

Cellulose-based building materials

Use, performance and risk



Research review

NHBC Foundation

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About NHBC Foundation

NHBC Foundation was established in 2006 by NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy technologies and the earlier investigation of what zero carbon means to homeowners and house builders.

NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from NHBC Foundation can be found at www.nhbcfoundation.org.

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Foreword

Interest and awareness about the embodied energy associated with the production, use and disposal of construction materials is increasing, and consideration of such energy is becoming ever more important in order to satisfy sustainability issues.

There are many examples of crop-derived materials having been used in construction and recent work has seen these traditional cellulose-based building materials being re-examined as potential low impact building materials, products and systems.

For such materials to become more widely accepted, it is important that they can be properly evaluated and assessed alongside other products and materials. To aid this objective, this report provides a brief history of the subject, and reviews the current developments in the use of cellulose-based building materials. It discusses use and performance issues and examines the potential benefits and risks associated with these materials. The report also provides examples of recent projects built in the UK.

It is important to emphasise that the current low incidence of use of the materials featured in this report in built properties means there is, as yet, relatively little statistically robust evidential data as to their long term performance. A primary purpose of the report, therefore, is its aim to assist those interested in pursuing the use of the featured materials in new homes and guiding them towards sources where further information and data may be obtained.

Further, the report does not seek to provide detailed design guidance, but provides information which should form the basis for assessment and evaluation of cellulose-based building materials when considering issues relating to buildability and long term performance.

This report should inform the debate and result in a better understanding about the use of low impact building materials products and systems.

Rod MacEachrane
NHBC Director, Retired

Executive summary

Recent work on embodied energy has seen traditional cellulose-based materials being re-examined as potential low impact construction materials. There are many examples of using crop-derived materials in construction, both traditional ones such as thatch and cob, and more recently hemp and lime in addition to straw bale construction. There has been increased interest in using these materials.

Early examples of cellulose-based construction, such as a social housing development for the Suffolk Housing Society at Haverhill in Suffolk, the Renewable House at the BRE Innovation Park and the BaleHaus at Bath University, have been surpassed by much larger social housing and commercial projects. The 3000 m² Adhams Distribution Centre (hemp and lime), the project at Denmark Lane, Diss, Norfolk (114 homes using hemp and lime), and the Waddington project in Lincolnshire (straw bales) are examples of completed developments.

There have also been developments in off-site construction using cellulose materials. Developments using straw bale panels and hemp and lime panels have been used to construct around 20 buildings in the UK including the Cheshire Oaks Marks & Spencer retail store near Ellesmere Port.

If use of these materials is to reach its full potential then questions on buildability, long term performance and risks need to be reviewed, assessed and evaluated.

This report uses the latest findings from BRE, BBA and other sources, as well as from some of the cellulose-based material companies themselves, to provide a balanced overview.

The broad aims of the report are to:

- clarify the nature and role of cellulose-based building materials
- review current developments
- describe the major factors to consider when using cellulose materials.

The study drew on the activities of BRE and their partners enabling access to representatives of the natural fibre building sector, associated supply chains and other research programmes. BRE undertook the role of technical lead through its existing expertise and that of the BRE Centre of Innovative Materials at the University of Bath. The Centre for the Built Environment (CBE)¹, part of the Adapt Low Carbon Group at the University of East Anglia, provided a focal point for contact with supply chain partners.

¹ CBE is part of the Exemplar Low Carbon Building project which was awarded funds from the European Regional Development Fund in October 2011. As a condition of this funding, the CBE provides free business support delivered through a series of bespoke CPD accredited seminars, webinars and other support showcasing the design, build and post-occupancy of the Exemplar Low Carbon Building.

1 Introduction



1.1 Overview

This report is designed to inform and provide general guidance on construction using building materials that are either cellulose based or contain cellulose-based materials.

In construction, some materials have been described as 'natural', 'green', 'bio' or 'renewable'. This report uses the term 'cellulose-based' to describe the emerging range of building materials derived from crops. Cob and thatch are included, as these historical materials share similar properties to newer materials and applications but are able to provide a longer established history of use, performance and risk management. Wood *per se* (as either timber, waste paper or sawdust although chiefly comprising of cellulose) is outside the scope of this report. Wood has its own well established research base and codes of use.

This report considers the case for the wider use of cellulose-based building materials and gives information on their potential uses, performance, risks and benefits. It does not give comprehensive design guidance on cellulose-based building materials, rather it highlights existing examples and illustrates the practical considerations required to build with cellulose-based materials. Manufacturers' and