emptying the tubs to return to the mixer. In the second case, it's important that the placing team retains responsibility for which sections of shuttering have been tamped, so that well-meaning ferrying people don't put a layer of loose mix over another loose layer, which hasn't yet been tamped.

Shuttering team

While the work of mixing and placing hempcrete is under way, don't forget to check on the shuttering team. Although they are working fairly independently of the other teams on-site, their job also determines the speed at which the placing work progresses, since they are removing sections of shuttering from cast hempcrete walls and re-fixing them on the section of the frame where the placing team will arrive next.

As with the other teams, the speed of this work is partly dictated by the different sections of the frame: long, straight runs are likely to go up and come down quite quickly, but any corners or fiddly details, or anything which involves cutting boards to shape (such as inside a roof space or on a gable end) can slow the work down considerably.

The shuttering team usually consists of two people.

As we have seen, the accuracy of the shuttering work is vital to the straightness and plumb of the finished walls, so there is no point in rushing it or assigning unskilled workers to this team, other than for fetching and carrying duties or as 'the other pair of hands' to a skilled worker.

Ideally, one or two of the placing team should have sufficient joinery skills to be able to help out the shuttering team when they are being caught up by the placing team. This might include cutting pieces to length, or removing old shuttering and collecting the screws and spacers, under the direction of the shuttering team.

At times, especially on a busy site, it can be helpful to stagger breaks so that the shuttering team can get a 'head start' on the shuttering before the others come back and get the next mix on.

The balancing act: summary

If the issues outlined in the scenarios described here are spotted by, or communicated to, the supervisor as soon as they appear, then the number of people assigned to each team can be adjusted accordingly to keep the speed of work going at its full potential. This might take a while to sort out if you haven't managed a hempcrete build before, but it soon becomes apparent how the flow of people can be managed to ensure that there isn't too much standing around.

After a while, experienced teams can even start to readjust themselves as necessary, adapting flexibly to the fluctuating demands throughout the day, based on their assessment of what is happening at any particular time and on the skills of each individual.

This concept of switching people between the teams is key to a successful build, particularly on a large job. It makes it even more important, in teams that include people with different levels of skill, and possibly volunteers, that a good level of supervision is maintained by the experienced team members, so that mistakes are avoided and the overall quality of work is kept consistent.

Smaller builds

While the process described on the previous page, of streamlining the placement of hempcrete, is important on larger, commercial builds, self-builders and those on smaller builds will be able to work at a more relaxed pace, with fewer people. A smaller build might involve only two to four people in total; everyone might first be involved in putting up a run of shuttering, then all work together to mix and place the hempcrete.

For the mixing and placing stage, one person can run up a couple of bell mixers at a time, while the other two or three people ferry and place the hempcrete. Another person can act in a hybrid role, helping the mixer by fetching more materials when needed, and also taking buckets to the placers and helping them as required.

The 'feel' of working on a small hempcrete build is very different from that of a large commercial build, with increased flexibility of roles, and a more relaxed atmosphere generally.

Site organization

With a bit of forethought, a hempcrete build can (within the limits of a particular site) be organized in such a way as to make the job easier. The following advice on site organization concentrates particularly on the second stage of the build: mixing and placing the hempcrete. Issues relating to site organization during the timber-frame assembly and the application of finishes should either already be familiar to those with experience of conventional builds or be found in general resources relating to the construction industry.

Storage of materials

The area for the storage of raw materials (hemp shiv and binder) needs to be clean, dry and cool, and close to where deliveries are arriving. It also needs to be accessible by forklift or telehandler, if you have one on-site, or by hand pallet truck if you are relying on the lorry driver. If it isn't accessible to one of these, you are going to be doing a lot of lifting and carrying.

Although far from ideal, pallets of binder and hemp *can* be stored outside for short periods, as long as you keep the binder pallet well covered once the original pallet wrapping has been removed. The hemp is usually supplied in plastic-wrapped bales, so rain is less of an issue, but they never stay 100-per-cent waterproof, especially as time goes on and they get knocked and snagged by people working around them.

A little bit of wetting of the hemp shiv, if it is to be used in the next few days, is not a complete disaster, but look out for any areas where the hemp is starting to turn black: this is a sign of rot starting, and these bits need to be pulled out and discarded rather than introduced into the mix.

Storage of any timber (usually untreated softwood, roofing battens and OSB sheets) should be under cover, and the same goes for any board used for permanent shuttering that is not of external grade. Wood wool board is external grade and can stay out in the rain, although we usually cover it just to be on the safe side.

Mixing area

From storage, the materials will be moving to the mixing area. The choice of mixing area is discussed in more detail in Chapter 15, but, essentially, you need to think about how easily you can transport materials there from the storage area, and how a reasonable quantity of materials can be stored next to the mixer and kept clean and dry. The mixing area will ideally be under cover but well ventilated, and ideally slightly apart from areas where other people are working, because of the binder dust flying about.

Wherever possible, have a clean floor to the mixing area, preferably boarded, so that any dropped hempcrete mix can easily be swept up and returned to the mixer. Needless to say, the mixing area needs to have a good supply of water with sufficiently high pressure, so it doesn't slow the mixing down while you are waiting for tubs, or a tank (or bore hole!), to fill up.

An area for cutting

Although the majority of the joinery work has been undertaken during the framing stage (before the site was cluttered up with people ferrying tubs of hempcrete around), the shuttering team still needs to cut, and re-cut, boards and battens, as the shuttering is taken down from sections of frame once they are cast and re-fixed to the next section.

As most of this cutting involves 2400mm x 600mm boards, and a table saw is not always practical, a corner of the floor is often turned over to an area for marking out and cutting boards with hand-held circular saws, and battens with a hand saw or a chop saw. Ideally, this job would be done in its own area, slightly away from the messy hempcrete-placing work, in order that expensive power tools are kept as clean as possible and people are not always walking through where you are measuring and cutting. However, in practice a well-defined separate area is rarely available, and on a larger build the cutting area will gradually move around the frame to follow the work, otherwise you end up carrying the heavy boards over long distances.

If one particular area where all the cutting is to be done has to be identified, then it makes sense to put this close to where timber and boards are stored. The distance from the cutting area to where the shuttering needs to be fixed will change throughout the job as the work moves around the frame, but materials are likely to be stored in the same place throughout.

Tools

It goes without saying that you need somewhere secure and dry to store tools if they are to stay on-site. Many people will be happier taking expensive tools away each day, but remember that you will also be storing tubs, buckets, endless pairs of waterproof gloves, goggles, waterproof clothing and boots, first aid kit, many boxes of different fixings, a nail float, chisels, hand saws, levels, squares, tape measures, access equipment. . . the list is endless! You are unlikely to want to pack that lot up every night to take home, so give some thought to secure lockable storage on-site.

Scaffolding and access

Unless you are working on a single-storey building with a simple roof design, then you are likely to need scaffolding, at least externally. We will not go into detail about this here, as the scaffold required is likely to be similar to that needed for any building project. Suffice to say that all scaffolding should be assembled and taken down by qualified persons, and should remain in place and not be adapted ad hoc during the build. Falls from height on-site are a major contributor to deaths and lasting disabilities caused on building sites, so ensure that you, and everyone else on the team, are familiar with safe working practices with regard to scaffolding and working at height, and insist that these are followed at all times.

The normal procedure is to hire the scaffolding from a firm who comes and puts it up before the work starts and takes it away afterwards. In negotiating this, wherever possible get a 'for as long as it's needed' price, rather than a weekly rate or a price for a fixed time, after which it reverts to a weekly rate. The main reason for this is that there may be an extended time between the walls being cast and external render applied (see Chapter 16, page 216). If the scaffolding has to stay up only because you need to come back later and render the walls, you are paying by the week for something that is not required in the meantime, and striking it and then re-installing it is likely to be even more expensive.

Otherwise, at the time of the scaffolding design, think ahead and consider what exactly is required in terms of the mixing and placement of hempcrete itself. For example, if you will be mixing off the scaffolding, do you need a reinforced platform section where large amounts of binder and hemp can be lifted up with a telehandler and stored on the scaffolding next to the mixer? Or, if you are mixing on the ground and lifting the mix up on to the scaffolding in tubs, is there a way to make this easier, for example with a block and pulley set up on a protruding pole above a removable section of rail? Will you be able to access each lift of shuttering as you move up the wall?

Think about the horizontal poles supporting the platform at each level (i.e. at 90 degrees to the wall).

Think carefully about scaffolding design, e.g. how will you access each lift of shuttering as you move up the wall?

Ensure that horizontal scaffolding poles are not too close to the wall to prevent shuttering being moved.

These need to not only stop short of where the face of the cast hempcrete will be, but also leave enough room between the pole end and the wall to allow large shuttering boards to be removed easily without denting the freshly cast wall. You will also need space to comfortably get a trowel and float in the gap when applying finishes.

Other than scaffolding, other useful access equipment includes stepladders, moveable trestles with height-adjustable platforms, and small folding hop-up platforms (usually about 45cm high). These 'hop-ups' are perhaps the most useful: they can be easily moved around and are often in near-constant use by the teams shuttering and placing the hempcrete, so it's worth having at least a couple on-site.

Somewhere for breaks and somewhere to get clean

Every hempcrete build needs a proper area to wash yourself and your equipment, and to get clean at the end of the day. Mixing and placing hempcrete, especially in poor weather conditions, can be a pretty messy business, and you end up getting covered in the stuff despite your best efforts with protective clothing and gloves. Because of the lime in the binder, the opportunity to clean the worst off your hands and face and out of folds in your clothing whenever you stop for a break is not just a luxury but an important part of preventing lime burns.

You will also want to wash out goggles and thick PVC gloves at the end of the day and put them to dry somewhere overnight, otherwise you will get small pieces of lime-coated hemp inside your gloves to rub against your fingers and cause lime burns, and inside your goggles to fall down into your eyes the next time you look up at the ceiling.

For similar reasons, it is certainly preferable to have a separate area away from the work to sit down for breaks and meals. You soon find that small pieces of lime-coated hemp get spread everywhere around the work area, no matter how well you keep on top of the sweeping. It's asking enough that you have to work with the stuff; you really don't want it getting in your sandwiches or cup of tea as well.

The weather and temperature

As you will be aware by now, the weather is a much more significant factor when building with hempcrete and lime than when using cement-based materials. Nothing is certain except death and taxes, as the saying goes, and if there *are* any other contenders for certainty, then the

UK weather is not going to be very high on that list, so we advise you to consider the points outlined below carefully before starting work.

Protecting your work (and your workers!)

Rain is the major environmental risk factor on a hempcrete build. As we have already seen, it is imperative to keep any excess water introduced into the hempcrete wall to a minimum (while ensuring the presence of *enough* water to activate the binder). Any unnecessary water simply extends your drying time (see Chapter 19, page 264), which is to be avoided at all costs.

For this reason, as discussed in Chapters 15 and 16, site the mixer in such a way as to avoid rain getting into the wet hempcrete, and avoid leaving tubs of hempcrete waiting to be placed where rain (or someone over-shooting with the hose) can add to their water content.

Remember also that all sections of wall where hempcrete is to be placed must be protected from rain during and after placement. If water is allowed to run down through the freshly placed hempcrete before it has set, this not only risks adding excess water but also carries the further risk of the water washing binder out of the wall and compromising its structural integrity.

Last but not least, rain increases the risk of workers getting lime burns, as powder or wet particles that would normally have stayed on the outside of clothing get washed into every nook and cranny by heavy rain. It is almost impossible to stop this, despite your best efforts to protect yourself. However, the risk can be reduced by making sure there is sufficient waterproof clothing on-site: cheap waterproof jackets and over-trousers, and steel toe-capped wellies or rigger boots for a start. Bear in mind that even in light rain, waterproof trousers or knee pads can

Waterproofs or knee pads help to minimize lime burns in wet weather.

prevent burns caused by kneeling on spilt mix on a rain-soaked scaffolding platform while tamping the hempcrete in the shuttering.

In serious rain, put a halt to mixing and placing work, unless your mixer is under cover and you can arrange things such that the sections of wall being cast are filled from inside, so that workers are not getting drenched.

Risk of freezing

The temperature is always a factor when placing hempcrete, for the same reasons as with any lime-based product, including (although to a lesser extent) ordinary Portland cement. What you are trying to avoid is the temperature dropping to below 0°C before the binder has had a chance to react chemically with the water (hydrate) to achieve its initial set.

At around -1°C, some of the water in the mix will begin to freeze, slowing down the speed of the hydration reaction. At around -3°C or -4°C, enough of the water freezes that hydration stops completely and, depending on the extent of hydration and the corresponding strength of the material, the force of the water changing state (ice typically occupies around 9 per cent more space than water) is a risk to the long-term integrity of the setting material.

Clearly then, for hydraulic-lime-based binders to work, a window of time is required when the ambient temperature remains well above freezing point while the binder reacts with the water. For the fast-setting cements this is a matter of hours, but with natural hydraulic lime (NHL) it takes days, depending on the strength of NHL used, with the more hydraulic ones setting faster and harder. Always seek, and follow, the advice of the binder manufacturer or supplier.

As a rule of thumb, work with any lime-based binder (including cement) requires a temperature of 5°C or above. Depending on the type of lime or cement being used, the period of time after application during which that temperature needs to remain constant varies. As an example, when working with NHL 3.5, you really need the minimum temperature to remain above 5°C for 7-10 days, with the risk of weakening due to a sudden temperature drop decreasing with each day that passes, as more hydration occurs.

Although never used as a hempcrete binder in their pure state (i.e. without a pozzolan added to make them more hydraulic), it is worth noting here that air limes (non-hydraulic limes), which set through carbonation in contact with air, set very slowly indeed; sometimes the mortar inside a wall never sets completely. Because of this slow setting time, these limes are even more susceptible to the effects of temperature, and this includes the risk of excessive heat drying out the surface of the mortar or plaster and causing cracking. If you are using these limes – for example, in fat lime (lime putty) plasters – ensure that you understand exactly how the material will behave in a given situation. At least one person on the team needs to be fully conversant with the preparation, application and after-care of these products, or you are more than likely to run into trouble.

When it comes to hempcrete binders, individual binder product manufacturers specify the minimum temperatures required for working with their products, and you should follow this advice. However, it is advisable to familiarize yourself early on with the temperature parameters required by the product you are using, as this stage of the work will be so much easier and less stressful if you are not racing against inclement weather.

The obvious conclusion is that the best time for casting hempcrete is in the late spring and summer, and this is indeed the preferred option, in terms of both avoiding the risk of freezing and to encourage faster drying times (see below). However, it is possible to cast hempcrete in colder weather, especially if the choice of binder is made carefully.

Prompt, as a natural cement, has a clear advantage here because it is naturally very quick setting and is extremely hydraulic, using up a lot of water from the mix very rapidly. This aggressive take-up of water also reduces drying times – another significant advantage, especially at colder times of the year. All of this allows Prompt to be used successfully in applications where minimum temperatures are not guaranteed over such extended periods as would be required for other binders. However, this does *not* amount to a blanket capability of the product to work in *any* conditions. When working in low temperatures, it is important to ensure that the supplier or manufacturer has signed off on the product's use after being given accurate information about the type of application, including the minimum temperatures expected and over what period, and the thickness of the material you are casting.

As well as thinking about the type of binder to use when working at lower temperatures, take other sensible precautions where practicable. For example, consider casting earlier on in the day to allow plenty of time for the hempcrete to take its initial set before night draws in, bringing falling temperatures. If you are really concerned about a sudden unexpected drop in temperature, then it is sensible to cover freshly placed material with hessian to trap some air against the surface of the wall and keep frost off, although if you find yourself doing this then you really are pushing the limits of what you can do with the material, and it might be less trouble in the long run to take a few days off until the weather warms up again.

Good drying management

The drying time, as discussed in Chapter 16, is one of the most important considerations when working with hempcrete. It is vital that a freshly cast hempcrete wall is given sufficient time to dry out before finishes are applied (see Chapter 16, page 215). In this way the water introduced when mixing is allowed to leave the wall quickly, so that a) there is no risk of the natural materials within (hemp and timber) being exposed to excessive moisture and so being at risk of rotting, and b) the thermal performance of the wall reaches its full potential as quickly as possible.

Since the finish for the wall is also going to be vapour permeable, the hempcrete below would eventually dry out through it, but most finishes will reduce the speed of drying considerably. In an ideal world, a cast hempcrete wall would be left unfinished, at least on one side, for as long as possible until it has had plenty of time to dry, and indeed it is not uncommon for the interior side to be left unfinished while the exterior is completed. But in many cases, and certainly on commercial builds, there is a great deal of pressure to apply finishes as soon as possible, and the slow drying of hempcrete is therefore seen as a negative attribute of the material.

We would hope that the construction industry will adapt to using natural materials, rather than the use of natural materials being adapted for the construction industry. There is no reason, except perhaps extra scaffolding costs or a desire to apply the external render before the onset of winter, why the exterior of a hempcrete building could not be left unrendered while the internal fixings and fittings were done and the use of the building commenced. The external finish could be applied several months later without detriment, as long as the hempcrete walls were not in such an orientation or elevation as to be exposed to driving rain, in which case they would need some temporary protection from the weather.

Currently, however, the construction industry is a long way off from this kind of thinking, and at the present time anything that requires finishes to be applied later than they would be on a conventional build causes suspicion and uneasiness. Drying time will always be an important issue, and is of course dependent on local conditions, but with good site organization and planning there are some obvious things you can do to minimize delays.

The effect of temperature on drying time is easy to predict, since warm air ‘holds’ more moisture (really meaning that the warmer the air, the more moisture can evaporate into it). Water droplets passing out of the open structure of the unfinished hempcrete wall do so more quickly if the air next to the wall is warmer.

Take appropriate steps, therefore, to maximize temperatures next to the wall. Outside the building, the effect you can have on temperature is limited, though don’t underestimate the

In severely exposed locations if casting late in the year, it is advisable to erect a screen around the hempcrete walls to protect them from the worst of the weather while they dry.

importance of clearing away anything that is stopping sunlight from falling on the wall's surface; in particular, make sure that nothing is left leaning up against, or stacked very close to, the wall. Inside, maximizing the temperature might mean sealing up and heating the interior space, if you are really worried that drying is happening too slowly. Avoid using gas-powered space heaters, as these emit a certain amount of water vapour into the air as the gas is burnt. If you have to resort to heating, however, think about what happens as soon as the temperature falls again. As the temperature of the air next to the wall drops, the wall is likely to reabsorb some of the moisture that was released into the air, if it is still present as moisture in the interior space.

For this reason, any sealing up and heating of the inside of the building should be organized carefully to ensure that the moisture that leaves the wall into the warm air is then taken out of the building through appropriate ventilation. On a very basic level, this might sensibly be done by sealing and heating the building overnight when no-one is there, and when work commences the next day, turning off the heaters and opening all doors and windows to encourage maximum airflow through the building. Dehumidifiers can be used during the night, while the building is sealed and heated, as long as they are used sensibly. All water collected in the dehumidifiers during the night should be taken out of the building to be disposed of, rather than leaving it inside to evaporate back into the internal atmosphere as the humidity drops.

Outside, despite the lower temperature, the greater airflow from wind will have a positive effect on drying times, although of course you are at the mercy of the weather. Don't forget also to think about the orientation of the various elevations, and the effect this will have on the drying time of each part of the building – either positive, through increased exposure to sunlight and wind, or negative, through reduced sunlight or undue exposure to rain. In extreme cases, where a wall is exposed to excessive driven rain, you may need to protect it while it dries, but ensure that this is done with sufficient ventilation to allow moisture to continue evaporating from the wall and to move away once evaporated. In a nutshell, cold, still, damp days will slow the drying process, whereas warm, sunny, windy days will produce the best drying conditions – what works for your laundry will do for hempcrete.

CHAPTER TWENTY

Restoration and retrofit

The original use of hempcrete, and still one of the most important, is in the repair or restoration of heritage buildings. Various terminologies exist to describe old buildings in the UK. In this chapter we use the generic term 'heritage buildings' to encompass both *historic* buildings (those buildings considered to be of historic importance: listed buildings or scheduled monuments, or those in a conservation area) and *vernacular* buildings (traditional buildings constructed before around 1850 by local craftsmen using local materials, and without recourse to formal architecture).

In fact, the vast majority of buildings constructed before the First World War were built using natural materials including lime or earth mortars, plasters and renders, in a breathable solid-wall construction. As discussed in Chapters 3 and 4, the use of vapour-permeable materials enabled the self-regulation of moisture levels within the structure, preventing the build-up of excessive moisture within the building's fabric.

The hygroscopic nature of many of the materials also buffered moisture levels in the indoor air, helping to keep the internal environment healthy for the occupants.

Misguided repair during the twentieth century using hard cement renders and mortars, gypsum plaster and non-vapour-permeable paints and finishes has left many of our heritage buildings in a 'non-working' state. Such repairs often result in high levels of moisture being trapped in the fabric of the building, causing damage to the structure, reducing thermal performance and leading to damp and mould within the living spaces. This has given old buildings an undeserved reputation for being uncomfortable places to live. Thankfully, in recent years, with increased understanding of the issues involved, there has been a resurgence in the use of traditional materials, and the mistakes of the past are being corrected. This is particularly true in the case of historic buildings, and any works carried out on them is strictly controlled by the responsible organization (for example, English Heritage in England).

Previous page: Hempcrete panels in a Grade II listed Tudor house.

Traditional buildings were always built from natural, breathable materials, such as these clay bricks, oak beams and clay/lime plaster.

However, our architectural heritage in the UK extends further than the 370,000 or so buildings that have a listing, and many people in the UK live and work in buildings built before the First World War. There is growing public awareness of the need to repair, restore and, where appropriate, improve these buildings using natural, breathable materials. Unfortunately, in the context of the current (very necessary) drive to retrofit insulation to older properties, there is again a risk of damage being done to the fabric of older buildings and to the health of their occupants by the use of inappropriate materials.

When asked to upgrade the insulation of older, solid-wall properties, the default response of the mainstream construction industry is to reach for the highest-spec synthetic insulation available, which is then either installed between joists or rafters or glued to the inside face of the external walls using chemical adhesives. Not only do these materials frequently contain harmful chemicals but also they are usually impermeable to moisture vapour, thereby sealing up the breathable wall of the property and causing the sort of problems just described.

In 2012, work undertaken by the Sustainable Traditional Buildings Alliance (STBA), a collaboration of not-for-profit organizations, including English Heritage and the Society for the Protection of Ancient Buildings (SPAB), raised awareness of the issues involved in the retrofitting of insulation to heritage properties and highlighted areas where future research is needed. Their work has led to government-driven retrofit insulation initiatives such as the 'Green Deal' belatedly acknowledging that pre-1919 buildings are vulnerable to harm caused by ill-conceived retrofit measures, and putting measures in place to avoid this happening. In particular, the STBA presents evidence suggesting that buildings of traditional solid-wall construction often achieve much better thermal performance than is expected from modelling, suggesting that the payback from retrofit insulation may be less than anticipated. They also underline the need for the development and use of *appropriate* assessments for traditional buildings, and the importance of a systemic whole-building approach when considering thermal performance, in order to minimize negative unintended consequences of retrofit measures.[1]

As a breathable natural material, hempcrete works in harmony with the existing fabric in older solid-wall properties, while improving the thermal performance of walls that were not usually built from highly insulating materials. Hempcrete was originally developed as a breathable, insulating replacement material for wattle and daub – the mix of earth, straw, dung and occasionally lime woven into a hazel, willow or ash framework to create walls in ancient timber-frame buildings. As well as this specific use, it has a number of other practical applications in the repair of, or retrofitting of insulation to, heritage properties. An overview of these uses is presented later in this chapter.

Hempcrete is the perfect material for repairing and increasing the thermal performance of ancient timber-frame buildings, due to its hygroscopic properties.

Hempcrete also fits against old timber frames much more snugly than board insulation does.

Key concepts in the retrofit of heritage buildings

It is not our intention to set out here comprehensive instructions for the use of hempcrete in heritage properties. Nor would this be possible, or desirable, since in the sensitive repair of or improvements to our architectural heritage every building should be treated on an individual basis, with a bespoke solution designed to provide the maximum insulation while remaining sympathetic to the specific needs of the building – and within the parameters set out by building control or, in the case of listed buildings, by the responsible body as part of the listed building consent. English Heritage has produced a free pamphlet to help owners of listed buildings understand the issues around improving energy efficiency without detriment to the building's character or existing fabric.[2]

About 50 per cent of our work at Hemp-Lime-Construct is on heritage properties, and while we have developed techniques that can often be reproduced in a number of situations, we find that to some extent each heritage job we undertake becomes a bespoke design-and-build project. The way that the hempcrete is applied in heritage buildings has to be adapted to work with the original building design and materials, as well as to meet the requirements of the client and the conservation officer.

English Heritage are generally supportive of the use of hempcrete within historic buildings, and it is one of the few materials they recommend for the upgrading of insulation in these properties. However, not all conservation officers have had first-hand experience of hempcrete, and some may need convincing before they are prepared to sanction its use. The main issue we come up against is a concern that the hempcrete will be applied in such a way as to alter the building's fabric in a way that cannot be reversed at a later date if necessary. However, this should not be the case, as long as application techniques appropriate to the situation are used, and such objections can usually be overcome with the provision of detailed information to the conservation officer and clear explanations of the proposed work. For example, spray application is not suitable for all aspects of work in historic buildings, owing to the force with which it is projected. When casting solid-wall insulation up against a hard stone wall, the force of projection causes no problems and in fact is an advantage, as it helps the hempcrete adhere to the surface. However, when casting up against the back of surviving plasterwork or wattle and daub, spray-applied hempcrete would adhere too closely to the historically important material, making later reversal of the works impossible without damaging the original fabric. For this reason, in most situations in historic properties, hand-placing is a more appropriate method.

It is recommended that anyone applying hempcrete in heritage buildings should not only be competent in the use of the material but also have specialist skills in, or at least understanding of, the repair of heritage buildings. This should include the repair of timber frames, cob, stonework and heritage roofs, and the use of lime (including fat lime – lime putty – plasters) and, where appropriate, clay mortars and plasters. It is not necessary for the hempcrete contractor to be skilled in every one of these areas, as other specialist contractors can provide these services, but an understanding of all of them is needed in order to be able to take a holistic view of the building and thereby design hempcrete insulation solutions that will complement and enhance the way the existing building fabric works.

The retrofitting of insulation to heritage buildings is a complex undertaking, even once appropriate breathable insulation materials have been identified. This is because the modern conventional wisdom on insulating buildings is to first achieve excellent levels of airtightness by sealing up any potential for draughts and leaks, where heated indoor air can exchange with cold air from outside.

In fact, older buildings were usually *designed* to have air leaks, with the burning of wood, or later coal, needing to draw air in from outside to feed the combustion of the fire or stove. Central masonry chimneys (and often thick stone walls) acted as thermal mass to store the heat produced by the fire, and also as a passive vent, allowing gradual changes of air within the building even when the fire was not lit. While this system was not anywhere near thermally efficient to the

Hempcrete, stone and cob alongside each other in a traditional cottage.

standards we require today, it did provide an effective passive regulation of heat and indoor air quality. More to the point, *it is how the building was designed to work*, so there is no point in sealing up the structure and trying to make it work like a conventional twenty-first-century new-build home.

This demonstrates the importance of having insulation solutions in heritage buildings designed by someone who truly understands how such buildings work. Rather than maximizing airtightness, the appropriate solution will be a balancing act. The idea is to leave the building (or restore it to) working as originally designed, and within this to 'tweak the edges' to get maximum thermal performance out of the system. This might include, for example, installing a wood-burning stove instead of the open fire, adding hempcrete solid-wall insulation (if possible to the *outside* of the wall), fitting natural-fibre loft insulation in the loft, reducing air leaks (but crucially not *all* of them), possibly introducing controlled ventilation, and installing natural insulation between suspended timber floors.

Hempcrete, sometimes alongside other natural-fibre insulations such as hemp-fibre or sheep's-wool quilt insulation, has proved itself capable of bringing solid-walled heritage properties up to a modern standard of insulation if used as part of a sensitive and thoughtful restoration or retrofit of the building. In the case of listed buildings, this is sometimes a little more difficult, because it is necessary to work within the sometimes exacting requirements of the responsible body with regard to maintaining the original appearance of the building inside and out. This can limit, for example, the available thickness within walls or roofs into which hempcrete can be cast. However, under the Building Regulations 2010, listed buildings, buildings in conservation areas and scheduled monuments are exempt from Part L of the Building Regulations (Conservation of fuel and power), so there is no longer a specific standard to be met. It is also worth noting that, according to English Heritage, special consideration under Part L should be given to "buildings of traditional construction with permeable fabric that both absorbs and readily allows the evaporation of moisture (which can conflict with modern materials and methods)".[3]

The aim for such buildings should be to improve energy efficiency as far as is reasonably practicable without affecting the character of the building or increasing the risk of long-term deterioration of the existing fabric. For a thorough discussion of how to retrofit insulation and renewable energy solutions to improve the sustainability, energy efficiency and comfort of heritage buildings without detriment to their character or to the vapour-permeable building fabric, a good resource is *The Old House Eco Handbook* by Marianne Suhr and Roger Hunt (see Bibliography).

Benefits of hempcrete for heritage buildings

Not only is hempcrete a suitable insulation material for use in a range of situations in older buildings, but in fact there are many situations, especially in listed buildings, where hempcrete is the *only* suitable insulation material. It is worth reiterating that, as with any structural intervention in an old building, hempcrete should be applied only within the context of a holistic review of the thermal performance of the entire building, undertaken by someone with specialist knowledge about the way in which old buildings work. That said, there are significant benefits to the use of hempcrete in heritage properties, which can be summarized as follows:

- Hempcrete works in harmony with, and in a similar way to, original materials in heritage buildings, ensuring that the breathable building fabric is maintained.

- It is more hygroscopic than wood, so it actively 'sucks' moisture away from timber frames and releases it into the air, helping to preserve the timber. This is especially important for frames with externally exposed timbers.
- Heritage buildings are not square and not built to today's standard measurements, and ancient timber frames will usually be quite warped. Wet-mixed hempcrete, being loose-fill, represents a huge saving in labour of cutting insulation boards to different shapes and sizes to fit in between the frame structures. In any case, cutting board materials to fit will never be entirely successful and will leave many gaps in the wall.
- Likewise, being loose-fill, hempcrete fills any voids and gaps when cast as solid-wall insulation against uneven stone walls.
- Finishes suitable for hempcrete are the same as for most heritage buildings, e.g. lime render, weatherboarding, hung tiles, brick or stone.
- Hempcrete, as a cast material, makes it easy to retain the curves and lines of original building, preventing any loss of original character as insulation is installed.
- Small amounts of hempcrete can be mixed up and used to fill those awkward small gaps and spaces that are always found in old buildings: small voids in walls; gaps behind door frames, at the end of joists, and at the top of the wall under the eaves. It's a breathable, insulating alternative to the menace of expanding foam!

Hempcrete can be used to fill small spaces and voids in old buildings, like a natural building equivalent of expanding foam.

Application method for hempcrete in heritage buildings

The main differences in the application method compared to that described in previous chapters, when it comes to working on heritage buildings, are in the framework and the shuttering. The hempcrete will usually be cast inside the building, next to or around some part of the original fabric, and while the interaction between the two materials can sometimes provide sufficient support, it is more usual for some form of frame to be screwed to the original building to create a key, or a reinforcement structure, for the hempcrete. An example would be a pattern of studs constructed within a timber-frame panel (as pictured opposite), to sit centrally within the hempcrete panel and provide a key against lateral loading from winds (see also Figure 15, page 276). Studs can also be attached to the inside of the frame to take shuttering screws, if the frame is to be left exposed as a decorative feature.

As anyone who lives in one knows only too well, old buildings are not straight, and nor do we want to make them so. Therefore, if applying hempcrete wall insulation externally around a building, for example, this should follow the original lines of the building rather than being cast perfectly square and leaving a structure with pristine

Reinforcing structure within a timber-frame panel.

The same wall with hempcrete cast and shaped.

new-looking straight walls. This is part of the skill of applying hempcrete sensitively in heritage buildings, and inevitably it makes the construction of shuttering a much more complicated and time-consuming business. A bespoke design will usually be required, with careful thought about how the shuttering will attach to the existing building fabric, and be removed, without causing any damage. Constructing shuttering on heritage buildings usually requires a lot of measuring and cutting of shuttering boards. Boards are likely to be smaller than on a new build, and are often needed in weird and wonderful shapes to fit around the existing structures.

Particular attention needs to be paid to how hempcrete walling will interact with the roof at the eaves, and with the bottom of the wall above ground level. Heritage properties are unlikely to have a damp-proof course, so a robust detail must be designed to ensure that it is not vulnerable to moisture ingress at the base of the wall.

The method of actually mixing and placing the hempcrete in heritage properties will be broadly similar to the method in a new build, although on heritage jobs the total amount needed is often smaller, and the work much more fiddly, than for a new build of the same size. For this reason it sometimes makes more sense to use a couple of bell concrete mixers instead of a large forced-action pan mixer, especially in the case of smaller timber-frame infill panels.

The choice of hempcrete binder used should be considered carefully. Often the limits of what is possible within the context of a heritage building necessitate designs that are inherently more vulnerable to air leakage along the edges of the cast material, so it is best to choose a binder that has very little tendency to shrink during setting (see Chapter 21, page 296), or account for this in the detailing by using hemp-fibre insulation (see Figure 15, page 276, and Chapter 21, page 298). It is advisable to cast some test areas and allow them to dry completely in order to gauge the success of your design (paying special attention to any shrinkage of the hempcrete, and the effect of this on airtightness) before starting on the project proper.

The range of finishes available for hempcrete are in perfect keeping with older properties, since they involve natural, breathable materials. Often, especially for listed buildings or buildings in a conservation area, the external appearance of the building is very important. Whatever is required – whether lime renders, hung tiles or slates, weatherboarding or stone or brick cladding – these can all be applied to the hempcrete walls and constructed from carefully sourced materials to match those originally used in the building.

As discussed in Chapter 2, various types of lime–hemp plaster exist, and the main use of these is within heritage properties. They add some insulation through the inclusion of the hemp fibre in the mix, and, while the insulation value is not as much as with the same thickness of hempcrete, they may be the best option for interior application where space is at a premium. They can be applied in thicknesses of 25-50mm, and it would be difficult and somewhat pointless (from a cost–benefit perspective) to cast hempcrete at such a thickness, as it would require such compaction to achieve structural integrity that the insulation value would be dramatically reduced. Lime–hemp plasters are also very useful for daubing out uneven old walls before they are plastered.

When using hempcrete in a heritage building, always keep in mind the main principles:

- Add as much insulation as possible in a way that does not detract from the character of the building or disrupt the way in which the original fabric was intended to work.
- Apply the hempcrete in such a way that it is reinforced and strong enough to take any loads placed on it.
- Hempcrete should work alongside the other natural materials in heritage buildings. However, it should not interact with them so closely, or in such a way, that the hempcrete could not be removed if required without damaging the original fabric.
- Bespoke solutions are likely to be needed to meet the requirements of the particular building in question.

Hempcrete infill panels to an existing timber frame

Infill panels in a heritage building tend to be much narrower than new-build hempcrete walls, so special care should be taken to create as low density a hempcrete as can meet the requirements for strength and integrity of the material, as the priority should be to create as much insulation as possible within the available space.

The following is our 'standard' method for constructing hempcrete infill panels to an existing frame. This method is adapted constantly to the particular requirements of the building we are working on, and, as already noted, it is more important to achieve the principles outlined above within the constraints of the building and planning conditions than to stick rigidly to the method described here.

Consider carefully any panels that contain original and/or historically important material, such as wattle and daub. If this is intact, the priority should be to preserve it, but sometimes even damaged panels with quite extensive loss of the original material can be preserved, with hempcrete added to replace the missing wattle and daub. The viability of preserving partially damaged panels should be assessed on a panel-by-panel basis (in the case of listed buildings this should be done in close liaison with the conservation officer). The method set out below is likely to vary slightly from building to building.

- Wear appropriate PPE when mixing and placing hempcrete, and ensure safe working practices are followed (see Chapter 9).
- Clean out all material from previous 'repairs': usually this consists of metal lath and cement, but we have also come across attempts at insulation panels using a softwood structure supporting polystyrene boards.
- Construct a row of reinforcing vertical studs centrally within the frame at intervals, specified by a suitably qualified person, sufficient to provide good lateral resistance to the hempcrete panel. These studs can be sawn battens, or coppiced roundwood (usually hazel or ash). They are fixed top and bottom into hardwood battens running left to right centrally within the frame. Their section size should be sufficient to provide the necessary reinforcing strength while allowing them to sit centrally within the frame with a good covering of hempcrete over them.
- If screws to hold temporary shuttering cannot be fixed directly into the outside (visible) faces of the timber frame for aesthetic reasons, separate hardwood battens can be fixed centrally down the inside of the frame to provide a fixing for shuttering screws, which can also be fixed into the vertical studs if necessary (see Figure 15(a) overleaf).
- If desired, a piece of natural-fibre quilt insulation can be fixed between the battens and the inside of the frame to improve airtightness at the edges of each hempcrete panel.
- All permanent fixings should be stainless steel or (in the case of nails) hot-dip galvanized.
- Board out the whole of one side of the panel in advance and then gradually build up shuttering across the other side, filling with hempcrete carefully to ensure all areas within the panel are filled evenly.
- Because the infill panels are generally narrower than for new-build walls, smaller lifts (200-400mm, depending on the frame) are usually required to ensure easy access when placing the hempcrete.
- If appropriate to the character of the building, the shuttering can be spaced out from the frame slightly using battens as packing, and the hempcrete shaped back afterwards to form a soft 'pillowing out' of the infill either side of the frame (see below). This provides an aesthetically pleasing effect while adding a little more insulation than is allowed by the width of the frame alone.
- When the top of the panel is reached, the shuttering board is moved up in smaller and smaller lifts (overlapping the hempcrete below), until a small space under the top frame timber is left. This is filled by pushing hempcrete in from the side, and it is best to do this with freshly mixed hempcrete straight from the mixer, as you are relying on the lateral adhesion of the most recent section of hempcrete to the previous one in order to keep it in the panel.
- When the shuttering has been removed, wait for the hempcrete to set sufficiently for any shaping work to be done using a nail float or multi-tool. Even if the panels are not being 'pillowed out', it is normal to cut the edges of the panel in behind the timber in this way, to about 25-30mm (see Figure 15(b)), so that when finishes are applied they are closed in thoroughly to the timber, with a 'shadow line' effect (see Figure 15(c)).
- When the hempcrete has dried sufficiently, apply finishes as normal. Note that because the panels are normally thinner than in a typical new-build hempcrete wall, the drying period can be shorter.

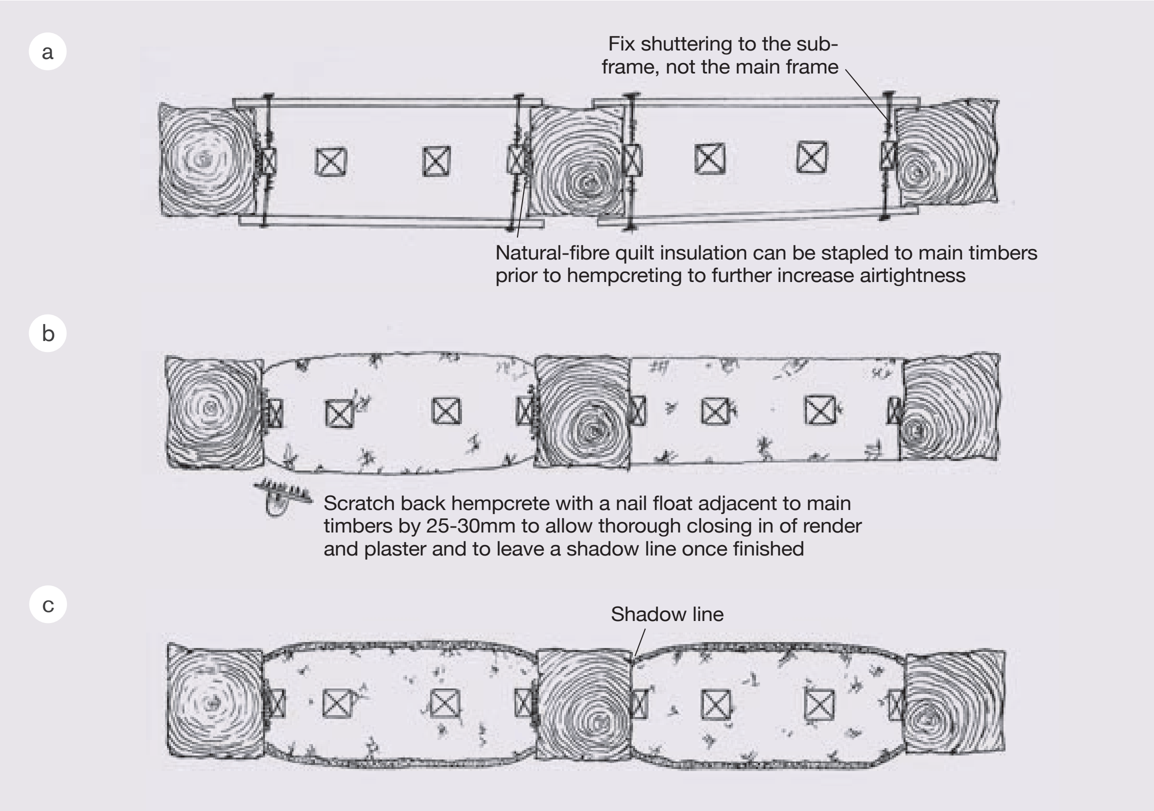


Figure 15. Hempcrete infill to a timber frame with the frame visible on both sides. (a) Shuttering fixed prior to placing. (b) Shuttering removed and hempcrete shaped back adjacent to main timbers. (c) Finishes applied, closed in to the main timbers.

Casting hempcrete as timber-frame infill panels.

Completed hempcrete infill panels before plastering.

Main uses of hempcrete in heritage properties

Of the various uses of hempcrete in heritage buildings, the most common are as follows.

Replacement of wattle and daub in timber-frame buildings

If wattle and daub still survives in a building, it has usually been (and should be) kept for its historic importance. Frequently, however, the original wattle-and-daub panels were replaced years ago, often having lasted many hundreds of years, and then failed after 'repairs' were carried out using a non-vapour-permeable render such as cement. In previous centuries, replacement infill was usually made from bricks laid in lime mortar, which, while not very insulating, was at least vapour permeable – until rendered with cement in the 1960s! This historic brickwork, while not original, is a very attractive addition to the building's character, and one that is often seen has having historic importance in its own right. However, in many cases the weight of the brickwork is too much for the ancient timber frame and can actually cause structural damage to the building. In such cases there is an argument for replacing historic brickwork (where it has to be removed anyway to repair the frame) with an appropriate insulating material such as hempcrete.

If the replacement of original wattle and daub was done in the second half of the twentieth century, it often comprised nothing more than a cement render over 'metal lath' (a kind of steel mesh) on both sides of the wall, with nothing in the middle of the panel. If cement render has been used around a timber-frame construction, this is inherently damaging to the building, as it will hold moisture against the timbers, and should be removed as soon as possible.

Hempcrete acts as a modern insulating version of wattle and daub, and stays very faithful to the original wall build-up, since it contains a fibre (hemp instead of straw), a binder (lime instead of earth or earth–lime) and a supporting wooden framework inside it. At Hemp-Lime-Construct we now normally use local coppiced roundwood for the supporting framework, although in a different configuration from the original wattle. The method of application is as described on page 274.

In the case of timber-frame panels where original wattle-and-daub materials are only partially degraded, it is possible to apply hempcrete in quite a thin layer (50-70mm) by daubing it over a reinforcing structure of split hazel poles, nailed or screwed to the frame timbers. This doesn't add a huge amount of insulation, but very few materials are suitable for this purpose, and hempcrete would add more insulation than the equivalent thickness of lime–hemp plaster, for example, while filling any awkward voids or tricky spaces.

Because wattle-and-daub panels tend to degrade on the exterior face (where they have been covered in cement, which causes more damage than the original exposure), the hempcrete is

Daubed hempcrete over a wattle-and-daub panel, using split hazel poles to provide a key.

most often daubed on to this face, which gives the historic fabric a better level of protection from the elements than a lime render alone, while preserving the character of the building (as shown in the photo on the previous page).

Insulating infill to lath-and-plastered walls in timber-frame buildings

The use of hempcrete cast up against the back of lath and plaster allows the retention of these original materials, usually internally to act as a 'permanent shuttering'. The hempcrete on the external side of the wall can be finished to replicate the original walls, for example with weatherboarding, hung tile or slate cladding or a lime render.

External temporary shuttering is cut to follow the shape of the ancient frame, which over hundreds of years will have twisted and warped to give the building a unique character. If the lath and plaster is fixed directly to one side of the timber frame, and you are wrapping hempcrete around the frame on the other side, remember to fix horizontal battens to the outside of the frame to provide a key for the hempcrete, as you would in an exposed frame design with internal shuttering.

Solid-wall insulation on masonry buildings

Hempcrete can be cast straight against masonry walls to add insulation. This can be done either internally or externally, depending on the requirements of the situation.

If the wall has been pointed or rendered with cement, or plastered with gypsum, these should be removed (in the case of cement) or hacked off (in the case of gypsum plasters), with pointing replaced with a lime mortar appropriate to the type and condition of the masonry. If pointing is lime and in solid condition, it can remain. It is important to give the wall sufficient time to dry out fully before casting hempcrete.

Clay plasters used in the repair of a historic timber-frame property.

The same repair from the back, before hempcrete is cast around the frame from outside.

The same wall with hempcrete in place.


Hempcrete cast as solid-wall insulation internally fits neatly into the uneven surface of the stone wall.


A completed wall of hempcrete solid-wall internal insulation.

Hempcrete is cast against the face of the wall, either by spraying or by hand-placing using shuttering. Aim to cast as much hempcrete as possible within the situation (and when it comes to calculating the U-value achieved overall, remember that the thermal resistance of the original masonry wall should also be factored in). Depending on the substrate and the thickness being cast, the hempcrete is usually tied in to the original wall, with bolts or screws fixed through, or cast into, the hempcrete. A reinforcing timber frame may be required in some instances, again depending on the thickness of hempcrete cast.

Hempcrete solid-wall insulation is especially useful where walls are of rubble stone or uneven block construction, with irregular stones which create an uneven wall. The hempcrete, being 'loose-fill' in its freshly mixed state, leaves no large voids between the insulation and the face of the stone. In contrast, a board-type insulation on an uneven wall carries the risk of voids being created within the wall, which are then prone to interstitial condensation as vapour passes through.

As it has a good amount of thermal mass, hempcrete complements the original solid walls perfectly, working in the same way but adding insulation. In terms of thermal performance, it is better to cast such insulation externally, as the thermal mass of the original wall is wrapped inside the hempcrete insulation. This also minimizes disruption inside the property, and doesn't subtract any of the living space inside the building. However, casting externally is not suitable for all situations: buildings where the original façade is of historic or aesthetic importance, for example, are usually best insulated internally. Also, casting externally usually involves some small extension of the roof overhang, in order that it covers the top of the hempcrete.

Hempcrete solid-wall insulation at a thickness of 70-100mm, with lime plaster applied.

Hempcrete, lime render and limewash complement the original materials and aesthetic of this building.

Casting hempcrete internally allows the retention of the original façade, but obviously involves more disruption for the building's occupants. Depending on the exact requirements and if the work is carried out carefully, it is possible to insulate internally with no more disruption than that encountered when replastering. Needless to say, spray application would not be advisable in this context. In general, internal insulation is a much more sensible option when a complete refurbishment of an old property is being undertaken.

Internal insulation will always demand a balance to be found between the insulation achieved and the amount of room space lost. Synthetic insulations perform better than hempcrete at lower thicknesses, but are to be avoided in older buildings as they seal up the breathable wall. The only other natural solid-wall insulation (unless you have the space for straw bales!) is a wood-fibre board, but unless the wall is completely flat this will leave voids behind it, and it may not stick very well (it's often glued in place with breathable adhesives).

In any case, the casting of hempcrete solid-wall insulation should always be considered within the context of the thermal performance of the whole building, rather than seen as a one-off measure that is assumed to automatically bring fuel bills down. You can cast all the hempcrete you want on the face of the walls, but if there is a howling gale blowing from leaky doors and windows, or up through the floorboards, or all the chimneys are wide open, or the loft insulation is below standard, you will find it has had little impact on the overall performance of the building.

Whether casting hempcrete internally or externally, careful thought needs to be given to detailing around doorways and windows, where the increased depth of reveals may necessitate alterations. In addition, cabling to electricity sockets and light switches will need to be extended, running in conduit through the hempcrete, and the new boxes set flush into the face of the hempcrete.

Hempcrete floor insulation cast in the void under a suspended floor in a late Victorian terraced house.

Breathable insulated floor slab

Vapour-permeable floors are very important in heritage buildings, which usually don't have a damp-proof course. Installing a conventional modern floor with a damp-proof membrane stops ground moisture from rising freely through the floor to be vented away or re-absorbed (depending on conditions) and causes a build-up of moisture under the floor. Eventually, when it reaches sufficient levels, this excess moisture will start to be forced up into the walls, causing damage to finishes at a low level, and potentially also to the structure of the walls themselves.

A hempcrete floor slab in a heritage building requires the same basic application method as described in Chapter 17 (see page 224), with the proviso that this must be adapted to the exact requirements of the building in question, and be designed in such a way as to complement and preserve the original fabric of the building. This means considering how all of the existing floor elements are working, and checking that they remain as originally detailed, especially with regard to the external ground level, as this has often been built up gradually over the decades or centuries – a process which can, for example, block air vents that are intended to take air below suspended floors, or bring the groundwater level outside to a level above the earth floors inside.

When retrofitting a breathable floor, special attention should be paid to adequate drainage in the form of French drains around the building. Where these exist, they may need clearing out; if they were not there originally, they are worth installing, as this is an efficient way of helping to divert the flow of groundwater around the building and so reducing the amount of moisture that the floor has to deal with. It also has little or no impact on the original fabric of the building, and so is usually possible even in listed buildings. French drains are especially important uphill of structures that are built into sloping ground. Where a building stands on 'flat' land and further landscaping is appropriate, try to do so in such a way that the ground adjacent to the building slopes gently away from the walls, to encourage rainwater to flow away from them.

Focus on self-build 2: Hemp Lime House

Leah Wild never intended to build a hempcrete house. She was ready to construct a steel-framed, earth-sheltered home, and had had the designs drawn up, got planning permission, and bought many of the materials. She was on the point of buying the plot of land on which she would build it, when the vendor pulled out at the last minute – leaving Leah, who had already sold her house, with three children and nowhere to live.

Hurriedly looking around at what was for sale locally, Leah found a 1920s railway worker's house: a single-storey chalet bungalow of timber-frame construction, with 5mm asbestos boards internally and externally. "There was nothing at all except the frame timbers sandwiched in between the asbestos sheeting. The suspended wooden floor was rotten, as was most of the frame itself," says Leah. "Absolutely every surface inside the house was covered in asbestos."

Always keen to build using natural materials, Leah was introduced to the idea of hempcrete by a friend. After discussion with William Stanwix, she decided that hempcrete was the perfect way of dealing with the building. "The hempcrete would be cast around the frame, providing it with racking strength and excellent thermal performance. Because it's a relatively lightweight material, it matched what was there in the original structure, so there was no need for expensive alterations to the foundations. The hempcrete was easy to work with, and it looks and feels beautiful. On top of that, the house in its original state was not considered to be a mortgageable property, but once we'd improved the overall strength of the timber frame and put the hempcrete in, upgrading the thermal performance, I was able to get a mortgage on what we had built."

Because mortgage companies were wary about lending on it, the house was priced cheaply considering its size and its location on a pretty Cotswold hillside just outside the town of Stroud. Leah clearly had the vision necessary to take on this dilapidated, freezing, toxic shell and turn it into the comfortable, healthy, thermally efficient house it is today. She says: "We stripped out all the asbestos, repaired the frame and cast 240mm hempcrete around it." The frame was positioned on the internal surface of the new walls, and wood wool board fixed to it as an internal permanent shuttering. Hempcrete was then cast between the vertical studs and around the outside of the frame. Leah's planning permission also allowed her to build two small extensions, to make the T-plan house into a rectangle. Since these were built in the winter, when using hempcrete would have been difficult, she used hemp-fibre quilt insulation in the walls instead. Finding herself unable to stop, Leah went on to convert an old shed in the garden into an 'annexe', where her teenage daughter now lives, using natural materials in that conversion too.

The hempcrete in Leah's house is finished in a mixture of home-made lime–hemp plaster and lime plaster in different places around the building, in the spirit of trying different things to see how they performed. A locally grown larch

1. Hemp Lime House sits up on a hillside nestled in a lush garden.
2. Leah has proven that a stylish interior can be created from second-hand and reclaimed items.
3. Local larch cladding was used on the gables.
4. Natural plasters and breathable paints create a soft feel throughout.
5. Although small, the house still manages to feel spacious and full of light.

cladding was used on the gables. Most of the plaster hasn't been painted, as "it was a lovely finish without anything being added to it". Where it was painted, a lime paint was used. The bathroom was finished in gypsum plaster, the surface brushed to give it a rough look and three coats of wax applied to simulate a Moroccan tadelakt look.

Leah designed the house "on the back of an envelope", having blown her architect budget on the house that never was, and freely admits she was broke and "had to beg, borrow and blag as much money as I could just to get the building to a stage where I could raise a mortgage on it". The ethos of Leah's build is reusing and recycling: window frames made from pitch pine beams reclaimed from an old church; £6,000-worth of low-emissivity argon-filled glass from eBay for £400; floor tiles, wall tiles and kitchen all surplus stock from eBay; and she has used natural, local and responsibly sourced materials wherever possible. This low-tech, DIY attitude hasn't prevented Leah from creating a beautiful and comfortable home with its own unique style.

There were no issues with Planning, who it seems were sympathetic to Leah's style of building. All the work was carried out under permitted development, and building control approval was sought retrospectively, as "the build just moved on so quickly". It took Leah and her friends just eight weeks (seven days a week) to complete the build, from starting the demolition of the old building to moving in. Leah used a lot of volunteer labour, and friends with relevant skills helped her out when needed. The main people involved in the build were Leah's friend Andy, her son Liam, and his friends Dan and Luke, with plans and elevations drawings provided by Leah's friend Tracey, in order to illustrate to the local authority the proposed development of the building.

The disadvantage of working with hempcrete, as far as Leah is concerned, is that "you are treading an unknown and unpredictable path, and when you phone hempcrete 'experts' they all give you different advice, or only want to give you advice at all if you are using their own products". Despite this, however, and despite the experimental nature of the build and materials used, Leah is happy that overall there have been very few problems, and where these have occurred they have mostly been due to inexperienced builders with too much youthful optimism about, for example, the number of fixings you need to hold a wood wool board up. A few slight problems with the design showed up a few months down the line: for example, a wall with spots of mould appearing on the render caused by water wicking up into, and running down, the render (as there was insufficient roof overhang – with no rainwater goods – and the render had been continued down over the plinth nearly to the ground). Leah says, "We corrected this by chopping out the render and the hempcrete at the bottom, building up the height of the plinth slightly, and extending the roof overhang, and we've had no problems since."

Leah is impressed with how thermally efficient her house is. "It's boiling hot out there today and it's lovely and cool in here. In the winter when you heat the place up and turn the heating off it stays warm for hours and hours, because the hempcrete acts as a heat store." Leah has a wood burner and a gas boiler with cast-iron radiators: "I recycled the old gas boiler that was already in the house, which in hindsight was a mistake – I think if I did it again I'd go for underfloor heating."

Asked about the reaction of friends, Leah says, "Everyone who comes in says it feels amazing – we get really positive responses from everyone who visits . . . it's got a really nice feeling to it – it never feels stuffy, or claustrophobic, or sweaty, or over-heated, or too cold, or . . . it just feels like a living, breathing building . . . you can sort of tell that it's been built with natural materials – it's just got that feel to it."

1. The open-plan living space.
2. The original building. *Image: Leah Wild*
3. The 'annexe'.
4. Leah brushed and waxed ordinary gypsum plaster in the bathroom to simulate a tadelakt finish.
5. Leah in her hempcrete home.

PART THREE

Designing a hempcrete building

CHAPTER TWENTY-ONE

Design fundamentals

There are currently no industry standard details for hempcrete in the UK. Each supplier or manufacturer has, to some extent, set out their own standard details for very basic hempcrete walls, floors and roof insulation and currently there is a lack of clear cross-industry standards. In part, this is due to the fact that building with hempcrete is a fledgling industry and new details, methods of construction and products are being developed all the time. Likewise, many of the materials and products that work with and complement hempcrete are also relatively new, for example recycled glass foam blocks, natural wood-fibre boards and hemp-fibre insulation; and this constant innovation, while very welcome in many respects, contributes to the problem of standardization.

Another contributing factor is that until quite recently the hempcrete market in the UK was effectively monopolized by one company supplying both hemp shiv and binder. The amount of hemp building which happened was not sufficient to warrant a more competitive marketplace or widely agreed standards for construction. This has resulted in testing of, and detailing for, proprietary products rather than hempcrete as a generic material. In recent years the market has begun to open up slightly, with more choices of binder and sources of shiv coming on to the market. It is hoped that this situation will create an atmosphere in which wider industry cooperation and agreement on standard detailing will emerge.

A cross-industry acceptance for hempcrete as a material would allow standard details and construction practices to be developed for the most common types of buildings, and for materials used alongside hempcrete. This could only be beneficial to the industry as a whole since it would simplify the building control process, and an accepted construction methodology would allow those building with hempcrete for the first time to use the material with greater ease. It would remove a lot of the stumbling

Previous page: A slightly tapered window reveal allows more light into the room and is an interesting alternative to a square reveal.

blocks which currently deter architects and builders from working with the material, and which sometimes complicate the process when they do use it.

More hempcrete buildings can only be beneficial to the hempcrete industry as a whole and to the environment. It is our hope that this book and the indicative details contained within will add to the impetus for the hempcrete industry (including contractors, designers, material manufacturers and bodies responsible for sustainable construction) to initiate the process of writing publicly available standards for hempcrete construction.

The two chapters in this part of the book aim to explain, to the building designer, the working characteristics of hempcrete: how it behaves during and after construction and how this may affect the design. Our hope is that designers will then be able to make informed judgements when detailing their buildings. Chapter 22 also demonstrates, with the aid of technical drawings, some in-use technical details in buildings from the UK and Europe.

With any building material, appropriate detailing relies on the architect or designer understanding the material in question. The following is a set of essential, but not exhaustive, points to consider when detailing hempcrete buildings:

- Structural limits of the material.
- Nature of the material.
- Construction process.
- Topography and climate of the site.

Structural limits of the material

As a wet-mixed, loose-fill material, cast hempcrete can form more or less any shape you can mould it to. And since it is a non-load-bearing element, its structural properties are not a critical factor in the success of the building as a whole. However, this doesn't mean that no thought should be given to hempcrete's own structural integrity in any given situation. The key considerations are outlined below.

Coverage over structural elements

A significant part of the strength of hempcrete derives from the interlocking nature of the hemp aggregate and the binder's set, but hempcrete also relies on its mass and monolithic structure for strength. It is a flexible material and will absorb the movements expected within a timber frame, but sections that are too thin or too removed from the overall mass constitute weak spots, which are susceptible to cracking. There is

Casting hempcrete at less than 50mm coverage over timbers causes weak spots.

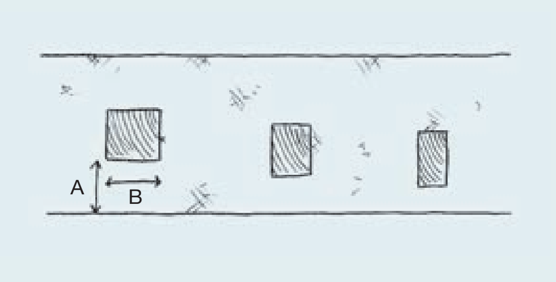


Figure 16. The coverage of hempcrete over timber (A) should be greater than or equal to the width of the timber (B).

therefore a limit to how thin hempcrete can be cast where it covers structural elements within the wall. For example, if the covering of hempcrete over studs within the frame is too thin, cracks could appear along the line of the studs.

There are no hard and fast rules to minimum coverage. Vicat have produced a coverage chart for their binder, Prompt, but this is not an industry standard chart. As a rule of thumb, all timbers or other structural elements should have at least 50mm covering of hempcrete, and the covering should be at least as thick as the timber is wide (see Figure 16).

Externally, the minimum coverage is limited not only by the structural integrity of the hempcrete but also by the risk of moisture ingress damaging the timber frame. During tests that simulated severe driving rain on a hempcrete wall, a maximum water ingress of 70mm was recorded:

> Tests for water penetration were carried out by the BRE for the Haverhill project on rendered hemp-lime walls 200mm thick. A rotary Spray apparatus was employed to apply water levels similar to one year's worth of wind-driven rain at a severely exposed location, or five years elsewhere, over a 96-hour period, after which the absorption had reached a 50-70mm depth . . . the test simulates a severe exposure and massive water application over a short period with positive results.[1]

Despite the fact that such weather conditions as simulated in this test are unlikely to occur, and that in fair weather the moisture that enters a hempcrete wall very quickly dries to the outside, this does suggest that any structural element should have a minimum of 70mm of hempcrete cover towards the outside face of the wall. If 70mm cover cannot be achieved, then a hardwood frame or external cladding may need to be considered. Hardwood is less susceptible than softwood to damage from exposure to moisture, and as such should be able to withstand the rare occasions of constant driving rain. Of course, if driving rain is a regular feature on the proposed site, and this cannot be mitigated through the siting of the building, then an alternative to render for the exterior finish should be considered. Well-detailed clad walls with a breathable membrane and ventilated air gap effectively eliminate water ingress (see Chapter 22, page 330).

Wall thickness

With regard to the overall thickness of the wall, the U-value of hempcrete limits the minimum thickness. UK Building Regulations regarding minimum U-values for new buildings are continually updated, but at the time of writing, the minimum width of a hempcrete wall should be around 250mm (see Chapter 11, page 140), depending on the choice of binder.

Of course the maximum width of the wall is governed more by the client's pocket and the law of diminishing returns than regulations, but it is worth noting that the labour cost of increasing a 250mm wall to 350mm is comparatively low, and that the bulk of the extra cost would be in materials alone. Building a 400mm wall does not cost twice as much as a 200mm wall, for several reasons. The shuttering, permanent or otherwise, remains a constant, as does the structural frame. Because hempcrete is a relatively lightweight material and placing it is a quick business, even doubling the labour of placing doesn't add significant costs to the build overall. However, casting walls in excess of 400mm wide will not produce much of an increase in performance relative to the extra cost, and the thicker the wall, the longer it will take to dry. For all these reasons, hempcrete walls are usually cast at thicknesses of around 300-400mm.

Where less stringent regulations apply to the required U-value, it is possible to build walls thinner than 250mm. This might be, for example, in a garden building, when constructing internal walls, or during the refurbishment of a listed building where protection of the original fabric and historical character of the building take priority over Building Regulations on insulation. An absolute minimum for a hempcrete wall has not been defined, since it is a thermal element and so one would usually be seeking to increase its depth rather than minimize it. In the past, 200mm and 175mm external walls have successfully been achieved, as have 125mm internal walls and 150mm external walls in the restoration of historic timber-frame buildings. Of course, the depth of cover over structural timbers must be considered when constructing thin walls (see page 290), so wall thickness will always be limited to the width of the structural frame within it plus the minimum recommended cover over this structure.

Racking strength

Hempcrete's monolithic structure provides not only insulation and a substrate for plasters and renders but also a great deal of additional rigidity to the structural frame (see Chapter 7, page 91). This rigidity, or racking strength, is the ability of the structure to resist movement as a result of external lateral forces, such as from wind. The higher you build, or the more exposed the site is, the greater the racking strength required. Some binders, for example Tradical® HB, have been tested for racking strength, and this information should be available from suppliers. All but the smallest and simplest of frames will require some braces to provide racking strength within the frame design, if only to keep the frame upright until the hempcrete has been placed, but thanks to the rigidity provided by the hempcrete, the bracing required will be less substantial than it would have needed otherwise.

It should be remembered, however, that the racking strength provided by the hempcrete is only as good as the workmanship of the hempcrete installer. If this was poor, i.e. with little attention paid to the placement of the hempcrete at a correct and consistent density and tightly against the structural members, then the racking strength it provides might be less than expected.

Chapter 22 looks in more detail how racking strength can be achieved (see page 319).

Nature of the material

The fact that hempcrete is a plant-based material will pose a challenge to most UK architects and designers, who may be familiar with the use of timber and thatch in buildings but, with the possible exception of straw bale, are unlikely to have come across the use of organic materials to construct walls. The use of a lime, or lime-based, binder will also be unfamiliar to most of those involved in conventional masonry construction, and brings other factors that need to be taken into consideration.

There are a few simple but necessary differences in the design principles that should be applied when using hempcrete as opposed to conventional building materials. Taking these into account should prevent the construction of buildings that are destined to work badly because the basic nature of the material was not properly understood at the design stage. The key factors are explored below.

Vapour permeability

As described in previous chapters, hempcrete is a vapour-permeable material. Thanks to the porosity of the hemp shiv at a microscopic level, of the cast material at a macroscopic level, and of the lime binder, hempcrete is also highly hygroscopic. The ability of a hempcrete wall to easily absorb and release moisture not only helps to maintain the building's fabric in good condition but also brings benefits for its occupants, as the structure passively regulates internal humidity, and thus maintains a healthy indoor air quality. The movement of moisture through a hempcrete wall also has an effect on its thermal performance, by playing a part in its hygrothermal behaviour (see Chapter 7, page 96).

For good reasons then, one of the main design principles which should be remembered throughout the detailing of a hempcrete building is that no materials should be introduced that may compromise the vapour permeability of the wall build-up.

In particular, special attention should be paid to the specification of finishes: cladding, plasters, renders and paints. Over recent decades our understanding of the importance of 'breathable' finishes has been lost, and the norm in conventional construction is now for the use of, for example, gypsum plaster, which does not release moisture in the same way that lime or clay plaster does, and paints that form an impermeable chemical coating on the surface of the wall. Vapour permeability is a theme which runs through much of the discussion in this and the next chapter, but it is of such fundamental importance that it is as well to highlight it here, so the designer of the hempcrete building has it in mind from the outset.

Vulnerability to moisture ingress

As it contains an organic aggregate material (hemp shiv), hempcrete will always be at risk if exposed to extended periods of moisture ingress, or if moisture is trapped within the wall. Of course, the use of vapour-permeable finishes allows moisture to leave the wall as well as enter it, and the lime in the binder acts as an effective anti-rotting agent, protecting both the timber frame and the hemp shiv, but appropriate detailing should aim to keep as much precipitation as possible away from the wall in the first place.

A robust approach should be taken to the prevention of water ingress. Eaves details should include a large overhang. There is no standard minimum overhang for hempcrete, but the approach should be to explore the maximum that works with the design rather than looking for the minimum. As a rough guide, consider an overhang of 150mm horizontally between the face of the wall and the end of the rafter for single-storey pitched roofs, or 300mm for double-storey, as an absolute minimum, unless exterior cladding or a hydrophobic render is to be used. In each individual case the climate and topography of the site should be considered carefully along with the design to ensure that an appropriate detail is chosen.

While a good-sized roof overhang is probably the most reliable approach, many successful hempcrete buildings have been built with a much smaller, or even non-existent, overhang. Where this is desirable, for example for aesthetic

Copper rainwater goods on a hempcrete house: a robust and attractive solution.

reasons, the key to successful detailing is to consider alongside the design of the eaves and rainwater goods the type of finish that will be applied to the wall. The usual render finish for hempcrete is a lime–sand render. This provides a good balance between breathability, flexural strength and resistance to rainwater, but it remains relatively porous to moisture. If a design with no or very little overhang is proposed, more protective forms of external finish should be considered. These might include, for example, a timber rain screen or cladding, a more hydraulic lime render, or a proprietary hydrophobic lime finish such as those made by Baumit and specified as part of the Tradical® Hemcrete® system.

Guttering should be of durable construction, and if within reach of falling leaves should have some sort of guard against blockages.

Drip details, at window ledges for example, should be appropriate for the volume of water likely to pass over them, and should extend further from the walls than is normally seen in

Oak drip details on a hempcrete house, above the window and at the sill.

A drip detail incorporated into the bottom of the render stops water from running down the plinth.

conventional masonry construction, to reduce the risk of the dripping water being blown back by wind on to the wall surface.

The inclusion of drip details in the render, for example above windows and at the bottom of the rendered wall where it meets the top of the plinth, is sensible practice. If natural drip details are to be used at the plinth (see Figure 14(b), page 246) these will need to be fixed in place before the hempcrete is placed.

At window or door openings, external render should be properly sealed to the frames, using either appropriate frame seal render beads or render stop beads with a suitable mastic seal (see Chapter 18, page 245). As lime renders tend to shrink back a little on drying, it is important to use a bead with a glass-fibre mesh to be incorporated into the render. A more natural alternative is to render up to the door or window frame and then place a hardwood corner bead to cover the join, held in place with a line of burnt sand mastic down each side (see Figure 13(a), page 245). Burnt sand mastic, as well as being free from the toxic chemicals and high embodied energy associated with conventional sealants, will retain its flexibility over time. In contrast, conventional mastics tend to go hard and brittle as they dry out, making them unsuitable for use with lime renders. Another alternative is to design out the bead altogether by extending the hempcrete over the window frame (see Figures 13(b) and 36(c), pages 245 and 337).

Within the structural frame, timber studs to which window or door frames are fixed should be protected with a 'breather' (vapour-permeable) membrane (see Figure 17). This is necessary because it is an area with a less-than-ideal covering of hempcrete, which is therefore susceptible to water ingress. An alternative would be to use hardwood or other rot-resistant timber in vulnerable locations such as these.

The plinth is designed to keep the hempcrete section of wall clear of any splashback from rain hitting the ground, and should therefore be at

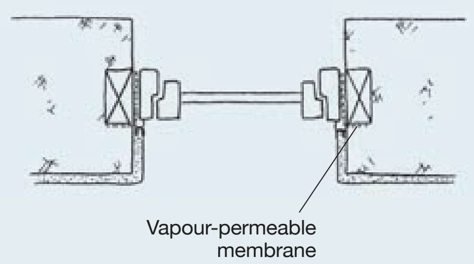


Figure 17. Timbers around openings are vulnerable to moisture and need additional protection.

least 250mm high. An increased plinth height should be considered if the wall is in the drip zone of trees or exposed to the prevailing weather.

Shrinkage

Because it is a wet-mixed and naturally flexible material, hempcrete tends to shrink very slightly as it dries out. Different binders result in different rates of shrinkage, depending on their strength and setting times: some slower-setting or weaker binders give a noticeable 1mm or 2mm gap at junctions, while others, for example Prompt Natural Cement, have practically no shrinkage at all. See Chapter 6 for details of different hempcrete binders.

Except when it is spray applied, hempcrete does not adhere tightly to the structural members within the wall. Instead, its strength derives from the fact that it completely engulfs and sets around them, with its fibrous aggregate tying it together. Therefore any frame component that extends from one face of the wall through to the other has the potential to create air leakage, as a result of gaps forming around it as the hempcrete dries. The use of such elements should be avoided wherever possible, but where they cannot be avoided, steps should be taken to mitigate air leakage. In the rest of this section we discuss how to counteract any shrinkage gaps at junctions. Airtightness as a whole is not discussed here, but is covered in more in depth in Chapter 22.

Exposed frame internally and externally

This situation may arise in the refurbishment of a historic timber-frame building where the main timbers are to be left exposed both internally and externally. If upgrading or replacing the panels of material between the timbers with hempcrete, the junction between the hempcrete and the main timbers is at risk of air leakage. To mitigate this, a binder with extremely low shrinkage, such as Prompt Natural Cement, can be used. Owing to its aggressive set, Prompt reaches full strength before all the water leaves the material, and is therefore strong enough to resist the shrinkage otherwise caused by drying. By adding a timber batten to the junction you increase the surface area of the junction and introduce an obstacle to the passage of air, reducing it further (see Figure 15, page 276). It is possible to introduce a natural-fibre insulation to this junction to further increase airtightness at the edges of the panel, but in our experience this is rarely necessary. The use of Prompt as a binder, together with the batten and a good standard of finishing, is sufficient for restricting air movement in a historic building that will never, and is not expected to, meet modern standards of airtightness.

The double frame

Usually seen in new builds where external cladding is specified together with an internal permanent shuttering board, the double frame is flush with both faces of the wall. It comprises an internal stud (usually the structural stud, taking the load of the roof and upper floors), which also provides the fix for the permanent shuttering board, and an external stud, usually of smaller-section timber, which takes the load of and provides the fix for the cladding. These are joined by squares of timber board such as OSB or plywood, fixed to each stud at vertical centres of around 1200mm. Although these extend through the wall, they have little effect on airtightness, because both faces of the wall are covered: internally they are covered by a plaster carrier board plus the plaster; externally there may be a protective basecoat render (see Chapter 22) and/or a vapour-permeable membrane, which can be joined to the airtight elements in other parts of the building. Again, hemp-fibre quilt insulation can be used at junctions with other materials, or alternatively a synthetic expandable tape, although as highly processed petrochemical-based products these tapes have a higher embodied energy and so increase the environmental impact of the build.

Junctions at the cross-over to another material

Where hempcrete meets another material, the junction needs to be carefully considered in terms of possible hempcrete shrinkage. Examples of this include the junction between the top of a hempcrete wall and quilt-type roof insulation material, or a hempcrete wall meeting a masonry wall in an extension to an existing building.

There are many such situations and countless different materials that the hempcrete might be adjoining, so we will consider a common situation: an offshoot extension to a solid-walled brick property. Using Prompt in this situation could reduce shrinkage, but since shrinkage is not the only factor to consider when choosing a binder (see Chapter 6), this may not be an appropriate solution.

Rather than trying to achieve a single solution to the problem, a more fail-safe approach would be to consider the airtightness of each element joining the brick wall individually. These elements will usually be a timber-frame stud, the hempcrete and the external finish (lime render or cladding), as shown in Figure 18.

The timber stud could be sealed to the wall using expandable tape stuck to the back of the stud before it is fixed to the wall. This will slowly expand once the stud is fixed, filling the gaps that inevitably occur when fixing a flat material to a brick wall. However, these tapes are made of synthetic materials and little information exists about their longevity, so they may not constitute

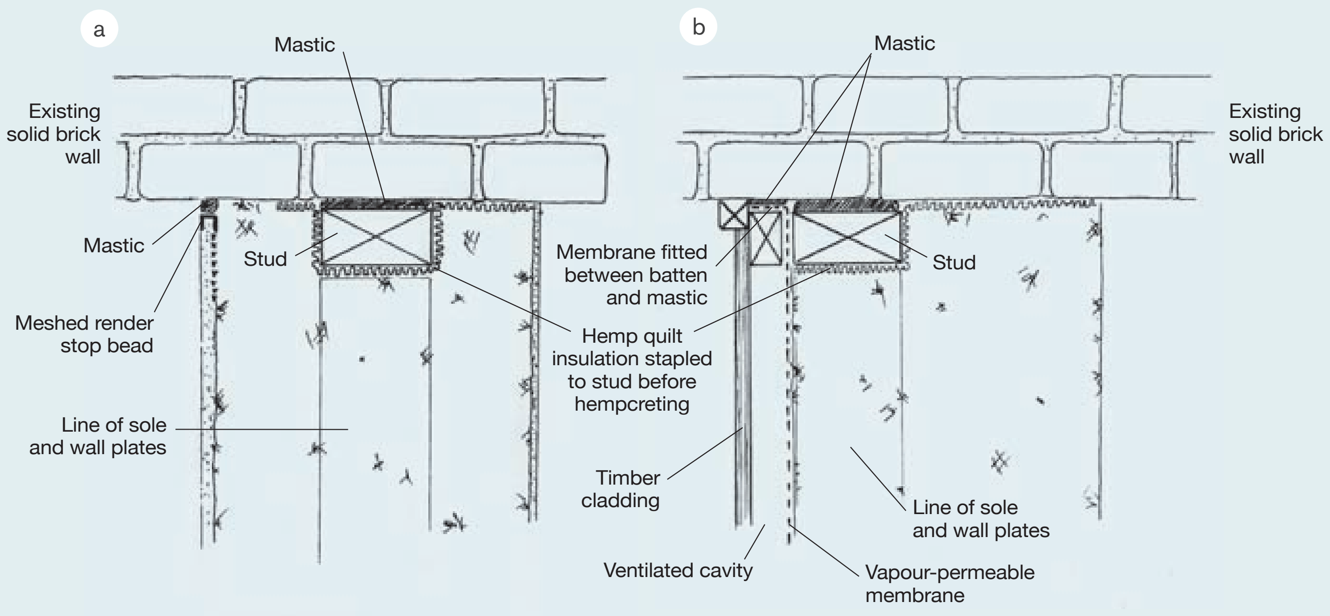


Figure 18. Plan view: methods of achieving airtightness at junctions between a hempcrete wall and a masonry wall, for (a) a rendered wall; (b) a clad wall.

Using hemp-fibre insulation to create airtightness at a junction between hempcrete and an existing wall.

a robust solution to airtightness in the long term. The same effect can be achieved by the addition of a natural mastic sealant prior to fixing the stud. Environmentally sustainable mastics include burnt sand or linseed oil mastic sealant, which can be used to good effect here.

Joining to the hempcrete is more difficult than to the timber, since the hempcrete may shrink back from the wall very slightly as it dries. For this reason, whatever is used to fill the gap needs to be able to withstand the initial damp environment and remain 'springy' enough to fill any gap caused by the hempcrete drying.

A natural, springy, fibrous insulation such as wood-fibre (or hemp- or flax-fibre) quilt insulation fits the bill nicely. The width of this insulation should be cut down to the size necessary for the following to be achieved. The insulation should be stapled to the three remaining visible sides of the stud (the sides of the stud facing into the void for the hempcrete wall), so that when the hempcrete is placed it can be pushed up against the insulation, and the insulation compressed between the hempcrete and the masonry wall. One edge of the insulation quilt should be close up to the internal shuttering board, and the other edge should sit back at least 70mm inside the external face of the wall, if this is not to be protected with a rain screen such as in the form of cladding. (These types of insulation are able to act as an effective moisture buffer, but since they are not recommended for external use, it is prudent to respect this minimum distance from the external surface.)

The springy insulation quilt will be compressed down, for example from 40mm thickness to less than 5mm, so any shrinkage of the hempcrete will be easily taken up by the insulation material expanding to fill the gap.

This solution can also be applied to the junction between hempcrete roof insulation and an existing masonry wall.

External render (see Figure 18(a), on the previous page) can be sealed to the wall using a render stop bead and appropriate (preferably environmentally sustainable) sealant, making sure that the stop bead is of the type that has a mesh attached to it which is rendered into the basecoat to stop the render from shrinking away from the bead itself. Render stop beads with a mesh are made from stainless steel or PVC.

Cladding (see Figure 18 (b)) will usually have a ventilated air gap between itself and the hempcrete, so any join between the cladding and the wall need only be to keep out the weather. The seal that needs to be made is between the breathable membrane (utilized in cladding systems) and the brick wall. This can be achieved by wrapping the membrane around, and stapling it to, a batten the same width as the cavity and fixing the batten within the cavity to the masonry wall, with expanding tape or a mastic sealant between it and the wall.

Taking this combination of steps will result in a better junction in terms of weather and airtightness than any one solution alone would have achieved, and the same multifaceted approach should be applied to other junctions within the building design.

Alkaline environment

Because of the lime in the binder, hempcrete is highly alkaline, so anything encased, or partly encased, in a hempcrete wall will have to be able to withstand the corrosive effect of such an environment. The worst-affected materials are metals. Steel, the metal most commonly used for fasteners and fixings in timber-frame construction, may corrode when it comes into contact with hempcrete.

The process of galvanizing covers steel with a sacrificial layer of zinc oxide, which protects it from corrosion. Different galvanizing processes exist, with the cheaper method of electroplating giving a thin layer of zinc oxide, which is shiny in appearance, and the more expensive hot-dip galvanizing giving a thicker coating with a matt grey appearance. No matter how thick it is, however, the zinc oxide is a sacrificial layer and will eventually corrode, exposing the steel beneath. What is more, when screwing fixings (such as straps or joist hangers) to the timber, the abrasive action of the screw turning against the fixing can scratch off the protective layer and expose the steel beneath, speeding up the corrosion process.

Steel is an alloy – a mixture of iron and carbon. In stainless steel, different elements are added to the iron, depending on the type of stainless steel, but always including chromium. The chromium combines with oxygen on the surface of the metal to create chromium oxide, which forms a stable layer over the steel, protecting it from corrosion. In this way, stainless steel works in a similar way to galvanized steel. The main difference between stainless and galvanized steels, however, is the way in which the protective surface works: if the stable surface layer on stainless steel is scratched, cut or disturbed, the exposed chromium quickly combines with oxygen to produce a new layer of oxides, protecting the newly exposed steel.

It has been suggested that higher-quality galvanized steel products could be sufficiently resistant to corrosion to be used within hempcrete, and certainly there is a common-sense argument that *all* metal fixings within a building corrode during their lifetime, but rarely to the extent that the structural integrity of the building is affected. However, fixings for buildings are generally made as cheaply as possible, and are therefore rarely produced using hot-dip galvanizing. Also, hot-dip galvanizing has proven unsuitable for screws and bolts smaller than M10, since the thickness of the coating fills too much of the thread. If using a nail gun, the use of either hot-dip galvanized or stainless-steel nails is acceptable.

In tests carried out by the authors, galvanized electricity back boxes placed in a hempcrete wall for only 2 weeks showed a very high level of corrosion when they were removed. Our current recommendation, therefore, is that without further research being carried out, or the emergence of a guaranteed product, galvanized steel structural fixings should not be used within hempcrete. Although electrical back boxes are not structural, if their potential corrosion is a concern then PVC back boxes could be used instead.

Any metal fixings within a hempcrete wall that are exposed to the cast material – however minimally – such as screws, joist hangers or straps, should be of stainless steel. If the particular fixing required is not available in stainless steel, then steel, or galvanized steel, can be pre-painted with an anti-corrosion coating and painted again once installed (in case the process of fixing has removed some paint) to protect it from corrosion; however, this solution should only be used as a last resort.

Of course the safest option is to try to substitute metal fixings as far as possible with timber. It would be very difficult in mainstream construction to remove the need for nails and screws entirely – even within a traditional pegged oak structure, a stud frame within the main timber frame to provide a key for the hempcrete will still need fabricating. However, with the right detailing it is quite possible to replace some of the multitude of hangers and brackets that are used in modern timber-framing construction. These elements are more vulnerable in their level of exposure to the hempcrete than screws, as the larger part of a screw is buried in the timber of the frame. For example, timber gussets can replace angle brackets in some situations

Steel fixings in contact with hempcrete should be painted with a protective coating.

A plywood gusset used to replace a metal angle bracket as a frame fixing.

Rafters bearing on the wall plate and fixed down from above with long screws, to avoid fixings coming into contact with the hempcrete.

(see photo opposite, bottom right). Likewise, instead of using joist hangers, joists can sit on top of the wall plate with heavy-duty screws fixing them; and to replace rafter hangers the rafters can sit with a bird's mouth joint over the wall plate, again fixed from above (see photo above), and if necessary be coupled with a plywood gusset plate to provide extra rigidity.

In the case of a large residential or commercial-scale building in which a steel frame is used, an entire stainless-steel structural frame would of course be extremely expensive to fabricate. It is therefore advisable that the steel frame sits independently inside the walls of the building, with as little steel as possible interacting with the hempcrete. This might mean, for example, connecting the hempcrete stud frame to the timber rafters of the roof (as shown in Figure 19). Where it is necessary for the hempcrete to come into contact with the steel frame, sections of steel should be supplied pre-painted with a protective paint, and should also be repainted around the screws, bolts and other fixings once these are in place.

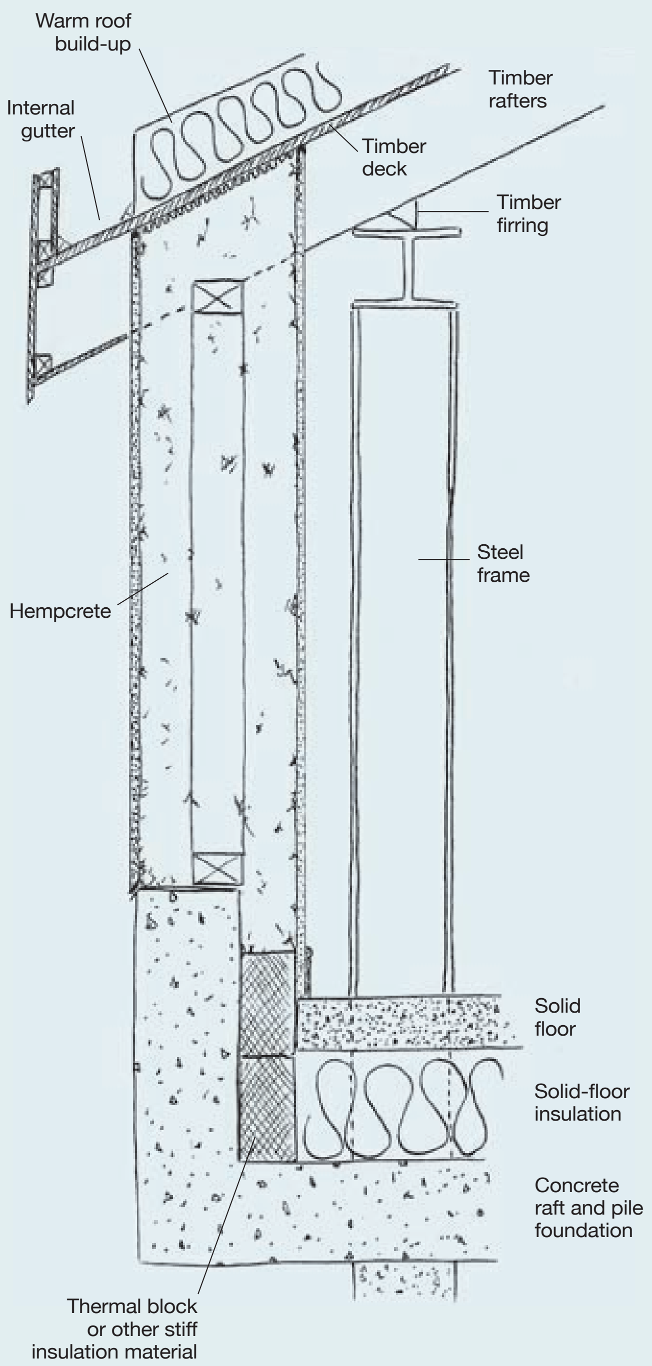


Figure 19. Steel frame set away from the wall internally.

Construction process

As contractors, it has often been our experience that details have been received from building designers that are impossible, or at least extremely difficult, to construct using hempcrete. It is strongly recommended that anyone designing or detailing a hempcrete building should first visit a site where the placing of hempcrete is in progress. This will enable the designer to get a better understanding of the construction process and gain first-hand experience of the consistency of hempcrete, which should lead to a realization of the practicalities of placing it, especially in tight or difficult-to-reach spaces.

To start the designer along this train of thought, some common issues that come up time and time again are outlined as follows.

Eaves

The trickiest part of a hempcrete wall to construct is the top. A great advantage of framed buildings is that the roof can be constructed as soon as the frame is up, in order to protect the frame and other work in progress beneath it. This is especially an advantage when building with hempcrete, which needs to be protected from exposure to rain during construction. However, it does pose a problem when it comes to placing the hempcrete at the top of the wall under the eaves with the roof already in place.

It is possible for hempcrete to be very roughly stuffed up into the space under the eaves from below, but this takes a lot of time and effort compared with building the rest of the wall, and is unpleasant and somewhat risky work, as particles of shiv coated in wet lime binder fall back down on the person who is stuffing handfuls up into the gap. It also leads to a far less predictable and consistent density at the very top, compared with the rest of the wall. Despite this, there are some instances, usually in the restoration or retrofit of older buildings, where the technique is employed as a last resort.

A better solution is to construct the roof up to the point of the breathable membrane or roof underlay, leaving the roof watertight but unfinished, and fit the membrane in such a way that at the eaves it can be folded or rolled back in order

Hempcrete at the eaves of a building: the waterproof roof membrane is in place but can be rolled back to allow the hempcrete to be placed.

to place the eaves hempcrete from above the rafters. Of course some roof coverings may not include such a membrane, but every effort should be made to detail the roof at the eaves in such a way that the roof can be constructed prior to the hempcrete being placed, in order to protect it, with a removable or partly finished section that allows the hempcrete to be placed from above.

Awkward placing

When it comes to placing hempcrete, awkward sections can arise anywhere that is not a simple straight run of wall. This includes areas around openings, at corners and at upper floor levels where floor joists may extend into the wall. These areas all require more timbers and brackets within the wall, for example where corner studs or studs around openings are being reinforced with noggins (horizontal timbers – see below) or where joists are fixed. The more structural elements in the wall, the harder it will be to place the hempcrete around them evenly and neatly.

Care should be taken at the detailing stage not to put too much 'stuff' in the way of hempcrete being placed, especially where a permanent shuttering board is being used and the wall is therefore accessible only from one side. Every time something is detailed within the wall, the designer should ask "Can hempcrete easily be placed around this?"

Horizontal timbers

Noggins – horizontal timbers connecting and supporting adjacent studs or joists – within the frame should be reduced to the absolute minimum. Noggins may be required in some instances, for example at door openings to reinforce the stud that supports the door casement, and the same may be true for large windows, corner studs and also at joins in the permanent shuttering board if one is being used. They are also commonly used as a support on to which back boxes for electrical fittings are screwed (see also Chapter 13, page 164).

Apart from such critical situations, horizontal timbers should be avoided, as they make it difficult to get the hempcrete beneath them. To do this the contractor would have to reach down into the shuttered section of the wall and try to stuff the hempcrete under the timber. It is common to see voids under these horizontal timbers when the shuttering is struck. This is not the end of the world, since these can be filled with more hempcrete, but this process is time-consuming and should be designed out as far as is possible.

Where a horizontal timber is absolutely necessary, specifying a triangular section timber (such as arris rail, or a ripped-down 50mm x 50mm timber) can make life easier. These might not be

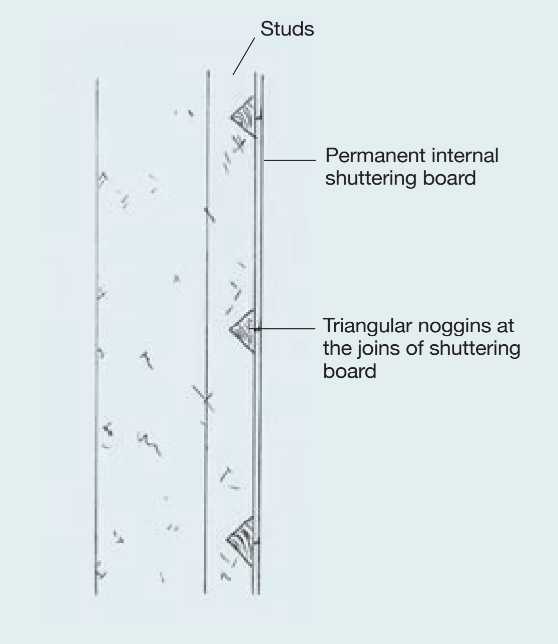


Figure 20. Triangular noggins for non-structural applications make placing the hempcrete easier.

suitable as structural timbers, but could be used for non-structural applications such as supports for fixings or at the joins of permanent shuttering board (see Figure 20).

Topography and climate of the site

There has been a tendency over recent decades, since the development of 'moisture-impermeable' building materials, to virtually ignore the siting and orientation of buildings during the design process. This is probably also due to the increased psychological detachment of many people in the Western world from the weather in their immediate surroundings. Nowadays it is common to spend little time outdoors and to go from centrally heated home to heated-and-air-conditioned car to heated office and back again, without even small and obvious changes in behaviour such as wearing a coat in colder weather. The most reaction many people ever have to the weather is to move the dial on the heating control.

Even if moisture ingress is not (theoretically at least) an issue in modern conventional masonry buildings, the lack of thought about the prevailing weather on-site during the design of new builds leads to high levels of inefficiency in power use as a result of poorly sited buildings. All of us will be able to think of times when we have sat in a home or workplace that was over-exposed to driving wind in the winter, making it too cold, or to direct sunlight in the summer, causing overheating. As well as incurring increased insulation costs, such buildings often need to be fitted with higher-powered air-conditioning or heating systems, which have a direct impact on the running costs and environmental impact of the building. In the last 60 years or so, such inefficiency was not a critical factor in design, but as we move forward into a world where energy resources are increasingly scarce and costly, such inefficiencies need to be designed out of all new buildings.

Furthermore, it is important to remember the vulnerability of all materials, including hempcrete, to excessive moisture ingress (as discussed on page 293), and the tendency of all walls to exhibit reduced thermal performance when moisture content gets too high. With these factors in mind, it is clear that to use any natural building material to best effect, thought needs to be given to how the topography and climate of the proposed site is likely to affect the performance of the materials. Simple changes to the siting and orientation of the building, the landscaping of the site, or the detailing of the building itself at the design stage can mitigate less-than-ideal conditions. With a little care it is possible to create a building that truly maximizes the potential of the natural materials, with potential problems designed out.

Much has been written elsewhere on this topic, and it is not our intention to replicate it here, but a few of the key issues, as applied to hempcrete, are outlined below as examples of things the designer should be keeping in mind.

Site-specific solutions

There is unlikely to be a 'one size fits all' solution when detailing hempcrete. First, consider the conditions and topography of the specific site and outline the challenges they bring through differing levels of exposure to prevailing winds, rain and sun. Consider the position of the sun at different times of the year – high in the sky in summer; low in winter. Is it possible to design in, through the siting and orientation of the building or through features such as windows and skylights, shade for the interior from the high, hot summer sun while making full use of the low winter sun by collecting the heat it offers into the building? Consider the likely orientation and force of the prevailing wind and rain. If these are of a direction or degree likely to have a detrimental effect on the breathable hempcrete walls, can this problem be resolved through the siting, orientation or detailing of the building?

Using natural features on the site

Wherever possible, work 'passively' to make best use of the natural features of the site that may provide shelter, rather than rushing to the solution of costly and energy-consuming landscaping. Consider the site topography, including slopes, natural banks and existing mature trees, and site the building accordingly to make the best use of the shelter or shading they provide. If this shelter is not thought to be sufficient, then add to and enhance natural features rather than re-landscaping the site. On a completely level site with no mature trees, design the landscaping and planting in conjunction with the siting and orientation of the building to provide maximum shelter and shading as appropriate. Wherever possible, design in the reuse of earth removed during ground works, which will reduce the cost of both landscaping and 'waste' removal from site.

Learning from the past

Take some time to look around the area in which the building plot lies. Any vernacular building (by which we mean any traditional house, farm building, village hall or chapel built before about 1850) was constructed from local, natural materials and was built with a solid breathable wall (see Chapter 10, page 118). In addition, these buildings were built with the full benefit of hundreds of years of local knowledge, handed down through generations, about how to make best use of natural materials within the context of the local topography and climate. It's probable that the standard of workmanship in these old buildings varied dramatically, but those that you can see around you are a self-selecting best of the bunch, in that they are still standing.

These vernacular buildings have lessons to offer the designer working locally with natural materials. What decisions were made about the siting and orientation of buildings in the immediate vicinity of the site? Look for any obvious details that were designed to mitigate exposure to the weather, such as the west-facing wall on all buildings on one side of a hill being clad in hung slates to resist driving rain, or significant roof overhangs in areas with high rainfall, and try to replicate these functions in the detailing of the proposed building.

Vernacular buildings, such as this Derbyshire miner's cottage built about 1840, can provide lessons in how to site and orientate a new building, and how to make the best use of local materials.

Site-specific effects on finishes

Clearly, in the UK the main influence on the suitability of different finishes is going to be exposure to rain, but consider the other side of the coin too: a render finish might be appropriate, even with considerable exposure to prevailing wind and rain, if this is also the south-facing elevation of the building and you can therefore be confident that the sun will dry out the surface between periods of wet weather. On a north-facing wall, however, where insufficient sunlight falls to have a drying effect between rainstorms, then a render finish may prove too permeable and the accumulation of moisture in the wall too great.

In this case, the solution will probably be to use a cladding finish with a vented air gap between the cladding and the face of the hempcrete wall. Cladding might take the form of a wooden screen, stone or brick masonry with lime mortars, or hung slates or tiles over wooden battens. As well as the level of protection offered by the cladding material, consider the likely level of maintenance required by the cladding itself in the particular situation. For example, wooden screens in highly exposed situations will need far more maintenance, through the application of protective oils or paints, than would stone masonry or hung slates.

Site-specific effects on wall thickness

In some instances it may be appropriate to vary the thickness of the walls around the building to cope with extremes of temperature on differently exposed elevations. In our experience this is rarely done, but it may be quite sensible, for example, to make walls thicker where they were exposed to excessive sun or to cold winds. This particularly applies in a building for which thinner-than-standard hempcrete walls are being specified.

Site-specific effects on roof and plinth

This is to some extent self-evident: in areas of high rain or snow, consider increasing the overhang of the roof and the height of the plinth, in order to reduce the amount of water that comes into contact with the face of the wall. By the same token, a good-sized roof overhang, or the continuation of the roof into a covered cloister or walkway around the edge of the building, can help with shading exposed walls of the building in very hot climes.

It is well recognized that the suitability of roof pitch and type of roof covering varies according

Sensible detailing on a hempcrete building in an exposed location: a moderate pitch of roof with a large overhang at the eaves. Oak shingles on the roof make an attractive counterpoint to the lime render.

to the prevailing weather in a given region. Take, for example, the very gentle pitch (well below 45 degrees) of the pan-tiled roof of a vernacular farmhouse in Tuscany, where there is little annual rainfall, compared to the very steep pitch (much greater than 45 degrees) of the slated roof of a Swiss farmhouse high in the Alps, where there is heavy annual snowfall and the priority is for all this extra weight to slide off the roof before it causes damage.

Traditional buildings in regions with a temperate maritime climate, as in the UK, exposed as they are to moderate levels of sun and rainfall and infrequent snow, tend to have roofs with a pitch much closer to 45 degrees. Don't forget, however, that variation in the suitability of roofs can also apply, to a lesser degree, at a much more local level. A house sited at the top of a hill might experience more frequent and heavier snowfalls than those at the bottom of the valley. Houses very close to each other but on opposite sides of the hill or valley might experience dramatically different levels of rainfall or exposure to sun.

Site-specific effects on the construction process

The main way in which the prevailing weather affects the construction process is in the planning for protection of work, both during the construction phase and while waiting for the hempcrete to dry.

During the placing of the hempcrete, walls under construction must be kept covered and sheltered from driving rain. High winds are also a nuisance at this stage, as small particles of lime-covered hemp get blown about and into people's eyes.

During the drying phase, the prevailing weather and the building's orientation will have an effect on the management of the drying hempcrete. Here, strong winds can be a help to drying, although temporary protection needs to be erected if the winds are driving rain towards the face of as-yet-unrendered or -unclad walls. Walls that are exposed to winds or orientated towards the sun are likely to dry more quickly, especially early and late in the year, while walls that are shaded, sheltered or exposed to rain will probably dry more slowly.

Mitigate these effects by temporary precautions put in place on-site to protect or expose the work as required, and by planning the schedule of works for the finishes according to the expected order in which different walls will be ready for finishes to be applied.

CHAPTER TWENTY-TWO

Indicative detailing

The aim of this chapter is not to show details of, for example, *the* plinth or *the* eaves ready to transpose directly into your design. There are so many potential variations and combinations of design and materials that this would be impossible. Instead, we highlight some of the common problems and recurring themes encountered when detailing some of the more technical parts of the hempcrete building, and, where appropriate, present some functioning solutions.

An important concept central to many detailing decisions when designing any building is airtightness. Hempcrete buildings are no exception, and we therefore discuss the concept of airtightness first in this chapter, and return to it throughout as we look in more depth at detailing specific parts of the building.

Note: all the details described or shown in this book are for indicative purposes only. They should be considered as inspiration for your own specific building design, the actual detailing of which should be undertaken by a suitably experienced or qualified designer, architect or engineer. The overall design of any building, including individual details thereof, remains the responsibility of the building designer. A building's design should be considered for appropriateness within its own site and climate. If your architect or engineer is in any doubt about this, then seek specific advice from someone who is used to working with hempcrete.

Airtightness

Airtightness has become the buzzword of the moment in the field of sustainable building, as those people who want future-proof homes rush to seal themselves into plastic boxes in the name of reducing energy consumption.

Airtightness *is* a key concept, and a certain level of airtightness is needed in order to stop heat transferring out of the building via draughts in

Previous page: Hung tiles used as cladding over hempcrete give extra protection to exposed areas, such as on this gable end.

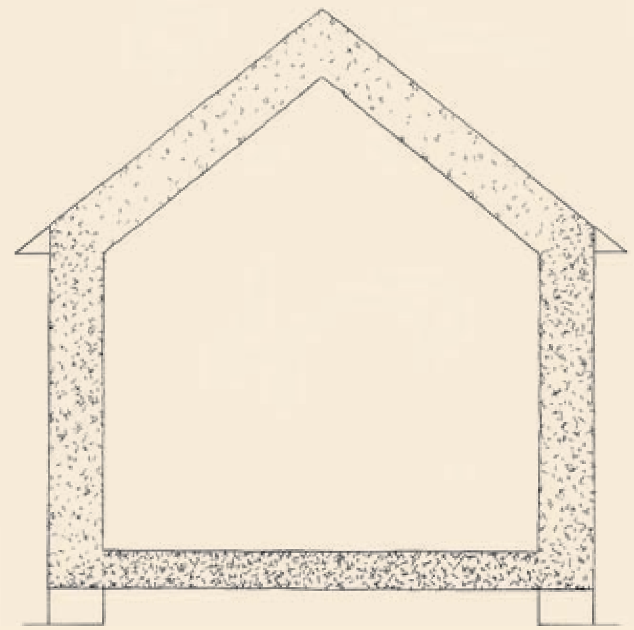


Figure 21. The 'thermal envelope' describes the three-dimensional surface that contains the building's internal heated volume. It is possible to cast the whole envelope in hempcrete, as described on page 326.

leaky buildings. The 'airtight line' is a conceptual line drawn around the thermal envelope (see Figure 21), along which all junctions of different building elements are detailed to ensure that air cannot escape between them. Where the building elements along this line are not in themselves airtight, they can be improved with an airtight membrane. In effect, the *conceptual* airtight line ensures that the building's designer has to consider the airtight envelope. Unfortunately, however, this widely used concept of the airtight line around the thermal envelope is often taken rather too literally.

This results in an arguably wasteful approach whereby the building is literally wrapped in an airtight membrane, taped at joins and around protrusions. In conventional construction methods this usually leads to the creation of a boarded-out void on the inside of the external walls, or even two – one to take the services and another to take the airtight membrane.

There are two problems inherent in this approach. The first is that it relies on an additional product in the wall build-up to achieve what could be achieved through thoughtful detailing. The second is that the placement of a physical airtight membrane, apart from being more expensive than simply using robust detailing, means that the airtight line is often on the interior face of the building. This means that the insulation, outside the airtight line, is exposed to cold air moving through it. A better approach is to position the insulation *inside* the airtight line, so that warm air is retained in the insulation material.

Hempcrete has an advantage over other building materials when it comes to airtightness, owing to its monolithic structure and its ability to be cast easily around protrusions and into different shapes. However, it is important to understand that it is the thickness and mass of the hempcrete, coupled with the density of the thin layer of render, that ensures good airtightness in a hempcrete wall. Where cladding is used, meaning that an attractive render finish is unnecessary, the airtightness of the wall can be ensured with an airtight membrane or a rough basecoat render applied to the face of the hempcrete under the cladding.

All of this means that when considering the airtight line, both the hempcrete and the render (or membrane under cladding, if you are using one) must be sealed at all junctions with other building elements. To improve the airtightness between hempcrete and these other elements, consider increasing the area of the join and also introducing a change in direction to it. By increasing the area, you reduce the risk that a small failure of one part could cause a breach at the junction, i.e. making it less likely that an isolated failure would have any detrimental effect on the overall join. By introducing a change in direction, you are further obstructing the

A note on airtightness versus indoor air quality

The level of airtightness in hempcrete buildings should be considered within the particular context of how the material works compared with conventional timber-frame insulation materials. Conventional timber-frame insulation is usually very lightweight and low density, and the insulation is provided solely by the air trapped in the structure of the material. In the case of hempcrete, trapped air in the material provides the same function, but in addition hempcrete has a relatively high density, giving it good thermal mass. This allows a hempcrete wall to act the same way that a heat brick does in a wood-burning stove or storage heater: storing heat and radiating it out into the room long after the heat source (whether fire or electrically generated) has disappeared.

In a lightweight timber-frame house with low-density insulation, a high level of airtightness is essential because it is only the hot air trapped inside the building, by the insulation, that is holding the heat. Any air leakage swiftly causes a transfer of heat out of the building. In contrast, in a hempcrete building the thermal mass of the walls stores the heat *in the material itself* and slowly releases it again. Therefore, even if warm air from inside a hempcrete building does escape, there is still further heat retained in the walls of the building.

This means that there is much more flexibility within a hempcrete building for natural ventilation, i.e. opening windows to allow exchange of air, rather than relying on mechanical heat-recovery ventilation systems such as those specified in high-tech super-insulated (but low thermal mass) buildings. In short, hempcrete is a combination of modern building elements (insulation through trapped air) with traditional ones (high thermal mass), and in many ways makes use of the best features of each technology to achieve its unique thermal performance.

Indeed, the potential of the heat store within the building created by the thermal mass of the hempcrete can be maximized by specifying hempcrete for the internal walls as well as the external ones. Using hempcrete internally also makes use of its excellent acoustic insulation properties to dampen the transfer of sound between rooms. For more information on the thermal and acoustic properties of hempcrete, see Chapter 7.

potential passage of air at the join. An example of such a solution is shown in Figure 29(c) (page 325), which illustrates airtightness detailing at the eaves.

As discussed in Chapter 21, the render can usually be sealed to other materials using a render stop bead and a suitable sealant such as burnt sand mastic or linseed oil mastic sealant, but the hempcrete will require an expandable material to take up any shrinkage (the material will also need to be able to withstand the wet environment if fitted against wet hempcrete). If a membrane is used in conjunction with cladding, it can be sealed with proprietary sealing tape or by compression when screwed between a batten and other building element (see page 331).

It is worth noting that the actual airtightness levels achieved by hempcrete in tests are very good, as illustrated by the following examples. During research carried out on the 'Hempod', an experimental hemp building with 200mm-thick walls built at Bath University:

> The air permeability of the Hempod was tested prior to the co-heating test in accordance with the procedures detailed in ATTMA TS1 [13] and BS EN 13829 [14] test Method A; thus the building was tested in its finished state with no temporary seals. The number of air changes per hour at 50Pa (n_{50}) was 0.55, which is within the Passivhaus limiting value of 60.6 air changes per hour.[1]

An airtightness test on a timber-frame construction with hempcrete infill as part of the Serve Project in 2010, at Cloughjordan Ecovillage in Co. Tipperary, Ireland, showed "an excellent airtightness level of 1.12m^3(m^2.h)@50Pa".[2]

Plinth

The main function of the plinth is effectively to be a 'good pair of boots' for the building, lifting the hempcrete walls at least 250mm above the outside ground level in order to protect them from splashing rain and groundwater.

The difficulty in plinth design lies in the conflicting functions required of it. The plinth needs to be strong enough to take any frame loading placed on it, yet still provide adequate insulation. It needs to be waterproof, yet not seal the hempcrete in among too many non-permeable surfaces (e.g. in the case of a breathable floor construction, as shown in Figure 26 (page 316), the hempcrete may continue down the inside face of the plinth, which thereby seals the hempcrete on its outside face). It is unlikely that you will find a material that is insulating, load-bearing, breathable and waterproof (though recycled glass foam comes pretty close). You therefore need to have a range of different materials doing different jobs in a relatively small place, which results in a technical challenge. Solutions to this problem have included employing multi-functioning or high-performance materials, or designing out one of the functions of the plinth.

Note that in Figures 22, 23, 25 and 26 on the following pages, which illustrate plinth detailing, floor heights are shown as in the most likely position; however, the exact floor height will vary dependent on a range of planning and design factors, for example the total maximum roof height allowed and/or the materials from which the plinth is built.

Multi-functioning materials

Recycled glass foam is becoming a popular solution to perimeter insulation throughout the construction industry. Its closed-cell structure prevents capillary action, i.e. it doesn't 'wick up' water as a lightweight concrete block would do. In addition, it has good compressive strength and can be used in structural applications, but is also low density and so provides insulation. Recycled glass foam can be used within the plinth construction, supporting the structural frame while simultaneously providing insulation. Like all materials, however, it does have limits in terms of its structural properties, and should therefore be specified by a competent person and in consultation with the manufacturer or supplier.

An example of recycled glass foam plinth detailing is shown in Figure 22, using engineering bricks at the external face and with a solid floor build-up: a free-draining design. The engineering bricks and NHL 5 mortar stop rainwater entering the plinth, and the non-capillary-action sub-base floor layer and glass foam blocks prevent rising damp. Coupled with a free-draining foundation, this build-up would not require any PVC damp-proof course or membrane. A similar detail is pictured on page 153.

Plinth with no inherent insulation value

If the plinth is narrower than the total wall thickness, a material with high thermal performance can be utilized to make up the difference in width. Although thinner than the hempcrete wall above it, a high-performing insulation should be capable of providing a similar level of insulation to the hempcrete. Unfortunately, many materials that suggest themselves for use

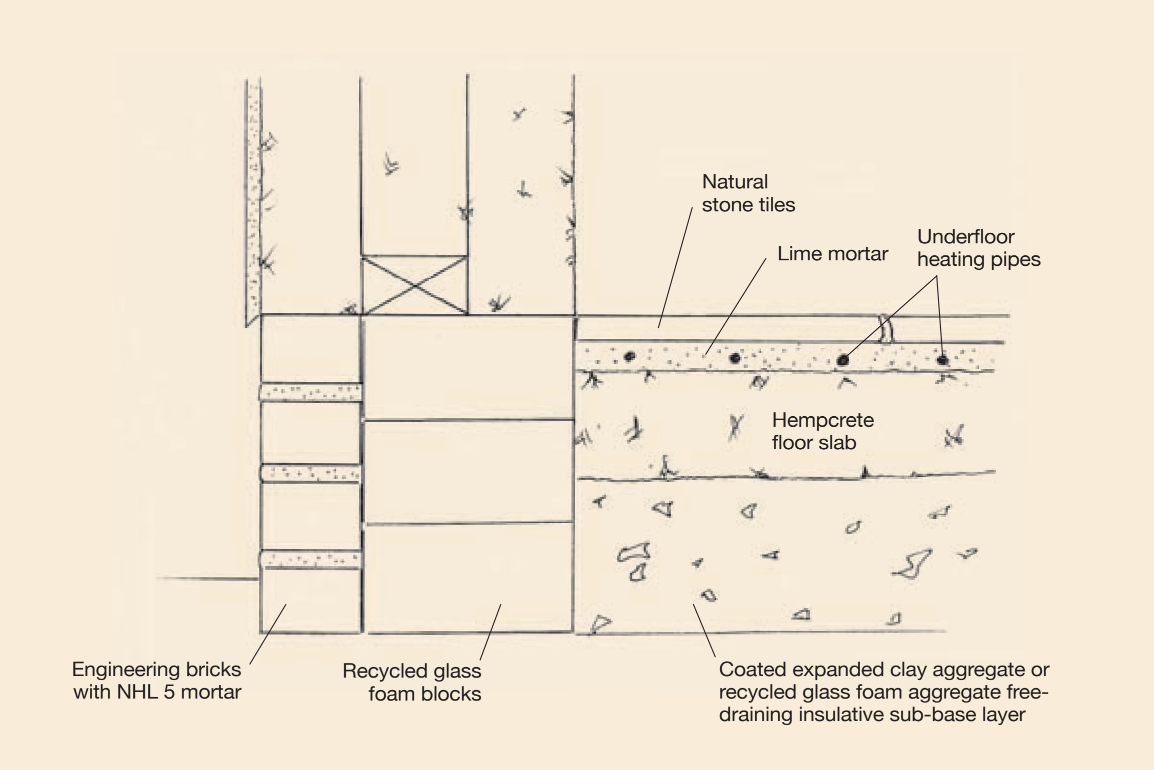


Figure 22. Recycled glass foam is probably the best load-bearing plinth insulation available currently.

in this situation are not sustainable, being mostly petrochemical-based. Sustainable solutions do exist, however – for example, loose-fill cellulose insulation. In this situation, a permanent internal shuttering board has to be used to give a continuous background for internal finishes, and it is wise to use either a loose-fill or spray-applied insulation to ensure complete filling of the void between the board and the plinth (see Figure 23).

In some situations it is possible to lift the insulated internal floor construction above the height of the plinth, so that the plinth is no longer required to be insulating, which makes its design straightforward (see Figure 24 opposite). However, this solution is not always possible owing to the consequent increased height of the building after raising the floor and the necessity for ramps or steps to access the building.

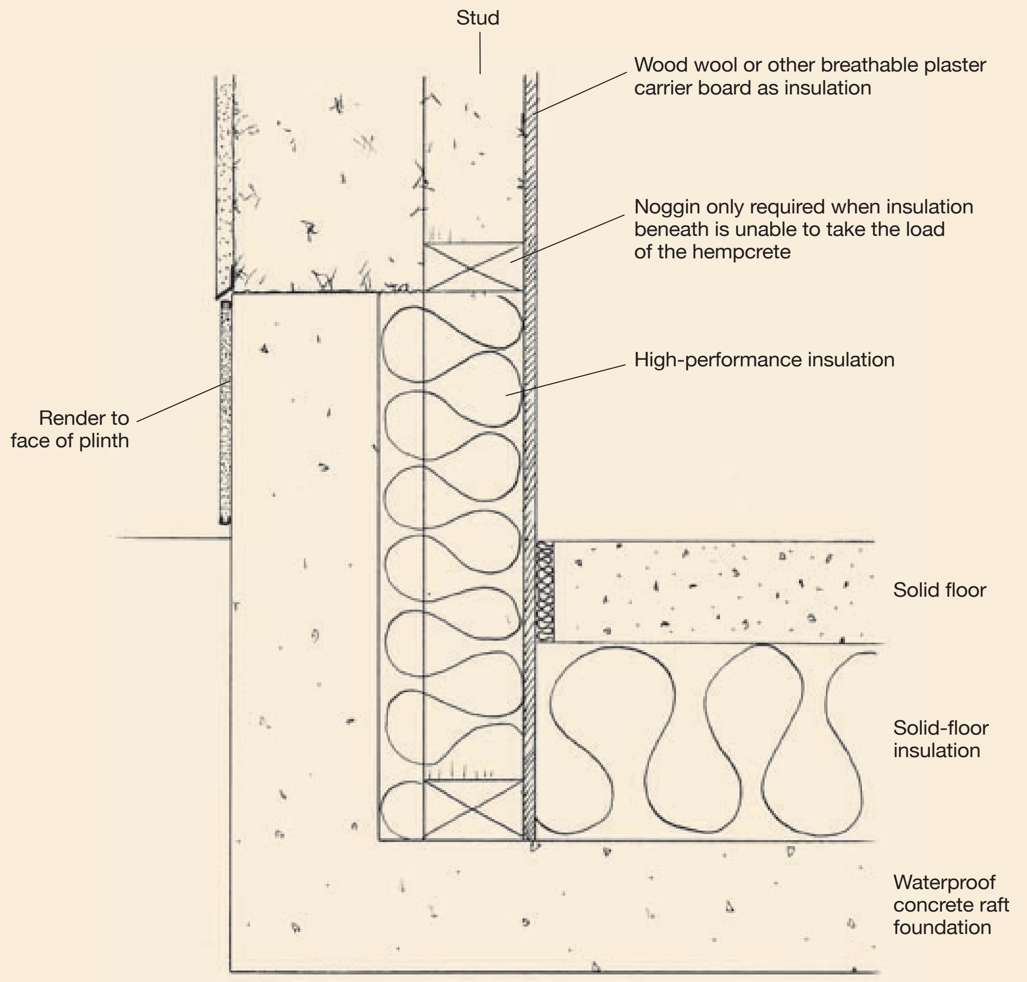


Figure 23. A plinth that uses non-load-bearing high-performance insulation.

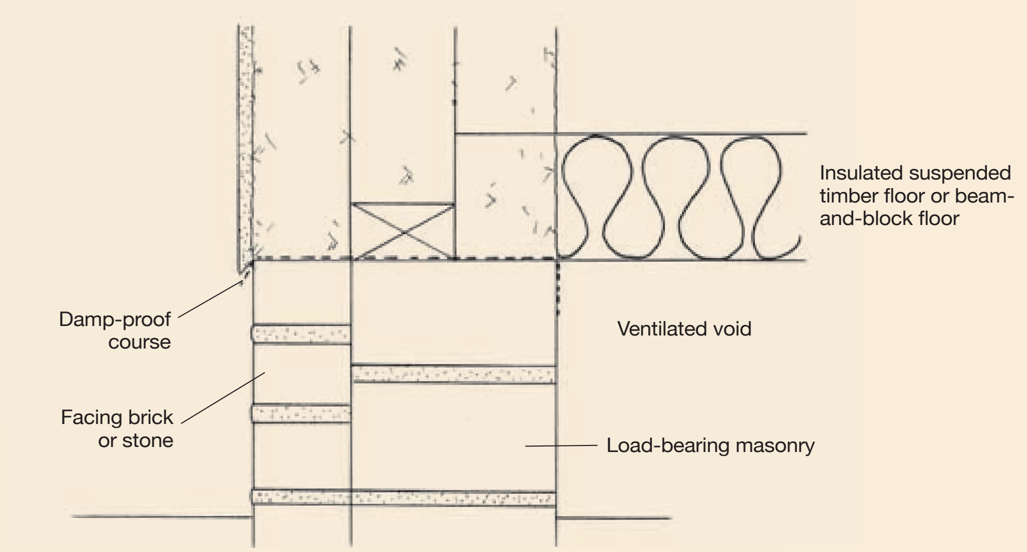


Figure 24. A high internal floor level avoids the need for plinth insulation.

Non-structural plinth

If the structural frame is set away from (inside) the walls of the building, as may be the case in a large building with either a steel, glulam or hardwood structural frame (see Chapter 13, page 156), the plinth no longer has to take the load of the roof and only has to take the load of the (relatively lightweight) timber frame and hempcrete, which permits a greater choice of materials for use within its design (as shown in Figure 25 overleaf).

In the case of a breathable floor material, it is possible to continue the hempcrete wall construction below the internal floor level, allowing the timber frame to bear directly on the foundation blocks. The protection from splashback and groundwater is then provided externally by engineering bricks, hard stone or other moisture-tolerant masonry to the outside face of the wall, with a damp-proof course (DPC) between it and the hempcrete (see Figure 26 overleaf).

This solution has the disadvantage that it introduces a non-vapour-permeable DPC to one side of the hempcrete where it abuts the masonry. However, the reduced thickness of hempcrete in this area, likely to be around 200mm, will enable effective drying to the inside face of the wall, and vapour permeability will be maintained not only to the inside of the wall but also through the floor perimeter. That said, it would be prudent to ensure full drying of this area, which may take longer than the rest of the wall, prior to applying finishes. It will also be even more critical to ensure that no vapour-impermeable finishes are applied to this part of the wall post-construction.

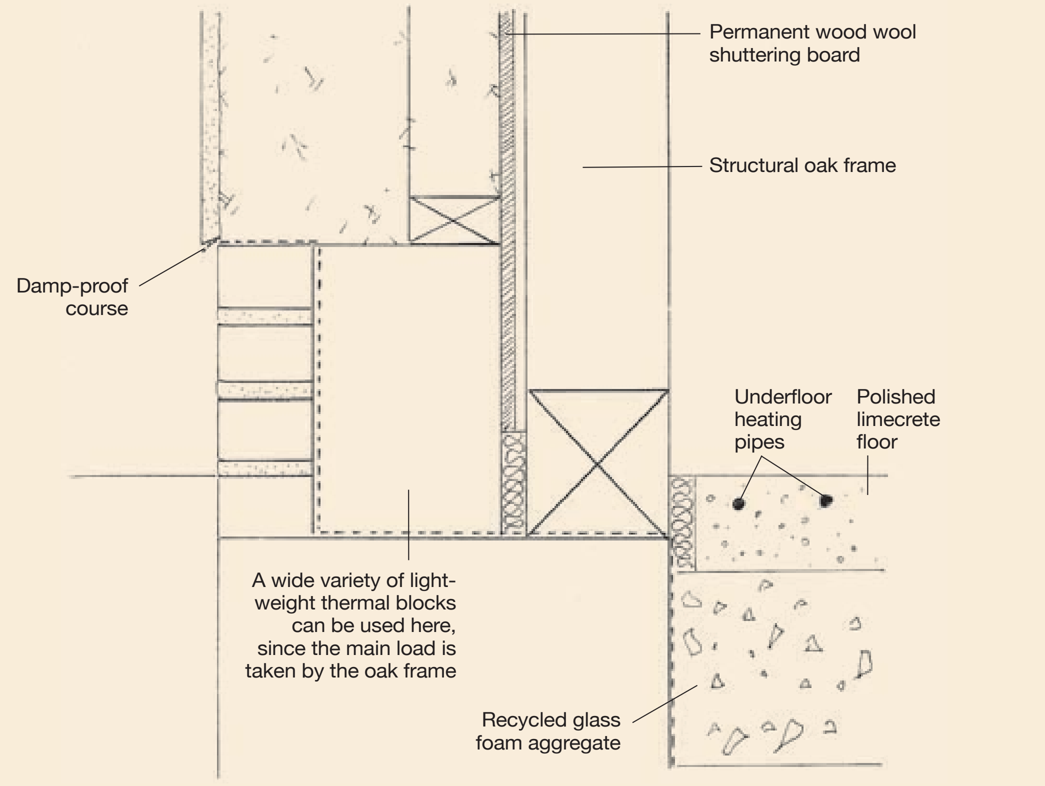


Figure 25. A separate structural frame (in this case oak) allows for a non-load-bearing plinth.

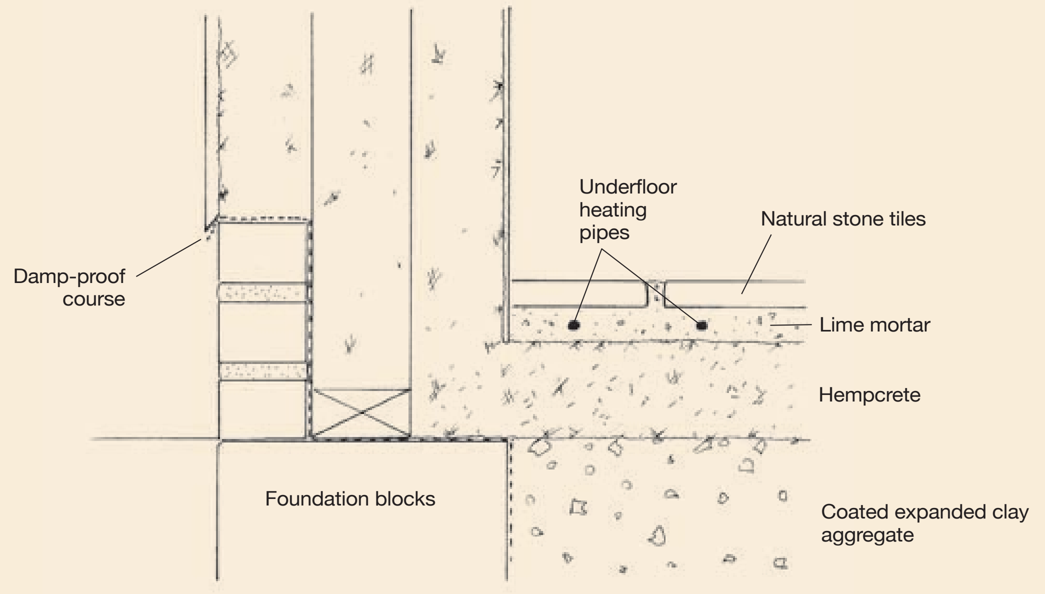


Figure 26. A breathable floor allows the timber frame to bear directly on the foundation blocks.

General design considerations

The plinth arrangement may affect, or be affected by, the position of the structural frame within the wall and, to a lesser extent, the position of the doors. The plinth design might only allow positioning of the frame to the inside, middle or outside of the wall, depending on the load-bearing capabilities of that section of the plinth construction, and so the structural frame and the plinth should always be considered together at the design stage.

The way in which the plinth interacts with door openings should also be considered carefully. In situations where the internal floor level is below the top of the plinth, the door frame will be meeting the plinth as well as the hempcrete wall above it. For this reason it is very important, at the design stage, to draw up a horizontal section of the door opening where it interacts with the plinth, as well as where it interacts with the hempcrete part of the wall. This may affect where and how the door frames are fixed, and thus the plinth detail at that location.

Airtightness at the plinth isn't as much of a problem issue as in other areas, since gravity acting on the mass of the hempcrete is compressing the junction between plinth and wall. However, there is a junction that goes from outside to inside across the DPC, and there remains a possibility of air moving along this line. If this is an issue, for example if a very slow-setting binder is to be used and there are concerns about the hempcrete shrinking away from the DPC, a seal can be formed between the DPC and the underside of the render stop bead with a linseed oil or burnt sand mastic. It is also possible to use a compressed hemp-fibre quilt insulation airtightness detail (similar to those described in Chapter 21, page 297) around the DPC. However, in reality this is very unusual, and in our own practice we

Plinths can be more sustainable than a concrete upstand with cement render, as shown by this plinth made from reclaimed brick and lime render.

have never seen a need to take specific airtightness measures at the plinth.

Hempcrete floors

Although widely used throughout France, hempcrete floors are less common in the UK, where the concept of a breathable – moisture-permeable – floor is largely an alien one. As discussed in earlier chapters, over the last 50 or so years there has been widespread use of inappropriate materials and detailing in the repair and restoration of properties dating from the Victorian period and before. This has caused countless instances of damp problems in floors and the lower parts of walls, since the traditional breathable solid-wall construction has been stopped from working properly. The cause of these damp problems has not been widely understood in the construction industry, and more often than not has been falsely linked with the original construction methods, including the use of lime mortars and traditional building techniques.

The UK building industry has therefore become suspicious of traditional methods of construction, and the prevailing attitude is that concrete and plastics are the only materials suitable to be in contact with the ground. The weight of this conventional wisdom has led to a very slow acceptance in the UK of the use of lime and plant fibres in floor construction, especially where a damp-proof membrane (DPM) is not used. However, if detailed correctly, hempcrete or lime-crete floors can outcompete their cement-based counterparts in terms of thermal performance, and are the best solution for the restoration or upgrade of historic buildings.

Having said this, not all sites are suitable for hempcrete floors; in particular, sites with very high water tables or in flood-prone areas would not be suitable, because if the water table were to rise higher than the sub-base level, water could fill this layer and reach the hempcrete. A hempcrete floor would survive a one-off flood and dry out, but would not be able to tolerate frequent wetting. In any case it is normal to construct your hempcrete floor slab at a height above the outside ground level. Note that breathable floors are also not suitable for areas where a radon barrier is required in the floor.

Detailing of hempcrete floors is quite straightforward. The existing hard core is levelled and compacted and, if necessary, a layer of pea shingle can be used to fill and smooth any large gaps (e.g. if a large-sized aggregate such as brick rubble has been used). A non-capillary, insulating sub-base (such as *coated* expanded clay aggregate or recycled glass foam aggregate) is the next layer. This effectively becomes the DPM, since moisture cannot move up through it. On top of this a breathable geotextile membrane can be used to keep the sub-base separate from the hempcrete, which forms the next layer (see Figure 27).

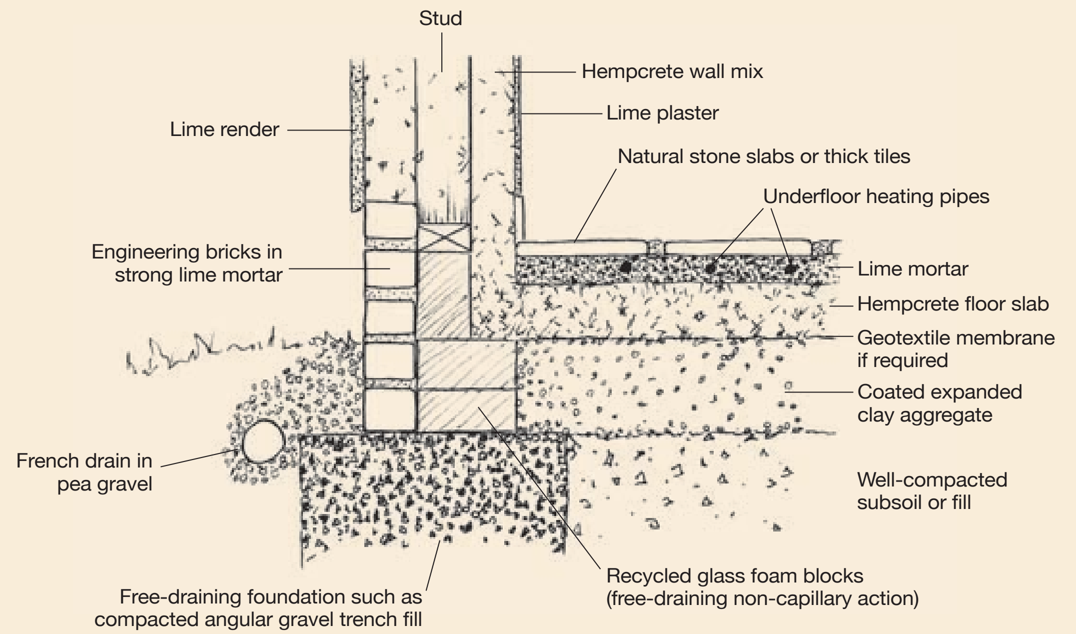


Figure 27. A 'breathable' floor build-up. The free-draining foundation and plinth, coupled with a vapour-permeable floor build-up, does not require a damp-proof course in the wall or a damp-proof membrane in the floor.

However, this is not strictly necessary if each layer is well consolidated and levelled and if care is taken during the application of each.

As discussed in Chapter 17, the hempcrete used in floors is a denser mix than wall hempcrete, so that it can withstand the typical loads expected of domestic floors. Possible finishes include solid timber (where a batten has been cast flush into the floor surface to provide a fix), natural flagstones set in lime mortar, or a lime screed with a natural stone or clay floor tile finish. Underfloor heating pipes can be included in the lime mortar layer for the flagstones, or in the lime screed layer for the natural floor tiles.

The thickness of these two main layers, hempcrete and insulating sub-base, depends on the desired U-value, which in turn depends on the dimensions of the floor, the quality of the perimeter insulation and the ground type. Generally, the hempcrete layer is worked out to be as thin as possible for the structure to be stable (typically between 80mm and 150mm), and the sub-base is then as deep as is needed to make up the U-value (typically between 120mm and 180mm). It is possible to satisfy the requirements of Building Regulations for a small extension structure with a total build-up of hempcrete and sub-base of 200mm. The exact thickness of the layers should be specified by the supplier, who can input dimensions of the floor, type of perimeter insulation, ground type, U-value required, etc. into a piece of software that will generate the depth of each layer required.

Since the hempcrete provides both the structure and part of the insulation in one go, whereas concrete provides only structure and requires a substantial amount of extra insulation, the depth of a hempcrete floor build-up will often be less than that of a typical concrete floor build-up, offering savings on excavation and waste costs.

Being a material with good flexural strength, hempcrete will not require expansion joints within the floor or at the junction with the plinth. However, if the designer was concerned about airtightness, then an expandable material can be placed between the hempcrete and/or screed and the vertical DPC within the plinth. It would also be possible to mechanically fix or tape the membrane in the floor build-up to the DPC, although this would incur the extra cost of a very strong, breathable, airtight membrane designed for use in the floor instead of the relatively cheap standard geotextile membrane.

When detailing a hempcrete floor, the DPC within the plinth construction (which cannot connect to the DPM, as there isn't one) should continue down the inside of the plinth, and foundation blocks if necessary, to at least the bottom of the sub-base layer. This will prevent lateral movement of water through the plinth into the hempcrete or sub-base layer.

All buildings with solid hempcrete floors should also include a French drain externally around the walls of the building, to assist in directing water away from the building. In addition, it is good practice to ensure that the ground in the immediate vicinity of the building slopes away from it whenever possible.

Structural frame (racking strength)

As described in the previous chapter, racking strength is the ability of a structure to withstand movement, for example from external stresses such as wind loading, without toppling over. Hempcrete provides a great deal of racking strength to the structural frame, but scientific data in this area is still quite limited, and many UK structural engineers and building control inspectors will remain unconvinced about the extent to which it can do this. Some methods by which extra racking strength can be provided are discussed as follows.

On large steel- or glulam-framed buildings, the frame usually sits inside the walls of the building, not within the hempcrete. The racking system will then have little interaction with the hempcrete and is likely to consist of diagonal frame members or steel ties.

On smaller builds of timber-frame construction, such as single dwellings or extensions, the frame is likely to be encased within the hempcrete, and as such the racking provision must not interfere with the vapour permeability and structural integrity of the hempcrete. For this reason, the usual method of adding racking strength to timber frames – OSB or plywood boards fixed to the frame within the wall build-up – is not suitable. Such boards, if placed within the hempcrete, would cause a continuous vertical break midway in the mass of hempcrete and thereby weaken the monolithic structure. Even if placed on the inside or outside face of the wall, so as not to cause a break in the hempcrete, these boards are not vapour permeable enough to be left in situ. Plywood, being layers of timber glued together, is pretty much impermeable to moisture (and can easily be waterproofed with oil or resin). OSB is somewhat vapour permeable, but not to the extent that it could be used within a 'breathable wall' build-up.

This is not to say that OSB can't be used within a hempcrete wall for other applications. For example, it is used as the through-wall connecting element in a double-frame structure (see Chapter 13, page 160). The difference between this and using it as a racking board is that when used as a racking board on one side of the hempcrete,

Social housing at Callowlands in Watford, built using a timber frame and cast-in-situ hempcrete.

the OSB forms a complete barrier against the lateral flow of vapour, forcing any moisture to travel through it. When used as the joining plate within a double frame, it is positioned in line with the flow of vapour and so does not form a barrier to it. Moisture will take the easiest route from one side of the wall to the other, which will be through the far-more-permeable hempcrete rather than the OSB.

Viable methods for providing additional racking strength to the softwood frame within a hempcrete wall are: a vapour-permeable plaster carrier board, diagonal timber bracing, diagonal stainless-steel straps, or any combination of the three. These methods are discussed below. It is important to stress that the total racking strength required is dependent on many factors, including prevailing wind speeds, the loading of the building, the shape of the building, whether there are structural internal walls, etc. The strength required, and the means used to achieve it, should be calculated, given knowledge of the building design and the declared racking strength of the materials to be used, by a suitably competent person such as a structural engineer.

Vapour-permeable plaster carrier boards

The two options available at the time of writing are wood wool board and magnesium silicate board, as described in Chapter 14. Magnesium silicate board provides the higher racking strength of the two, and, having a very smooth surface, it requires only a skim of topcoat plaster to finish it. However, since this will usually be a gypsum skim it is not the ideal finish for a breathable hempcrete wall. The smooth surface of these boards also means they do not key to the hempcrete very well, and in our experience they seem to de-laminate from the hempcrete as it dries. This is corroborated by a 2013 evaluation of the Renewable House Programme, which notes that "a further factor reported by builders was that the hemp and lime may have de-bonded from the Resistant [magnesium silicate] board permanent shuttering".[3]

Magnesium silicate boards are also made up of a very dense material which, while sold as vapour permeable, doesn't seem to have the same clear breathability characteristics in use as more open-structured boards do. We have noted large patches of damp and discolouration occurring on these boards, which remained for several weeks after the casting of the hempcrete. These were presumably caused by the moisture passing very slowly out through the board. Nor are these boards able to carry traditional lime plasters, due to their very smooth surface, and this can significantly reduce finishing costs on a hempcrete build. To our knowledge, at the time of writing magnesium silicate boards are all produced in India and China and so may have a high carbon footprint owing to being transported halfway around the globe. Very little information is available about exactly what goes into the boards, the quality standards of the products, or working conditions in the factories.

Wood wool boards have a very open surface structure, similar to that of hempcrete. Because of this the hempcrete keys very well to the board, leaving no voids. However, the open, rough surface of the wood wool board means that at least two skims or a basecoat and a topcoat will be required to finish the board. An alkali-resistant plasterer's mesh is usually incorporated into the basecoat to stop cracking at joins between boards. Some wood wool boards have the advantage of being external grade and so can be used internally or externally to carry the render. At the end of the day, the deciding factor in choice of carrier boards may be budget, with magnesium silicate board at the time of writing costing approximately four times as much as the most expensive wood wool boards.

Diagonal timber bracing

This is the usual option for providing racking strength to the frame, and for those who value the simplicity of a monolithic hempcrete wall, with finishes on both sides applied directly to the surface of the hempcrete, it is probably the best. These bracing timbers usually consist of pieces of timber 50mm x 100mm or 50mm x 150mm in section, or 150mm-wide strips of 25mm thick ply, screwed to one side of the frame diagonally. The size, type, quantity and spacing of the timbers should be specified by a suitably competent person. Diagonal timber bracing is sometimes used in conjunction with timber gussets: triangular pieces of plywood fixed to the junctions of the studs with the sole or wall plates. They add extra racking strength and also provide an excellent fix between the studs and the wall or sole plate, as an alternative to angle brackets.

Diagonal stainless-steel strapping

Not usually relied upon as the sole means of applying diagonal bracing to a frame, this consists of stainless steel that comes on a roll and is screwed to the frame diagonally. It is available in various widths and thicknesses and can be found in most builders' merchants. This strapping only works in tension, so it is important to understand which way you are trying to stop the building leaning when using it for racking strength. If in doubt, fix it diagonally in both directions.

Roof

The main considerations when detailing any modern roof, apart from waterproofing, obviously, are the requirements for airtightness and insulation. The use of cast hempcrete as roof

Timber frame with diagonal plywood braces and timber gussets.

Diagonal stainless-steel strapping used as a brace. *Image: Peter King* insulation, as described in Chapter 17, has the advantage of introducing increased thermal mass into the roof structure.

Eaves

The main function provided by good detailing at the eaves is the first defence against precipitation by means of a good roof overhang. The other important consideration with this detail in hempcrete buildings is how to form a robust junction between the wall hempcrete and the roof insulation that is also straightforward to construct and airtight – which can be difficult to achieve. As discussed in Chapter 21, it is also necessary to consider the construction process when detailing the eaves, with regard to the advisability of placing the hempcrete from above.

Airtightness at the eaves is more difficult to achieve than at other junctions. One of the reasons for this is that at the eaves of most buildings the rafters project through the airtight line, because the vapour-permeable roof membrane which in most pitched roofs is used on top of the insulation has to come down and join with the airtight element in the wall. This usually requires the time-consuming job of taping a hole in the membrane, rather clumsily (and not very effectively), around each of the rafters. This problem can be solved by using prefabricated bolt-on rafter ends, as they are fixed after the airtight line has been completed, meaning that the roof membrane can continue seamlessly down to the top of the wall (see Figure 28 overleaf). Bolt-on rafter ends also offer the following advantages to a hempcrete build:

- They do not get covered with hempcrete, as they are fitted after the hempcrete is installed. This is useful if the rafter ends are to be left exposed at the eaves (visible from the ground outside).
- Because they are absent when the hempcrete is placed, the rafter ends don't obstruct this process as they would do otherwise.
- Because they are not a continuation of the main rafters, as would be usual, this allows the main rafters to be an engineered I-section timber while the rafter ends can be a solid timber. On large roofs this results in a cost saving, while still allowing aesthetically attractive exposed solid-wood rafter ends. These are often desirable, for example on attractive oak-framed buildings.
- They make it a simple process to reduce the pitch of the roof at the eaves (a standard detail on roofs with a medium-to-steep pitch, which helps to slow rainwater down as it approaches the guttering).
- The rafter ends are very easy to replace, which can be useful since they are most vulnerable to the weather and are prone to rot.

The main disadvantages to using bolt-on rafter ends are that:

- They are more complicated to build and they are a relatively recent innovation, so not all construction workers will be familiar with them.
- There is a limit to the weight of the roof covering that can be used, since the bolt-on rafter ends are inherently weaker than a continuous rafter; for example, they would not be able to support the weight of a green roof.

Bolt-on rafter ends will not be suitable for every building design, but in our opinion they bring so many advantages that they should be incorporated wherever possible.

Another situation in which airtightness at the eaves can be difficult to achieve occurs when a lightweight quilt insulation is used in the roof (also shown in Figure 28). The answer to this is to use an insulating wood-fibre sarking board to compress the quilt insulation against the top of the hempcrete wall, as described on the following pages.

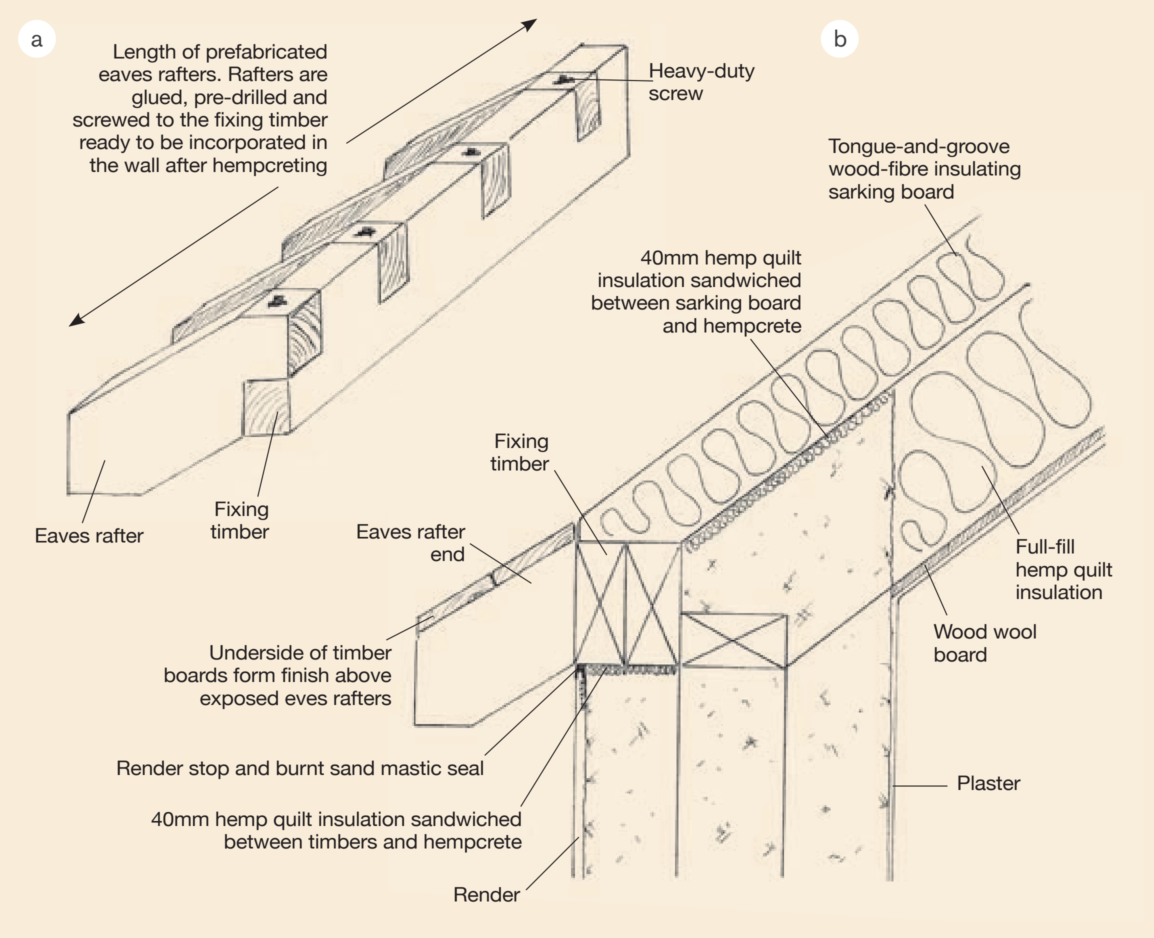


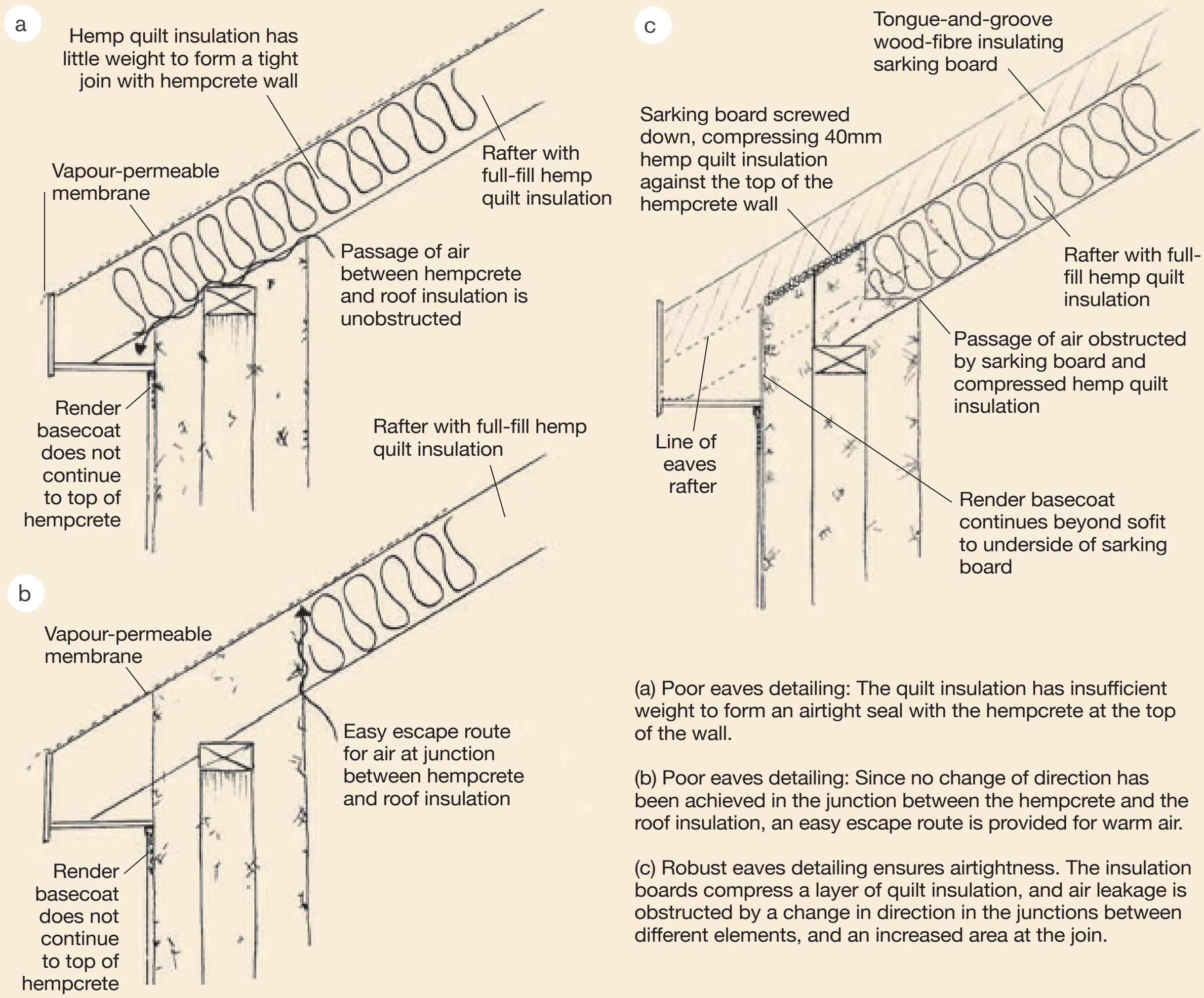
Figure 28. Prefabricated bolt-on eaves rafter ends. (a) Rafter ends are attached to the fixing timber before fitting to the wall. (b) Rafter ends in the finished wall.

Airtightness over the roof

The vapour-permeable membrane generally used on top of the roof insulation provides a second line of defence against any moisture that penetrates the roof covering. Any moisture that moves out of the building via this membrane, which condenses as water droplets on the underside of the roof covering, is also then kept out by the membrane. The membrane, when joined with tapes designed specifically for the purpose, can also be used as the airtight layer in the roof build-up, and should be sealed to the hempcrete and the render (or cladding membrane). The longevity of tapes in this situation is still largely untested, and in our experience it is very hard to get the overlap of membranes to lie perfectly flat for easy taping. For those who share our concerns, an alternative to using tape for airtightness at the roof membrane is shown in Figure 29 opposite.

The use of tongue-and-groove wood-fibre insulation boards for pitched roofs and walls is increasingly popular in the natural building world. Many of these boards perform the same function as a vapour-permeable membrane in terms of keeping water out while adding extra insulation. They are also more sustainable than such membranes, since although a processed material transported from Europe, they are produced from a natural material, wood, which acts as a carbon sink. Used as a sarking board, they can be installed over the rafters to provide a water barrier, and left without a final roof covering for up to three months while construction proceeds below. The tongue-and-grooved edge makes fitting easy, as the join between two boards doesn't have to sit above a rafter.

This join also gives a good level of airtightness in the roof, although some manufacturers also provide tapes to seal the joins. There are many different types of wood-fibre insulation boards available on the market, so it is important to make sure that weatherproof boards, specifically designed for this function, are used.



(a) Poor eaves detailing: The quilt insulation has insufficient weight to form an airtight seal with the hempcrete at the top of the wall.

(b) Poor eaves detailing: Since no change of direction has been achieved in the junction between the hempcrete and the roof insulation, an easy escape route is provided for warm air.

(c) Robust eaves detailing ensures airtightness. The insulation boards compress a layer of quilt insulation, and air leakage is obstructed by a change in direction in the junctions between different elements, and an increased area at the join.

Figure 29. Good and bad airtightness detailing at the eaves.

The use of wood-fibre boards also assists in achieving airtightness at the eaves, for two reasons, as shown in Figure 29. First, it is very easy to introduce an obstruction to the passage of air at the airtight junction. Second, as described earlier, one of the main reasons that a good seal at the eaves is hard to achieve when using soft quilt roof insulation is that it is so lightweight that there is nothing to compress the seal between the insulation quilt and the top of the hempcrete walls. When fixing the boards down, a layer of quilt insulation can be trapped between the board and the hempcrete, squashing it down to give a much tighter seal.

Airtightness in a flat roof

Most modern flat roofs are constructed as a warm roof, with the insulation on top of the timber deck. Here the airtightness will be provided by the roof covering, which should be sealed to the airtight component in the walls, usually via the roof deck, with the roof covering glued to the top of the roof deck and the airtight component in the walls sealed to the underside. In a hempcrete wall this means sealing both the hempcrete and the render to the underside of the roof deck. The simplest way of doing this is to use some form of render stop bead and mastic to seal the render, and hemp quilt insulation sandwiched between the hempcrete and the roof deck to seal the hempcrete (see Figure 30).

In the case of a cold deck, the airtightness in the roof is provided by a vapour-permeable membrane on top of the hempcrete and under the vented air gap. This membrane can also form the airtight component in the wall, where a cladded finish is present, by continuing over the roof and down the wall, becoming the vapour-permeable membrane in the cladding build-up (see Figure 32, page 329). This cold roof build-up also allows the hempcrete wall to seamlessly become the hempcrete roof insulation with no join necessary.

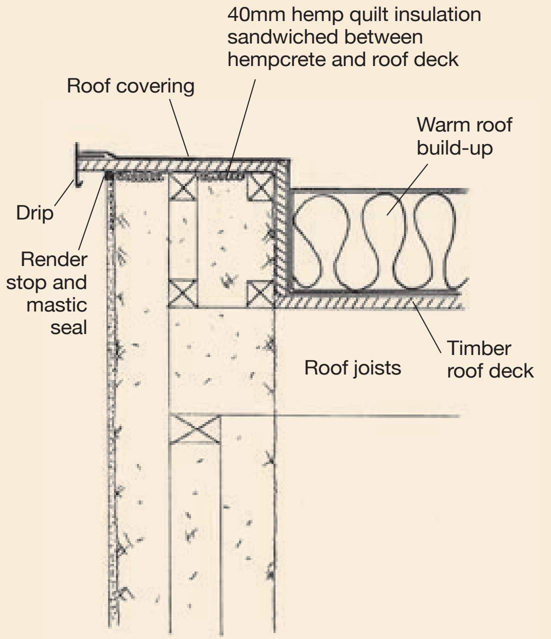


Figure 30. The airtight junction at the eaves of a flat roof with a warm roof build-up.

Hempcrete roof insulation

Cast hempcrete can be used as a roof insulation material, although, like floor slabs, this is an application that is far more common in France than in the UK at the time of writing.

If using cast hempcrete insulation in the roof space, the problem of airtightness in the eaves detailing is reduced, since the junction between wall and roof insulation no longer exists: the hempcrete continues up into the roof, forming a seamless join with the less dense roof hempcrete.

This concept can be extended further: if hempcrete roof insulation is used together with a hempcrete floor slab, it is possible to create a seamless ‘box’ of continuous cast natural insulation to provide an incredibly simple yet incredibly effective whole-thermal-envelope solution (see Figure 21, page 310). An extremely good level of airtightness can be achieved in this way, by designing out the presence of other materials and thus junctions and the use of sealants, tape and other 'weaker' elements. And, as discussed in earlier chapters, unlike synthetic whole-envelope systems, the hempcrete also provides a natural, breathable walling system with all the benefits this brings for the comfort and health of the building's occupants.

Although the use of hempcrete roof insulation can enable this elegant solution in terms of whole-building design, it has some disadvantages:

- It is heavier than most other roof insulations, and so may require a stronger roof construction than would otherwise have been required.
- As a mixed-on-site insulation, hempcrete involves an extra construction process compared with normal roof insulations, with associated additional labour costs.
- It has a lower U-value (at equivalent thickness) than fibre quilt insulation materials, and thus requires a thicker layer in the roof.

All three of these issues can be mitigated to some extent by the introduction of a layer of natural-fibre insulation (quilt- or board-type) above the hempcrete. This solution retains the advantages of the excellent airtightness and the thermal mass provided by the continuous cast hempcrete, while enabling a thinner layer to be used than would be required for hempcrete alone.

Hempcrete insulation in a pitched roof

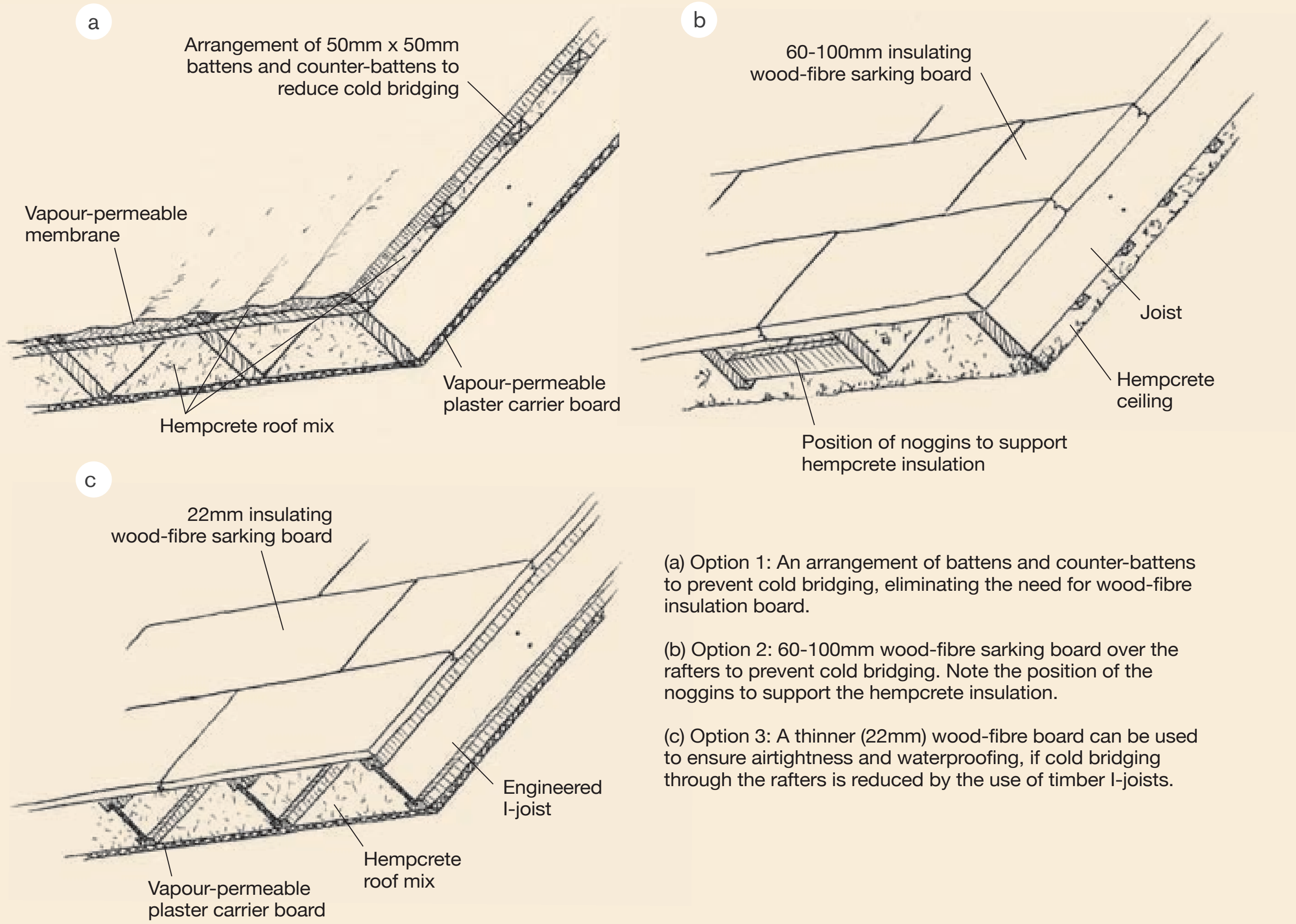
Many options are available for insulating a pitched roof, depending on the type of rafter used, whether or not a hempcrete ceiling is desired (see page 330), and whether or not an insulating wood-fibre sarking board is to be used. Three such ways are illustrated in Figure 31 overleaf. In each illustration the tiling battens have been left out for the aid of clarity.

Down the length of the rafters, noggins will be needed to stop each newly filled section of hempcrete from sliding down the roof and compressing that at the bottom. (These are needed in all three options illustrated in Figure 31, but for simplicity they are shown in 31(b) only.)

The spacing of these noggins will depend on the pitch of the roof, with steeper roofs needing them at smaller intervals. These noggins can be thinner than the main rafters by 50mm at the top and bottom, in order to reduce any cold bridging effect. For example, if the main rafter were 200mm deep, the noggin could be 100mm deep, with its base 50mm above the base of the main rafter.

The simplest, and cheapest, method of insulating a roof with hempcrete is shown in Figure 31(a). To take full advantage of the loose-fill nature of the material, the main rafters have two sets of counter-battens, at least 50mm x 50mm section, fixed on top of them: the first horizontally and the second vertically in line with the rafters. This provides a fix for the horizontal tiling battens, and also allows the cast insulation to fully cover the rafters, minimizing cold bridging and also removing the potential air gaps right through the insulation along the side of the rafters. Between the counter-battens and the tiling battens a vapour-permeable membrane or wood-fibre sarking board is required as usual. If using a sarking board, however, it would only need to be 22mm thick for airtightness and waterproofing, which is much cheaper than 80mm boards.

The system of having layers of counter-battens sounds complicated, but actually the depth of a roof containing only hempcrete insulation needs to be at least 300mm in order for sufficient insulation to be achieved. Using a 300mm-deep rafter is expensive compared with using a 200mm



(a) Option 1: An arrangement of battens and counter-battens to prevent cold bridging, eliminating the need for wood-fibre insulation board.

(b) Option 2: 60-100mm wood-fibre sarking board over the rafters to prevent cold bridging. Note the position of the noggins to support the hempcrete insulation.

(c) Option 3: A thinner (22mm) wood-fibre board can be used to ensure airtightness and waterproofing, if cold bridging through the rafters is reduced by the use of timber I-joists.

Figure 31. Hempcrete insulation in a pitched roof.

rafter and two 50mm counter-battens, and the latter solution also results in a more robustly detailed roof in terms of maximizing airtightness and minimizing cold bridging. This system can also be used with other loose-fill insulations, for example recycled cellulose insulation.

The spacing of the counter-battens will depend on the weight of the roof covering they are supporting, and, along with the depth and type of the roof joist, should be specified by a suitably competent person.

Since cast-in-situ hempcrete in a roof is placed from above, there is an issue with keeping the work dry as it progresses, which applies to the walls too if these have already been cast. This can be achieved with a waterproof tarpaulin temporarily fixed at the top of the roof and rolled down each time work stops. However, fixing these coverings down and rolling them up when work starts again is a time-consuming and risky business, and on larger roofs the best solution is probably a scaffolding roof over the whole structure.

Keeping the work dry can be a challenge when casting roof insulation. *Image: Margot Voase*

Hempcrete insulation in a flat roof

When constructing a flat roof with cast-in-situ hempcrete insulation, a vapour-permeable membrane covers the top of the hempcrete, with a vented air gap above that (see Figure 32). To ensure airtightness and reduce cold bridging within the hempcrete layer, counter-battens can be used as they are in a pitched roof (see page 327). An air gap is achieved by running roofing battens on top of the vapour-permeable membrane and fixing the roof deck to these. Vents can be inserted into the fascia on either side of the roof to make the spaces between these battens into a series of air tunnels. Battens should be of good-quality treated or hardwood timber, owing to the potential exposure to moisture and the weight of the roof deck they are supporting. Once again, a suitably competent person should specify the spacing of the battens and the depth and type of the rafters.

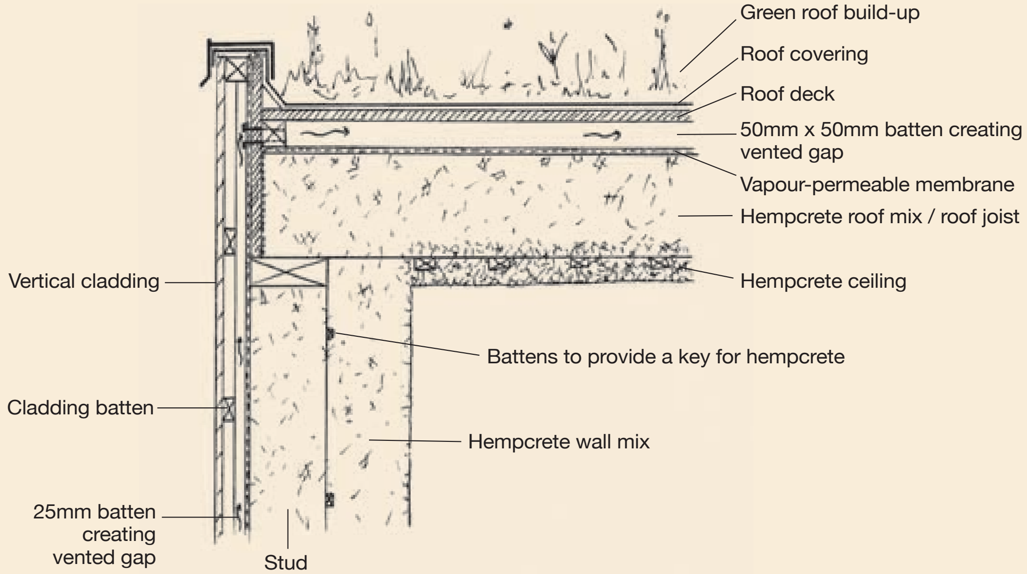


Figure 32. Hempcrete insulation in a flat roof.

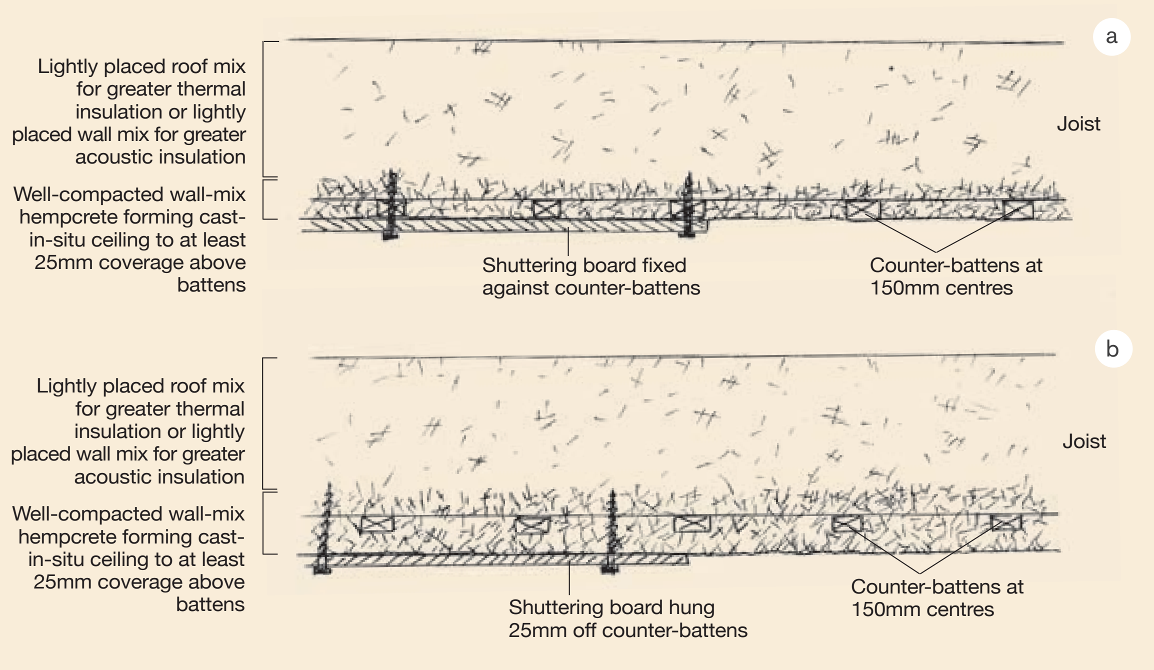


Figure 33. A cast-in-situ hempcrete ceiling. Small-section timber battens are attached to the underside of the joists, and the hempcrete is cast around these. Shuttering board is either attached directly to the battens (a) or hung underneath them so the battens are not visible in the finished ceiling (b).

Hempcrete in ceilings

When using hempcrete roof insulation, it is important that the whole roof build-up is breathable, including the interior finish. If the roof space is to be used as a room, with a ceiling on the inside of the rafters, this can be achieved by using either a breathable plaster carrier board or a cast hempcrete ceiling coupled with a breathable finish. A hempcrete ceiling is constructed as a cast-in-situ structure from above and requires a layer of wall-mix hempcrete, firmly compacted and reinforced with timber battens to create a ceiling board. The lower-density hempcrete roof insulation is then placed on top of this (see Figure 33). See Chapter 17, pages 226, for full details.

If the ceiling is being cast between floors or below a loft space rather than as part of a roof build-up, the preference may be for greater acoustic insulation rather than greater thermal insulation, in which case the mix used directly above the ceiling, between the joists, should be a (higher-density) wall mix.

Cladding

Cladding materials used on hempcrete walls, and the detail for fixing these to the cladding battens or frame timbers, is much the same as in any other building. As with most cladding systems for any building, a vented air gap should be created between the face of the hempcrete and the cladding matter. However, because of the nature of the hempcrete itself there are additional issues to be addressed in this detailing. The main considerations are as follows:

- The vapour-permeability of the hempcrete wall must be maintained.

- If an externally exposed frame detail is used to aid fixing of the cladding, these frame timbers are vulnerable to moisture ingress and this issue needs to be resolved.
- Since airtightness is not ensured in the absence of a render finish on the hempcrete, other measures need to be taken to maintain airtightness on the face of the wall.

The cladding by itself, with a vented air gap, provides sufficient protection for the hempcrete, but the requirement to protect the frame timbers and achieve extra airtightness presents a choice of solutions, with varying associated costs. This is an evolving science, with a variety of details in use and other possibilities that have not yet been proven. The full range of options is too extensive to discuss in detail here, but the three example options outlined on the following pages show different ways of resolving the issues of frame protection and airtightness.

Non-masonry cladding

As with any other timber-frame building, non-masonry cladding for a hempcrete wall, which may include timber, other boarded cladding or hung slates or tiles, is fixed to cladding battens that are situated within a ventilated air gap. The simplest way to ensure protection of the frame timbers and to achieve extra airtightness is to place the structural frame flush with the external face of the wall and fix the cladding battens directly to this, with a taped vapour-permeable membrane sandwiched between the two. The air gap between the cladding and the membrane, in which the battens sit, is vented at both ends to ensure a good flow of air behind the cavity (see Figure 34(a) overleaf).

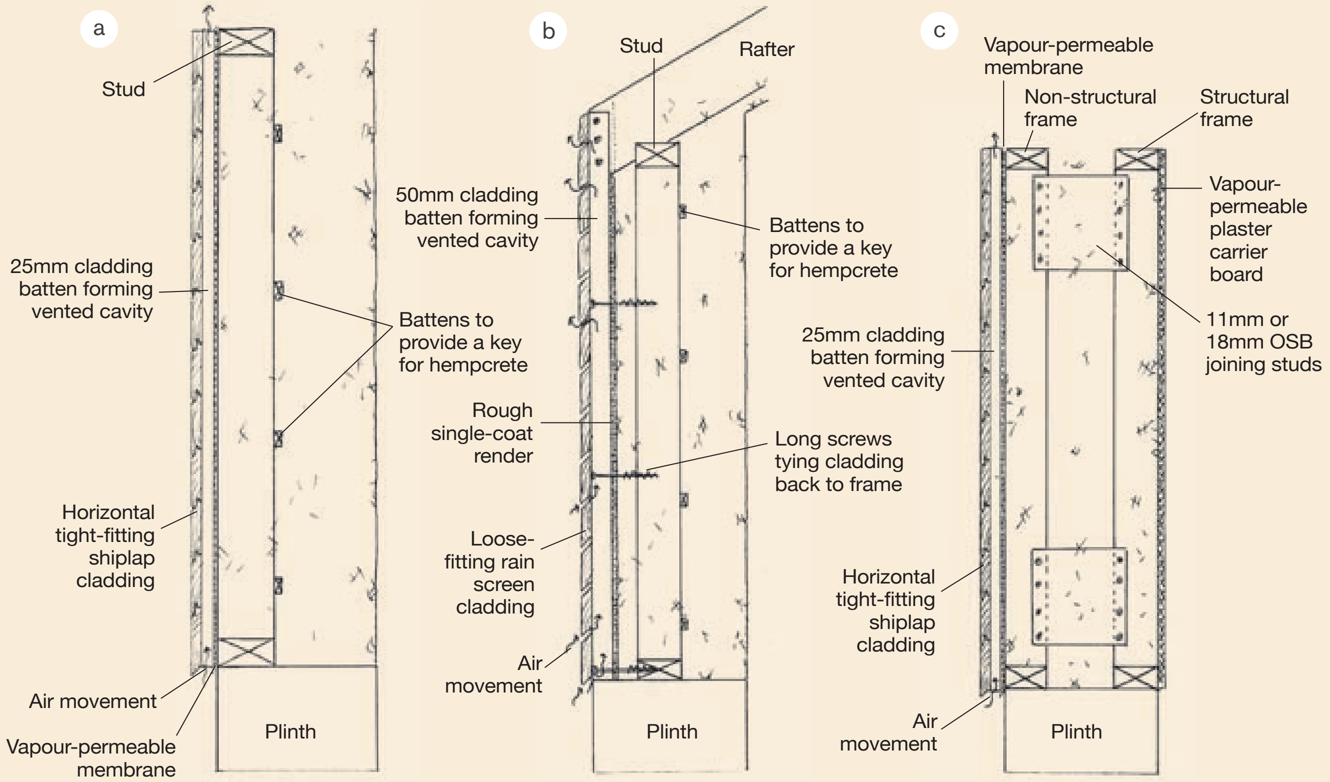
This option has the advantages of both low cost and simplicity of construction, while achieving the key principles of ensuring airtightness and protecting the frame. However, the following 'cons' should be considered:

- Although protected by the membrane, the external face of the wall is still a vulnerable position in which to place a softwood structural frame. Replacement of this section of the frame with hardwood would solve the problem, but increase costs.
- The use of a vapour-permeable membrane introduces highly processed, high-embodied-energy synthetic materials into the building, which increases the environmental impact.
- The effectiveness of using a taped vapour-permeable membrane to ensure airtightness in the long term depends very much on the quality and longevity of the membrane and tape, as well as on the thoroughness with which these are applied on-site.

A second, more sustainable, option avoids the need for a synthetic membrane by using a render coating to ensure airtightness under the cladding (see Figure 34(b)). Renders are not usually applied under cladding in conventional construction, since the material underneath is not usually capable of carrying a render, but hempcrete provides the ideal key for render. The costs are cheaper than for a standard external render, since a single rough basecoat is sufficient to provide airtightness and will not be seen under the cladding, so an attractive finish is not required.

While the render provides airtightness, it is not considered sufficient protection for a timber frame immediately below it, so the softwood structural frame is moved 50mm back into the wall. Normally a coverage of 70mm hempcrete would be recommended to protect timbers, but in this case, with the extra protection afforded by the cladding, 50mm is ample.

Placing the frame 50mm inside the hempcrete wall means that the cladding battens will not be fixed directly to it and therefore cannot transfer the load of the cladding to it. The battens are still



(a) Simple timber cladding detail. The structural frame is placed flush against the external face of the wall; airtightness and protection from moisture ingress are provided by a taped vapour-permeable membrane fixed across the frame.

(b) Natural cladding detail comprising a timber rain screen fixed to vertical cladding battens, which sit within the 50mm vented cavity and are fixed to the rafters and bear on the plinth. The structural frame is placed 50mm inside the wall and a rough basecoat of lime render is applied to the face of the hempcrete.

(c) Double-frame cladding detail, in which timber cladding is attached to a softwood cladding frame placed flush with the surface of the wall under a vapour-permeable membrane. The structural frame is on the internal face of the wall and therefore not vulnerable to moisture ingress.

Figure 34. Non-masonry cladding details.

fixed to the frame, with long screws through the hempcrete to hold them against the face of the wall, but in addition they need a structural fix to the rafters and also need to bear on to the plinth. Since the cladding battens are now taking the load of the cladding, they need to be larger in section than they would be if fixed directly to the frame. The size of these timbers should be specified by a suitably competent person, who should also consider the load of the cladding on the rafters (via the cladding battens).

The extra protection provided by the render may also allow the use of a simple rain screen cladding rather than a conventional tightly fitting or overlapping cladding. A rain screen cladding is constructed from boards that only need to butt up to each other, allowing the use of reclaimed timber instead of the usual featheredge or shiplap board.

A third option is to use a vapour-permeable membrane, as in Figure 34(a), but to improve the frame detail by using a double frame (see

Figure 34(c)). This involves moving the softwood structural frame to the internal face of the wall, where it is well protected, and connecting a separate non-structural cladding frame to it (see Chapter 13, page 160), which sits on the external face of the wall immediately under the membrane.

Since in this case the cladding frame only supports the weight of the cladding itself, rather than the load of the upper floors and roof (as in Figure 34(b)), it may be possible to construct it from smaller-section timbers (as specified by a suitably qualified person) than the structural frame. This in turn may make the use of hardwood a more viable option for this section of the frame, which further improves the detail. Weighed against this, however, are the additional material and labour costs of a using double frame, and the fact that a synthetic vapour-permeable membrane should still be used to provide airtightness, although in the case of a hardwood frame it would not be needed to protect the timber. One of the biggest arguments in favour of the double-frame solution is the reduced labour and material costs on the shuttering, since temporary shuttering boards can be screwed straight to the frame on both sides.

From the examples set out here, it should be clear that the detailing of various claddings for hempcrete is an evolving 'conversation' rather than a hard-and-fast set of rules. As long as the basic principles of structural integrity, airtightness and protection of surface timbers are addressed, there is no 'wrong' way of detailing it. The details discussed here are not intended to provide the reader with an exhaustive list of options; rather

Timber cladding over a hempcrete section in a cob wall.

Hung-tile cladding provides extra protection to this exposed hempcrete gable. This replicates the original gable detail in this listed timber-frame cottage.

to show some ways in which the issues can be addressed, while demonstrating that the way in which you deal with one issue can have an impact on the others – making the process quite complex and demanding of a holistic solution.

Masonry cladding

When applying masonry cladding to a hempcrete wall, the cladding bears on to the plinth and is tied back to the timber frame with stainless-steel cladding ties. As with other forms of cladding, a ventilated air gap is included (see Figure 35). Owing to the weight of masonry cladding and therefore its requirement for good support, it is sensible to keep the cladding as close to the timber frame as possible, which means the frame should be on the external side of the wall, with a vapour-permeable membrane fixed to it for airtightness and protection against moisture ingress. In this situation it is vital that the cavity between the membrane-covered frame and the masonry provides *effective* ventilation, so it is essential that it is sufficiently wide and well vented, and does not get filled with dropped mortar. As many vents as possible should be provided at the base and top of the cladding.

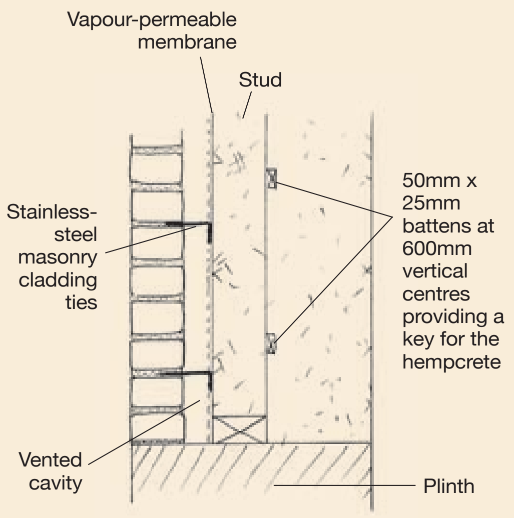


Figure 35. Protecting frame timbers and ensuring airtightness if using masonry cladding.

It is recommended that a lime-based mortar be used for masonry cladding, even *with* a vented air gap, as this has several advantages:

- This is a more robust detail in terms of breathability: a lime mortar helps to keep the masonry cladding permeable to vapour, which improves the overall breathability of the building, and allows any moisture in the cavity to exit through the cladding as well as through the vents.
- Lime mortar is more flexible and better equipped to absorb the slight movements that occur in timber-frame buildings.
- It is a more environmentally sustainable option.
- It will be more in keeping with the overall design and finish of the building.
- It will allow the use of softer stones and brick without causing damage to them.

Different types of building lime can result in wide variations in a mortar's hardness, tensile strength and vapour permeability, as well as in its other characteristics. When specifying a lime mortar for masonry, the main principle is that the mortar should be softer, in its set state, than the stone or brick used. This is so that any moisture taken in through the surface of the wall can easily be released through the 'sacrificial' mortar joints, rather than being held in the masonry where it has the potential to cause damage. Lime mortars should always be specified by a suitably qualified or experienced person who is used to using lime in masonry work.

The main issue when specifying a mortar for masonry cladding is that the mortar is both softer than the surrounding masonry while also strong enough for what is likely to be a relatively

Masonry cladding on a hempcrete building. Note the external frame enabling the cladding to be tied in to the wall, and the vapour-permeable membrane.

thin masonry veneer. For such a thin depth of masonry cladding, bricks or a well-dressed or cut stone are likely to be the material of choice, for the increased stability their even shape brings.

Masonry cladding with no vented cavity

One possibility that many people are discussing currently, but which has not yet been proven in practice, is the idea of casting hempcrete directly up against masonry cladding, with no cavity. This could be advantageous because, where a cladding is to be used anyway for aesthetic reasons, this method simplifies the process and allows cost savings: on labour, as the external temporary shuttering is not needed, and on materials (e.g. the membrane and vents for the cavity).

To explore the effect this would have, it helps to compare the masonry cladding to a vapour-permeable lime render, which is the standard finish for a hempcrete wall. Imagine the masonry cladding as a very thick lime render (the mortar) with huge pieces of aggregate set in it (the bricks or stones). The problem is that this 'giant-sized aggregate' effectively creates breaks all the way through the render from the outside to the inside along the edges of the brick or stone.

There is a risk that water could move by wicking (capillary action) along the join between the brick and the mortar, straight through the 'render' and into the hempcrete. The hempcrete, being breathable, normally releases any moisture to the outside through the render once the rain has stopped. However, in this case, due to the wicking, there could be more moisture than normally expected, and an additional risk that some of this will get trapped behind the stones or bricks, which should be less vapour permeable than the mortar.

For this reason, it may take longer for the moisture to be released to the outside through the cladding than through a standard lime render. If the moisture hasn't been released by the time it rains again, then there could be a gradual build-up of moisture in the wall over time, to levels that the hempcrete would not be able to tolerate.

To counteract this effect, it may be possible to use a hydrophobic (water-repellent) yet vapour-permeable render on the inside face of the masonry prior to casting the hempcrete. Such products are available from manufacturers of high-tech proprietary lime-based renders, for example Baumit or Parex. This would stop any moisture droplets that wicked through the cladding from entering the hempcrete, but would still allow moisture vapour to pass in and out. Unfortunately, the cost of such renders is currently very high compared with that of a standard lime render, and as such might outweigh any savings gained by the elimination of the air gap.

The solution of using a hydrophobic render also presents problems for hempcrete drying, since there is liquid water as well as vapour which needs to dry out of freshly cast hempcrete. With a hydrophobic render already applied, then only the vapour could exit through the external cladding. All liquid water would have to dry to the inside of the hempcrete, which would happen eventually, but this would slow the drying time significantly. It is worth remembering, of course, that the simple presence of a masonry cladding directly against one side of the hempcrete wall will already have a huge impact on the drying time of the hempcrete and could potentially cause delays in the application of internal finishes, depending on the thickness of hempcrete used.

In addition, if moisture *vapour* can enter through the cladding, there is a risk that any vapour that subsequently condenses inside the hempcrete would not be able to leave again through the hydrophobic render. Again, this carries the risk of a build-up of moisture in the hempcrete.

This idea, then, requires more investigation, and trials in practice. It may be that where the wall is in a very sheltered position, the detail of hempcrete cast against masonry cladding *without* a hydrophobic render could work. This would be based on an assumption of limited weather exposure, and plenty of time between heavy soakings for the wall to expel all the water from the last rain. But if the wall was subject to even average exposure to rain, except perhaps in very dry climates, such a detail would certainly be inadvisable. In exposed locations, frequently subject to rain and high winds, this detail would not work, and indeed a more appropriate material in such a case might be a hung slate cladding.

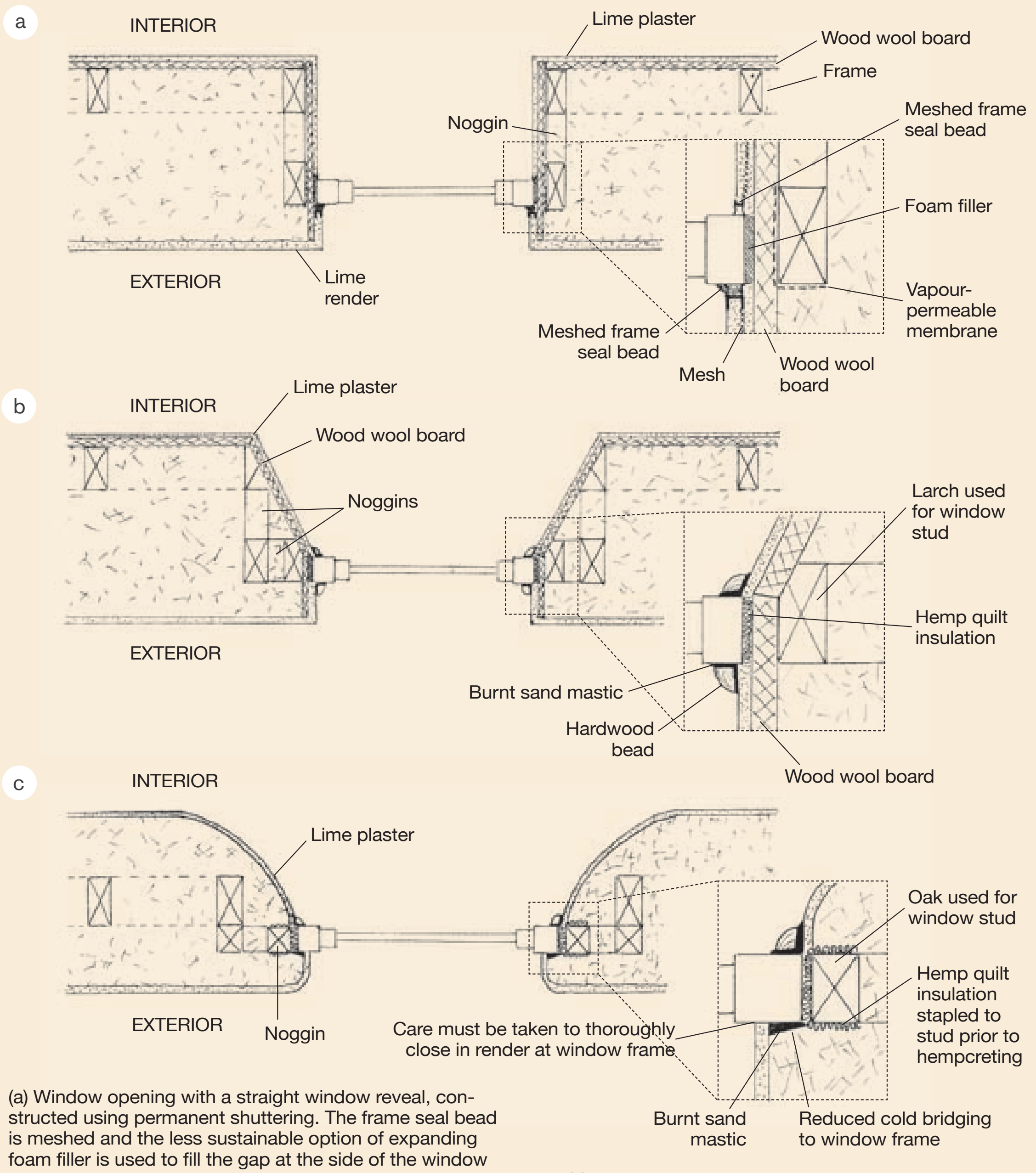
Openings

The main considerations at openings in the hempcrete wall, apart from the familiar question of airtightness, are the need to provide a secure fixing for the window or door frame and to ensure that the hempcrete is well supported above the opening.

Fixing windows and doors

Window and door frames need to be fixed to the structural frame or to something that is strong enough to take the window or door frame fixings back to the structural frame.

Where the structural frame sits in line with the desired position of the window or door, the fixing can be achieved with little difficulty. In situations where the two are not in line, the detailing must provide a secure fix for the window or door frame. This can be done by boxing out with plywood or studwork and covering this with wood wool board to reduce cold bridging and provide a substrate for renders and/or plasters if required. However, where the windows sit towards the outside of the wall and the structural frame is positioned on the internal face of the wall, a straight boxing-out would create a deep ‘tunnel’ window reveal that cuts out light due to the depth of the wall. A more tapered or even a curved reveal can disguise the depth of the wall and increase the amount of light that can enter. This is achieved by stepping the frame and tapering the shuttering: the reveals can be left tapered, or brought to a curve with a nail float once the hempcrete has been placed (see Figure 36 opposite). It is more difficult to taper the reveals if a permanent internal shuttering board is being used, but if a 15mm wood wool board is used for the reveals this can be bent to form the taper and fixed to the studs as required.



(a) Window opening with a straight window reveal, constructed using permanent shuttering. The frame seal bead is meshed and the less sustainable option of expanding foam filler is used to fill the gap at the side of the window frame. The fixing stud is of softwood and so needs a vapour-permeable membrane to give extra protection.

(b) Window opening with a splayed window reveal, constructed with permanent shuttering. Here the bead detail is hardwood sealed with burnt sand mastic. The fixing stud is of larch and so doesn't require a vapour-permeable membrane.

(c) Window constructed using temporary shuttering. The hempcrete has been shaped by scratching back with a nail float to create a curved reveal. The hardwood stop bead has been designed out by extending the hempcrete over the window, and hemp quilt insulation has been used around the oak fixing stud to ensure airtightness.

Figure 36. Horizontal sections of window openings.

Unless hardwood or treated timber is used, the timbers around openings should be protected with a vapour-permeable membrane, owing to their proximity to the outside face of the wall.

Airtightness around openings

The area around openings is a potential weak spot in terms of airtightness. The window manufacturer's recommended methods for closing the gap between the window frame and structural timber frame should be followed, and, in addition, the internal plasterwork and external render should both be sealed to the window frame using a render stop bead and mastic seal, or a frame seal bead, the latter of which is aesthetically far more discreet for use internally (see Chapter 18, page 245).

Shuttering for an opening

Openings can be created using either temporary or permanent shuttering. If permanent shuttering boards are used for the walls, then it makes sense for these to be used for the reveals also.

Where the internal walls are created using temporary shuttering, then doing the same for the reveals gives a more consistent background for the plaster and allows the hempcrete to be curved with a nail float after placing. However, the use of temporary shuttering for the reveals requires the placing of the hempcrete around the openings to be very thorough and even, so that the corners created in the cast hempcrete are strong and stable. This takes extra time, since it is an awkward space to physically get into when placing the hempcrete. For this reason, those inexperienced with hempcrete building may wish to use permanent shuttering to make the placing of the hempcrete at this section less critical.

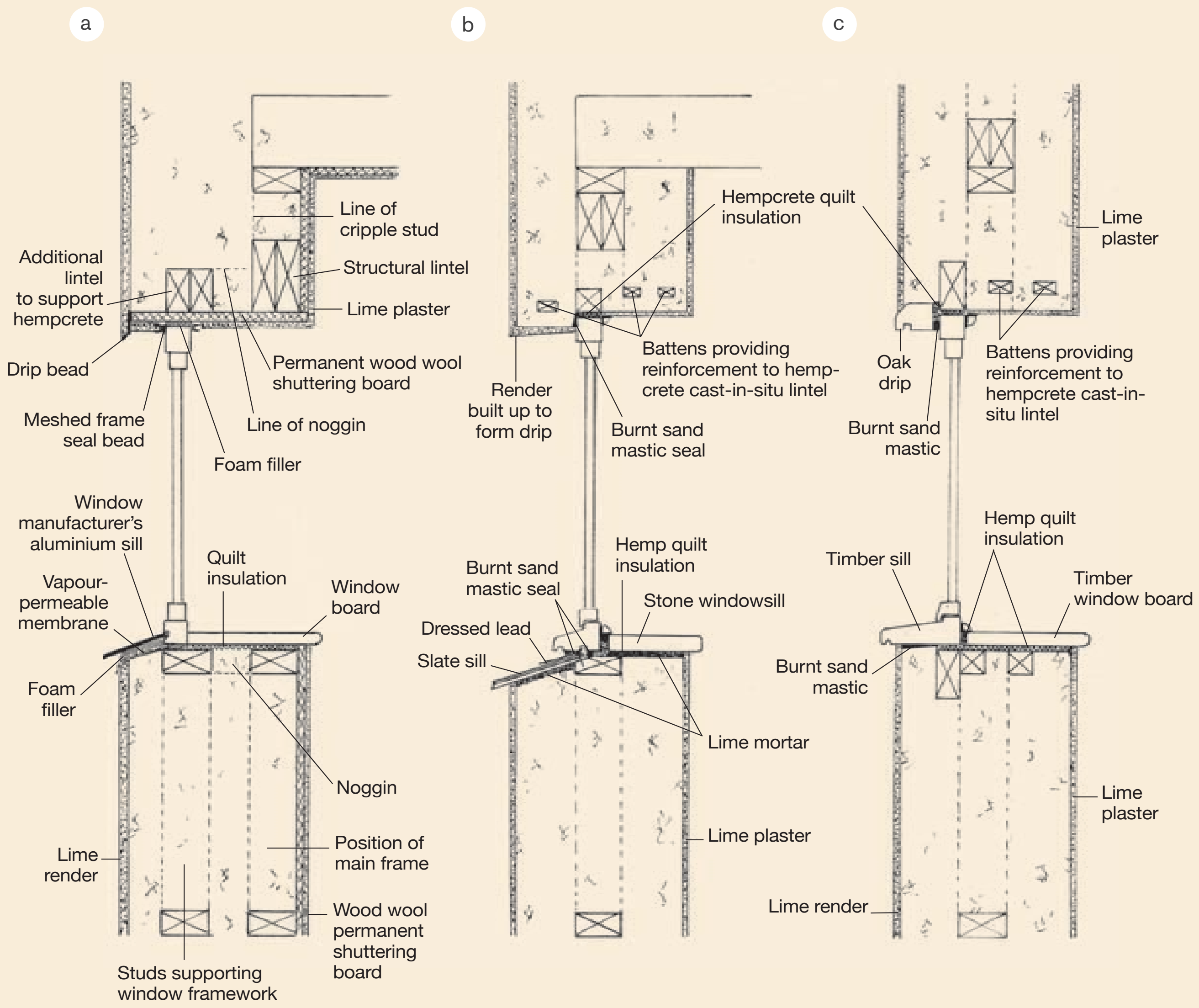
Permanent shuttering also makes it easy to support the hempcrete above the opening, since the permanent board forming the top of the opening is in place to hold up the wet hempcrete as it dries out through the board (whereas temporary shuttering has to be removed for the hempcrete to dry out). However, most permanent shuttering boards are inherently weaker than temporary shuttering boards, due to their lower density, so may still require additional temporary bracing to be fixed underneath while the hempcrete is being placed, to avoid movement.

Lintels

Permanent shuttering might at first seem the obvious solution when casting the top of an opening, but it is not difficult to provide support for drying hempcrete if temporary shuttering is used. Battens laid across the opening, spaced 50mm apart and at least 50mm from the external face of the wall, are cast into the hempcrete above the opening to provide reinforcement, extending across the whole opening into the wall on either side. These are either fixed to the frame or laid loose inside the cast material, bearing on the hempcrete on each side (see Figure 37 opposite).

Openings that do not have frame loads (joists or rafters) bearing on them need only the framework to provide a fix for the door or window frame and extra timbers as necessary to support the weight of the hempcrete. For short spans, these extra timbers might just be battens as described above, in addition to the door or window framework, but for longer spans, larger-section timbers or a separate structural lintel may be required to support the hempcrete. Openings bearing frame loads also require a structural lintel within the frame.

For extra structural integrity in the cast hempcrete at this vulnerable area, the lift of hempcrete that goes over the opening (and extends beyond each side of the opening) is placed in one go to form a cast-in-situ 'lintel' of hempcrete.



(a) A wide-span window opening on a building with an internal frame, showing permanent shuttering and additional lintel for the hempcrete, together with supporting studs for the window itself. Note the aluminium windowsill and drip detail created using a drip bead.

(b) A normal-sized window opening on a building with a central frame, constructed using temporary shuttering. Reinforcing battens are cast into the hempcrete above the window to support it. Note the natural slate and lead sill detail, and the drip detail created using render.

(c) A window opening with the same construction as (b) but showing a timber sill and drip detail.

Figure 37. Vertical sections of window openings.

Sill details

Windowsills in a hempcrete wall should have a good-sized drip detail on them to take water away from the surface of the wall. There are many options for doing this, and airtightness should be maintained using the methods described on page 338 and shown in Figures 36 and 37. Standard aluminium or timber sills can be used (but, depending on the placement of the window within the wall, a longer sill may be needed (see Figure 37(a) and (c)) or a secondary sill can be placed below it (see Figure 37(b)). Natural slate provides an attractive and durable option, and can easily be cut to the required size (see photo below).

Natural slate makes an attractive and effective sill detail.

Designing a hempcrete building: summary

As a natural, plant-based material, hempcrete presents the designer with a number of new factors to consider that do not apply when designing for conventional building materials. However, with proper understanding and a little forethought, hempcrete is a rewarding material to work with; its adaptability means that scope exists for a wide variation in different designs, and there are many different materials that perform well alongside it.

It is hoped that the indicative details shown in this section, together with the information and advice in the rest of this book, will provide inspiration to building designers and assist them in understanding not only the range of options available but also the consequence of these choices for the finished building, in terms of performance, cost and longevity.

In detailing a hempcrete building there are four main themes that the building designer must understand, as discussed in the previous chapter. These are: the limits of the material, in terms of its performance and structural integrity; the nature of the material, in terms of its key characteristics; how it behaves during and after construction; and how it will behave in the context of the particular site. The chance to visit a hempcrete building site during the construction phase, including seeing some unfinished but set hempcrete, will give the designer a real sense of the material and will provide a much more thorough understanding of the issues than a book could ever hope to convey. While this is not always possible currently, it should be much easier as hempcrete builds become more commonplace.

Some essential questions to ask when detailing and designing for hempcrete are:

- Does the design make sense within the structural limits of the material?
- Can it be constructed easily?
- Is the softwood structural frame safe from water ingress?
- Can all the materials and fixings used withstand the alkaline environment?
- Is vapour permeability maintained?
- Is airtightness maintained?
- Does the design reflect the demands of that particular building, on that specific site?

We recommend that, wherever possible, designers avoid complicating additions to the basic wall design, as the real beauty of hempcrete is in its simple, low-tech approach, with a minimum of specialized technical solutions required. Even in the use of permanent shuttering boards, for example, something intangible is lost. There is true elegance in the simplicity of the basic monolithic hempcrete wall with a central timber frame, and a lime render and plaster finish.

Once the key issues are understood, the process of designing a hempcrete building should be a relatively straightforward and rewarding one. The materials and methodology are low-tech and the process of building is simple. Architects who are involved in designing sustainable buildings and want these to be realized in a truly low-impact way, as well as those who are influenced by the traditional vernacular and seek the beauty of a simple, natural finish, will find much of value in hempcrete.

The structural frame for a new-build hempcrete extension. Note the glulam ridge beam and temporary bracing put in place to support the frame while it is being built.

Focus on self-build 3: Bridge End Cottage

When Bill met Jo Smith, she was living in a two-up-two-down brick 1880s Victorian cottage. When the house next door (the mirror image of Jo's, but with two large extensions added to the rear and the side) came up for sale, Bill bought it. The couple, together with Bill's young daughter Mollie and Mollie's grandfather Dave, then set about knocking the two buildings together.

The first thing that strikes you on walking into Bridge End Cottage, set in a quiet valley in the rolling North Wales countryside, is the sheer size of the home that Bill and Jo have created. Tardis-like, one room gives way to another . . . and yet another. Most of the individual rooms are large, and the light colours and large windows at the rear of the property give a feeling of light and space. The place is huge, and the mind boggles at how long the project must have taken them.

"It's been five years up to this point," says Jo, "and we've still got a little way to go." Almost everything about the house was replaced or renovated along the way: new roofs, a complete refurbishment of both properties and alterations to the layout of the internal spaces – the rooms on both floors, together with the connecting corridors and staircases. This got rid of any impression of 'two houses knocked into one' and made it feel like a single house with a layout that makes sense.

The poorly constructed kitchen extension on the rear of the second house was demolished and rebuilt with a green oak frame and hempcrete walls set outside of this. Hempcrete has also been used to insulate a flat roof, and to add breathable solid-wall insulation externally to the brick walls of the draughty Victorian properties, achieving not only a high standard of insulation but also tying together the 'mish-mash' of Victorian brick, twentieth-century add-ons and Bill and Jo's new extension, giving a consistent appearance to the whole house externally.

Bill and Jo were "sold on hempcrete right from the beginning" because they wanted to create a well-insulated home. Bill's brother-in-law Peter is an architect interested in sustainability, and helped to get Bill "fired up about insulation". Bill liked the idea of hempcrete, and had read some studies reporting that its performance in situ was significantly better than expected, due to its thermal 'buffering', whereby temperature changes are transferred through the walls so slowly that a constant comfortable temperature is maintained.

The other attraction of hempcrete was that "it was a low-tech job we could do ourselves, and didn't require any complicated equipment". Peter had rightly suggested that external insulation would be the best way to insulate the draughty Victorian property, since it would keep the thermal mass of the existing brick walls inside the 'tea cosy' of the hempcrete insulation. Bill developed a system of home-made ply I-joists nailed against the house wall which could have temporary shuttering fixed to the outside. 125mm hempcrete was then cast between the brick wall and the shuttering.

A lightweight Baumit lime-based coloured render containing polystyrene balls for extra


1


2


3

1. Bridge End Cottage, still warm in the snow. *Image: Bill Smith*
2. The kitchen in the new hempcrete extension.
3. The house is full of clever details, such as this window drip created within the render itself.
4. Upstairs in the hempcrete extension: the master bedroom.
5. This wood burner, together with heated towel rails upstairs, is the only heating the Smith family have used to date.


4


5

insulation was applied externally, and lime–sand plasters and breathable paints internally. A glass-fibre mesh was integrated into the render across the external surface to stop it cracking over the wooden I-joists visible on the surface.

For the rebuild of the kitchen extension, a green oak frame was erected and an additional 'four by two' softwood studwork frame offset from this to support the hempcrete. Internally, a wood wool permanent shuttering board was used. The next stage of the ongoing project will be the detached garage, which will also have hempcrete walls.

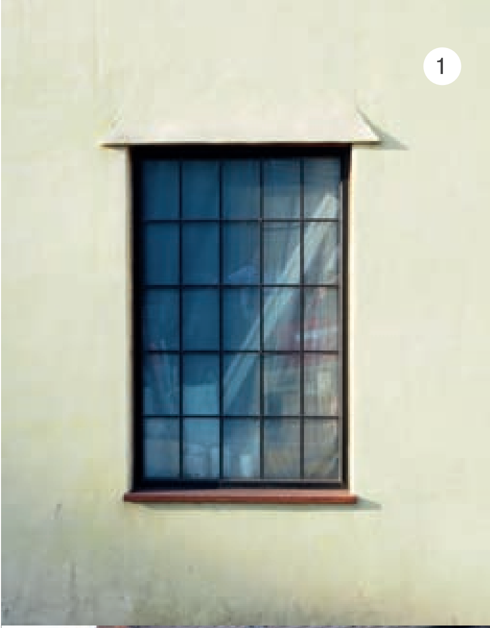
Bill and Jo's driving principle in the build has been thermal performance, and Bill's engineering background shows in the technological solutions they have found. They have not stuck exclusively to natural materials – for example, using renders containing polystyrene, and foam insulation boards for the insulation at rafter level in the warm roof. However, the oak structural frame in the new extension and oak second-fix carpentry throughout, together with the lime plasters, gives the house a very natural feel. Bill and Jo were keen to ensure a high level of airtightness (they commissioned and passed an airtightness test before they had finished the building!), and therefore ventilate the house with a mechanical heat-recovery ventilation system.

Getting planning permission for the build was "a nightmare from the start": the local planners not liking anything about the project – neither the hempcrete nor the plan for the amalgamation of the two houses. Luckily, however, the planning committee saw things differently and granted permission. After some initial problems with local authority building control, Bill and Jo switched to using an Approved Inspector, which smoothed the rest of the process considerably.

The scope of the project they have taken on would be daunting to many, but Bill is clearly a man who is not happy unless he is getting his teeth into a challenge. Bill and Jo designed and detailed the building themselves with help from Westwind Oak, who drew up the plans for the oak frame in the extension, based on Bill's original ideas. The build was completed by Bill and Jo together with Dave, with a little assistance from subcontractors along the way. Once they had worked out how to do it, they found hempcrete very easy to use, and affordable, although they did not make any direct cost comparisons with other materials.

The bulk of the work has been carried out by the family, with Dave working on it while Bill was out at work, and Bill taking over out of office hours. This shows in the level of care and attention to decorative detail visible in the building, and the overall effect is of a home that has been built with love. Although they were often learning the necessary skills as they went along, it is clear from the result that what Bill, Jo and Dave lacked in experience they more than made up for in the care they took with the work, and that they invested a bit of their personalities into every wall built and finish applied.

So, with a kitchen in the hempcrete extension and a few severe winters having passed since the hempcrete solid-wall insulation was installed, are Jo and Bill happy with the thermal performance of the hempcrete? "More than happy!" Jo says: "We've been through three hard winters with just the wood burner in the living room." The underfloor heating, which is fed by a ground source heat pump, has been in for a while now, but Jo says "we haven't used it – we haven't needed to – and we've only bought £150-worth of firewood in that time, to supplement what we already had from some trees we had to cut down in the garden. We've got no heating either, except heated towel rails upstairs fed from a small gas boiler, which also provides domestic hot water – no radiators at all."



1. Window detail at Bridge End cottage.
2. Two cottages wrapped in hempcrete.
3. The original houses. *Image: Bill Smith*
4. What they lacked in experience, these builders made up for in attention to detail.
5. Every fixture and fitting in the house has a 'built-to-last' feel.
6. Jo and Bill (and Doris) outside their hempcrete home.

CHAPTER TWENTY-THREE

A look to the future

So, what next for hempcrete? In bringing to a close what is intended to be the most comprehensive account to date of this exciting new method of building, it is only natural to ask this question. Perhaps it is an appropriate moment to reflect on the place hempcrete has carved for itself within construction in the UK and beyond.

Over a decade has passed since the first hempcrete houses were built in the UK, and the use of this material in countless projects in that time – from one-off self-builds to housing estates to large-scale commercial and industrial buildings – speaks for itself. The application of hempcrete for upgrading the thermal performance of heritage buildings is almost an industry in itself, and, with retrofit of insulation to older properties becoming an increasingly high priority, we are sure to see the use of hempcrete in this sector continuing to grow. As a reliable breathable insulation material that works perfectly *with* the existing fabric of traditional buildings, it is unrivalled in its versatility and unique thermal performance.

While hand-placed cast-in-situ hempcrete has been the 'core' methodology to date, practices are continuing to evolve, with increasing use of spray application and pre-cast systems, especially for large-scale projects. The fact that hempcrete has been adopted so quickly in such a wide range of contexts, despite being a relatively new and low-profile material, is a strong indication that it will continue to become more widely accepted and employed.

From its original development in France, the use of hempcrete quickly spread internationally, with the highest levels of use seen in European countries, including the UK, and growing numbers of hempcrete buildings going up in Canada, Australia and South Africa. The next big market to open up will surely be the USA, with the planting in 2013 of the first 'legal' hemp crop of a significant size in many decades. At the time of writing, the bizarre legal situation persists in the USA that industrial hemp is legal to import into the country, and use, in its processed state, but *illegal* to grow there, as it comes under Federal

Previous page: Hempcrete houses with a striking modern design.

The availability of hemp shiv for building is increasing in Europe and across the world.

drug prohibition laws. However, in the face of mounting public pressure, the first states have begun to make industrial hemp legal under State law, so surely it can only be a matter of time before its cultivation is allowed across the United States. To our knowledge, a hempcrete house under construction in Oklahoma at the time of writing is only the fifth of its kind in the USA, but we will surely see rapid change in this area over the next few years.

Given the relatively low-tech construction method, and the advantage of being able to use locally grown crops to provide an environmentally sustainable construction material, we would expect to see a key future market in developing countries. That there has been limited use of hempcrete in the developing world to date is possibly due to supply chain issues, or a general lack of awareness about the material.

The UK market has, until recently, suffered from having a limited number of binder materials and hemp shiv on the market, but this situation is now starting to change, with a choice of three binders now available and, at the time of writing, another three in development. The hemp shiv market is starting to open up, with independent shiv producers and French hemp processors looking to expand into the UK.

While not exactly complicated, the skills needed to use hempcrete successfully are not currently widespread in the construction industry.

The key challenge for the UK industry now is how to take forward the development of agreed standards of construction across the industry and improve the standardization and testing of binder and hemp shiv materials. The aim should be that those wishing to build with cast-in-situ hempcrete can do so with the confidence that comes from acting within clear best-practice guidelines, with materials which have a high degree of consistency and quality control.

The development of skills and knowledge across the wider construction industry is also vital. The importance of application technique in the use of hempcrete means that there is a risk, when

A self-build barn conversion using hempcrete for external insulation and internal walls.

used with a lack of experience, of poor standards in application causing problems, particularly with regard to extended drying times. This then puts companies off using the material again, especially in large commercial projects. Such 'false starts' are perhaps unsurprising in what is essentially the start of a huge paradigm shift within the construction industry.

Hempcrete is the first natural, sustainable construction material to be adopted on any significant scale in the mainstream UK construction industry. This is no small feat in an industry that is notoriously suspicious of change and of new, 'untried' materials. Hempcrete has on its side the benefit of being, compared with straw bale or cob, for example, a material that has a passing resemblance to things that are understood by the conventional builder. The materials arrive on-site on pallets and, while the bales of hemp usually raise a few eyebrows, the binder is reassuringly packaged in bags like cement, and the construction method of building temporary shuttering and mixing and casting the material is easily recognizable to the modern builder.

Despite all this, however, hempcrete does *not* act like the conventional materials that the builder of the late twentieth century is used to. Thought and proper understanding of the material are required to apply it successfully; in other words, there is a need for increased understanding across the industry not only of *why* we should use hempcrete, but also of *how* we should use it.

We hope that, in some small way, this book furthers that aim.

Notes*

Chapter 1

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3 Williams, M. (2006) *Bridport and West Bay: The buildings of the flax and hemp industry*. English Heritage: Swindon.

4 Adapted from *Hemp Horizons* by J. Roulac, page 15.

5 Raabe, S. (2013) First major hemp crop in 60 years is planted in southeast Colorado. Article in *The Denver Post*. www.denverpost.com/ci_23232417/first-major-hemp-crop-60-years-is-planted

Chapter 2

1 Energy consumption in cast-in-situ Tradical® Hemcrete® buildings has been noted to drop by as much as 75% in the first three years of occupancy. Patten, M., Hempcrete Projects Ltd. (June 2013). Personal communication.

2 Tŷ-Mawr Ltd. www.lime.org.uk/directlinkdownloads/10226Ty-Mawr_lime_hemp.pdf (page 3).

3 Tŷ-Mawr Ltd. www.lime.org.uk/directlinkdownloads/10226Ty-Mawr_lime_hemp.pdf (pages 2 & 3).

4 Womersley's Ltd. www.womersleys.co.uk/acatalog/Hemp_Lime_Plaster_A%20Guide.pdf (page 4).

5 Woolley, T. (2013) *Low Impact Building: Housing using renewable materials*. Wiley-Blackwell: Chichester (page 11).

6 Black Mountain's literature states that their production processes "use up to 90% less manufacturing energy compared to alternative insulation products". www.blackmountaininsulation.com/NatuHemp_Technical_Sheet.pdf

7 Black Mountain Insulation Ltd. www.blackmountaininsulation.com/NatuHemp_Technical_Sheet.pdf

8 At the time of writing, Black Mountain's literature states that their hemp-fibre insulation quilt contains 95% hemp fibre and 5% recycled adhesive binder (www.blackmountaininsulation.com/NatuHemp_Technical_Sheet.pdf), whereas Thermafleece describe their hemp-fibre insulation as containing 60% hemp, 20% recycled polyester, 10% polyester binder and 10% ammonium polyphosphate (a flame-retardant chemical) (www.thermafleece.com/sites/default/files/downloads/Thermafleece%20Hemp%20MSDS.pdf; page 1).

Chapter 4

1 Centre for Alternative Technology (2010) *Zero Carbon Britain 2030: A new energy strategy*. CAT Publications: Machynlleth.

2 Zero Carbon Hub (2013) *Zero Carbon Strategies for Tomorrow's New Homes*. NHBC Foundation: online only. www.zerocarbonhub.org/sites/default/files/resources/reports/Zero_Carbon_Strategies_for_Tomorrows_New_Homes.pdf (page 4).

3 Woolley, T. (2013) *Low Impact Building: Housing using renewable materials*. Wiley-Blackwell: Chichester (pages 125-6).

4 Hens, H. (2012) *Passive Houses: what may happen when energy efficiency becomes the only paradigm*? Online only. www.thefreelibrary.com/Passive_Houses: what may happen when_energy efficiency becomes_the...-a0295268301

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1 Cited in Woolley, T. (2013) *Low Impact Building: Housing using renewable materials*. Wiley-Blackwell: Chichester (page 138).

2 Lime Technology Ltd. (2007) Tradical® Hemcrete® Information Pack. As cited in Woolley (ibid.).

*These notes are available as a pdf with live hyperlinks at: www.greenbooks.co.uk/hempcrete-notes-and-biblio

Chapter 6

1 Sources of information: Batichanvre®: *Hemp Mortars Using St Astier Natural Hydraulic Limes and Products.* www.stastier.co.uk/nhl/guides/pdfs/Hemp_Mortars.pdf

Prompt Natural Cement: *Le Prompt Vicat: Hemp Solutions. Application guide: concrete and hemp mortars.* www.cornishlime.co.uk/pdfs/Hemp%20and%20Prompt%20Solutions.pdf

Tradical® HB: www.tradical.com and *Tradical® Hemcrete® Installers Information Pack.* www.limetechnology.co.uk/pdfs/Tradical_Hemcrete_Installers_Pack.pdf

Chapter 7

1 Bevan, R. and Woolley, T. (2008) *Hemp Lime Construction: A guide to building with hemp lime composites.* IHS BRE Press: Bracknell (page 75).

2 Daly, P., Ronchetti, P. and Woolley, T. (2013) *Hemp Lime Bio-composite as a Building Material in Irish Construction.* Environmental Protection Agency Ireland: online only. http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=202 (page 44).

Chapter 13

1 Lancashire, R. and Taylor, L. (2011) *Timber Frame Construction* (5th edition). TRADA Technology Ltd.: High Wycombe.

2 More information can be found in *Framing Roofs*: see www.tauntonstore.com/for-pros-by-pros-framing-roofs-071229.html

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1 Lime Technology Ltd. (www.limetechnology.co.uk) Tradical® Hempcrete® (contractor FAQ document).

Chapter 20

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Chapter 22

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3 Woolley, T. (2013) *Low Impact Building: Housing using renewable materials.* Wiley-Blackwell: Chichester (page 114).

Glossary

Text in **bold** refers to terms that appear elsewhere in this glossary.

Airtightness A measurable property: the degree to which air leaks through the **thermal envelope** in a building. Leakage of warm air can account for significant energy wastage, especially in old buildings. The Building Regulations set out standards for levels of airtightness in new buildings. Airtightness in a particular building is tested by artificially raising the air pressure inside and measuring the volume of air leakage, per hour, per m^2 of thermal envelope, at an internal/external air pressure differential of 50 pascals. Thus airtightness is expressed as $m^3/h/m^2$@50Pa (metres cubed [of air entering/leaving the building] per hour per square metre [of thermal envelope] at a pressure of 50 pascals).

Carbon profiling A method of assessing both **embodied energy** and **energy in use**, at the same time, to allow comparison between different methodologies in the built environment. Carbon profiling is a mathematical process used to calculate how much CO_2 is put into the atmosphere from $1m^2$ of a building per year.

This enables very different buildings constructed using different technologies to be subjected to meaningful comparison, which in turn allows governments, investors and owner-occupiers to make informed choices about the most sensible carbon-saving measures on which to spend money.

Embodied energy A measure of the total energy use associated with a material at all stages of its life, or in the delivery of a service, considered as if this associated energy was 'embodied' in the final product itself.

Energy in use The carbon emissions associated with the occupation and use of a building. This includes, for example, the energy used for heating and/or cooling the building and for powering appliances. Many of the energy-saving technologies that have become commonplace in the UK construction industry today focus on reducing energy in use, but fail to consider the implications of the **embodied energy** used in the manufacture of their materials.

Future-proof A term used to denote the ability of (for example) a building to withstand the stresses and strains of future events: specifically, in this context, the anticipated decreasing availability of fossil fuels and associated high energy costs, and the demand for energy-efficiency measures within society as a whole. A future-proof building can be seen as 'protecting' the owner or occupier against the uncertainties of our energy future.

Hygroscopicity A property of a substance, referring to its ability to attract and hold moisture from the ambient environment. A hygroscopic building material will take up moisture in response to an increase in the **relative humidity** of its surroundings, releasing it again when the humidity drops.

Lifecycle analysis (LCA) (also known as **lifecycle assessment**) A technique used to assess environmental impacts associated with all stages of a product's life, including raw material extraction; materials processing; manufacture, distribution, use, repair and maintenance; and disposal, recycling or reuse at end of life: a 'cradle-to-cradle' approach. Lifecycle analysis is seen as the 'gold standard' in assessment of the environmental impact of any product or service; however, the costs associated with such in-depth analysis mean that it remains a rarity, especially in the UK, where (compared with Europe) legislation has stopped short of compelling companies to carry out lifecycle analysis on their products.

Low impact Describes doing anything in such a way as to have minimum impact on the environment. This includes an emphasis on sourcing products locally and favouring natural sources of materials instead of highly processed synthetic materials, which often have harmful by-products or use a lot of energy in their manufacture and distribution. Low-impact buildings are constructed using natural materials with low **embodied energy**, and often involve relatively simple techniques that hark back to traditional ways of building.

Off-gassing The evaporation of chemicals, especially **volatile organic compounds (VOCs)** from a material. Many modern mainstream construction materials, including coatings such as paint or varnish, glued products such as composite boards, and insulation products such as those synthetic insulations that contain formaldehyde, give off potentially harmful chemicals at atmospheric pressure and room temperature.

Relative humidity The amount of water held, as vapour, in a body of air at a given temperature (the capacity of air to hold water increases as its temperature increases). Relative humidity is expressed as a percentage of the total maximum amount of water the body of air *could* hold, at saturation point, at that temperature.

A relative humidity in the range of 40-60 per cent is most conducive to human health. There is an increased risk of respiratory tract conditions for those living in an environment that is too dry or too wet.

Thermal bridge (also known as **cold bridge**) A break in an insulation layer that allows heat to bypass it. This is usually found where a material with high thermal conductivity interrupts or penetrates the insulation layer.

Thermal conductivity A measure of a material's ability to conduct heat. Often denoted as the 'lamda value' or 'K-value', thermal conductivity is measured in W/mK (watts per metre kelvin). The thermal conductivity of a material, unlike its **U-value**, is always the same irrespective of its thickness, since it is a constant characteristic of the material itself.

Thermal envelope The area of floors, walls, windows and roof or ceiling that contains the building's internal warm heated volume.

Thermal mass The ability of a body of material within a building to absorb, store and subsequently release heat, as a function of both its specific heat capacity (the amount of heat energy required to raise the temperature of 1 kilogram of a material by 1°K) and its mass. This is defined as the number of joules required to raise the temperature of the entire body of material by 1°K.

A body of material of a given size will therefore have a higher thermal mass if it has a higher density, since its mass will be greater. Buildings built with high-density materials such as stone, brick or concrete have a high thermal mass and therefore respond slowly to changes in temperature, absorbing and storing heat during the day and releasing it slowly through the night.

Thermal performance A material's success, or otherwise, in conserving heat and power in a building. The overall thermal performance of a material used in a given situation may result from different properties of the material, e.g. its insulation value and/or its thermal mass.

U-value A measure of how easy it is for heat to pass through a material, or build-up of materials, therefore describing how good an insulator the material is. U-values are measured in W/m^{2}K (watts per square metre per degree kelvin), and are routinely used in construction to describe how much heat loss there is through the a wall, roof or floor that forms part of the building's **thermal envelope**. The lower the U-value, the better the material performs as an insulator.

Vapour permeable ('breathable') The degree to which a material allows the passage of water vapour (but not necessarily liquid water) through it. 'Breathable' is a (slightly misleading) term in common usage in the construction industry to describe a material with good vapour permeability. It is desirable to maintain vapour permeability when building with natural materials, as the free passage of moisture prevents the formation of damp, which can harm the building's fabric as well as its occupants.

Volatile organic compounds (VOCs) Organic compounds, often used as solvents in construction materials, that evaporate very readily. Certain VOCs may be air pollutants in their own right, but they also cause chemical or photochemical reactions in the atmosphere that cause damage to vegetation, materials and human health.

Zero carbon Refers to an ambitious target set by the UK government that all new homes should be 'zero carbon' by the year 2016. The concept of 'zero carbon' relates to the development of methods of construction, coupled with energy-conservation technologies in the building, that result in zero-carbon emissions or a net carbon saving during the life of the building. This target has now been watered down beyond all recognition, probably due in no small part to the sheer impossibility of achieving it within such a short space of time in a sector that is currently responsible for more than half of the UK's total carbon emissions.

Resources

The following is a directory of sources of further information and services that we consider useful for people considering building with hempcrete and/or wishing to find out more about the topics discussed in this book. For the sake of brevity, this directory is limited to organizations and services operating within the UK. Readers in the USA, Australia and New Zealand should visit www.greenbooks.co.uk/hempcrete-us-anz-resources for further information.

The lists included here are not intended to be exhaustive, but instead represent our knowledge of available services based on our own experience in the field. It should be remembered that as a dynamic, emerging field, the hempcrete industry is developing on an ongoing basis, with new organizations and services coming into being all the time.

While some of the organizations listed below have worked with HempLime-Construct in the course of their own practice, others have not, and inclusion in the lists here is not intended to imply the personal recommendation of the authors.

General information

Alliance for Sustainable Building Products (ASBP)

www.asbp.org.uk
A not-for-profit organization in the UK working to further the increased understanding and use of building products that meet demonstrably high standards of sustainability.

Association for Environment Conscious Building (AECB)

www.aecb.net
A UK-based not-for-profit organization comprising a network of individuals and companies with a common aim of promoting sustainable building.

BRE Group (formerly Building Research Establishment)

www.bre.co.uk
A UK-based independent and impartial research-based consultancy, testing and training organization, aiming to create a better, safer and more sustainable built environment and to support the innovation needed to achieve this.

Building Limes Forum

www.buildinglimesforum.org.uk
A charity with the aim of encouraging expertise and understanding in the appropriate use of building limes.

Centre for Alternative Technology

www.cat.org.uk
A UK education and visitor centre demonstrating practical solutions for sustainability and covering all aspects of green living, including environmentally friendly construction.

Low-Impact Living Initiative (LILI)

www.lowimpact.org
A non-profit UK-based organization dedicated to helping protect the global environment by researching and promoting sustainable, low-impact ways of living, including low-impact building.

Natureplus

www.natureplus.org
An international organization that aims to increase sustainability within the construction sector through the development of a meaningful 'Kite mark' for sustainable building products.

Sustainable Traditional Buildings Alliance (STBA)

www.stbauk.org
A collaboration of not-for-profit organizations that acts as a forum for developing the sustainability of traditional buildings in the UK.

Timber Research and Development Association (TRADA)

www.trada.co.uk
A UK organization that is internationally recognized as a centre of excellence in the specification and use of timber and wood products.

Hempcrete services

Contractors specializing in cast-in-situ hempcrete

Hemp-LimeConstruct
www.ukhempcrete.com

The Limecrete Company
www.limecrete.co.uk

Contractors specialising in pre-cast hempcrete panels

Hemcrete Projects (part of the Lime Technology group)
www.limetechnology.co.uk
info@hemcreteprojects.co.uk

A selection of architects with experience of hempcrete

Chris Davies Architect
Gloucestershire
www.chrisdaviesarchitect.co.uk

Ecological Architecture
Inverclyde/Perthshire
www.ecological-architecture.co.uk

Glenn Howells Architects
London/Birmingham
www.glennhowells.co.uk

Justin Smith Architects
Derby
www.justinsmitharchitects.co.uk

Mark Hines Architects
London
www.markhines.co.uk

Modece Architects
Suffolk
www.modece.com

Native Architects
Yorkshire
www.nativearchitecture.co.uk

Noel Wright Architects
Hampshire
www.noelwrightarchitects.co.uk

Rachel Bevan Architects
Co. Down
www.bevanarchitects.com

Vincent and Gorbing Chartered Architects and Town Planners
Hertfordshire
www.vincent-gorbing.co.uk

Specialist hempcrete design and consultancy

Hemp-LimeConstruct
www.ukhempcrete.com

The Limecrete Company
www.limecrete.co.uk

Professor Tom Woolley
c/o Rachel Bevan Architects (see above)

Mixer hire

Hempcrete Mixer Hire
www.hempcretemixerhire.co.uk
Forced-action pan mixers specifically adapted for hempcrete mixing; also provides on-site training.

Kilworth Machinery
www.kilworthmachinery.co.uk
Forced-action pan mixers.

Multi-marque Production Engineering
www.multi-marque.co.uk
Forced-action pan mixers and roller pan mixers suitable for preparation of lime putty mortars.

Training

Building Limes Forum
www.buildinglimesforum.org.uk
Directory on their website of organizations within the UK that offer training in the use of building limes.

Centre for Alternative Technology
www.cat.org.uk
Offers training in a range of sustainable construction techniques, short courses and postgraduate-level education.

Hemp-LimeConstruct
www.ukhempcrete.com
Offers training in building with hempcrete: both a basic training course and bespoke on-site training for organizations.

Low-Impact Living Initiative (LILI)
www.lowimpact.org
Offers training in a range of sustainable construction techniques, including hempcrete.

Hempcrete materials

Binders

Batichanvre®

Manufacturer

St Astier
www.stastier.co.uk

Suppliers

Anglia Lime
www.anglialime.com

Cornish Lime Company
www.cornishlime.co.uk

Lime Green
www.lime-green.co.uk

Womersley's
www.womersleys.co.uk

The above suppliers are able to advise on the use of hempcrete. For a full list of UK suppliers see the St Astier website.

Prompt Natural Cement

Manufacturer

Vicat
www.vicat.com

Suppliers

Anglia Lime
www.anglialime.com

Cornish Lime Company
www.cornishlime.co.uk

Lime Green
www.lime-green.co.uk

Womersley's
www.womersleys.co.uk

Tradical® HB

Manufacturer

Lhoist UK
www.lhoist.co.uk

Supplier

Lime Technology
www.limetechnology.co.uk

Hemp shiv

Anglia Lime
www.anglialime.com

Hemp Technology (previously 'Hemcore') – part of the Lime Technology group
www.limetechnology.co.uk
Supply Tradical® HF hemp together with Tradical® HB binder.

K J Voase and Son
www.kjvoaseandson.co.uk

Lime Green
www.lime-green.co.uk

Tŷ-Mawr
www.lime.org.uk

Womersley's
www.womersleys.co.uk

Hempcrete blocks

H. G. Matthews Traditional Brick Makers
www.hgmatthews.com

Hemp Construct
www.hempbuildsystem.com

Hemp-LimeConstruct
www.ukhempcrete.com

Hempcrete panels

Lime Technology
www.limetechnology.co.uk

Other natural and traditional building materials

Anglia Lime
www.anglialime.com
Key products: lime products, aggregates, limewash.

Back to Earth
www.backtoearth.co.uk
Key products: clay boards and plasters, wood-fibre insulation boards, lime-based render systems.

Black Mountain
www.blackmountaininsulation.com
Key products: hemp, flax and sheep's-wool quilt insulation.

Clayworks
www.clay-works.com
Key products: clay plasters, books and training on clay plastering.

Cornish Lime Company
www.cornishlime.co.uk
Key products: lime products, aggregates, limewash, breathable paints, lime–hemp plasters.

Lime Green
www.lime-green.co.uk
Key products: wood wool boards, lime products, breathable paints, lime–hemp plasters.

Lime Stuff
www.limestuff.co.uk
Key products: lime products, limewash, aggregates, breathable paints, decorating materials.

Mike Wye and Associates
www.mikewye.co.uk
Key products: lime products, limewash, breathable paints, tadelakt and training on how to apply it, traditional tools and materials.

Natural Building Technologies
Key products: wood-fibre insulation boards, lime-based render systems.

Natural Insulations
www.naturalinsulations.co.uk
Key products: sheep's-wool quilt insulation, wood-fibre insulation boards.

Rose of Jericho
www.rose-of-jericho.demon.co.uk
Key products: traditional lime plasters, limewash, traditional paints.

TAS ECO Systems
www.tas-ecosystems.com
Key products: hemp quilt insulation, unfired clay bricks (including hemp-lime-clay bricks), hydraulic limes.

Thermafleece
www.thermafleece.com
Key products: hemp and sheep's-wool quilt insulation.

Tŷ-Mawr
www.lime.org.uk
Key products: wood-fibre insulation boards, wood wool boards, lime products, aggregates, limewash, breathable paints, lime–hemp plasters, limecrete for breathable floors.

Womersley's
www.womersleys.co.uk
Key products: wood wool boards, lime products, limewash, breathable paints, lime–hemp plasters.

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*This bibliography is available as a pdf with live hyperlinks at: www.greenbooks.co.uk/hempcrete-notes-and-biblio

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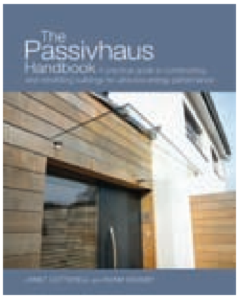

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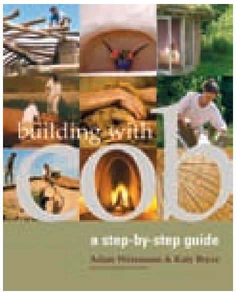

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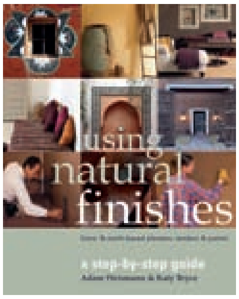

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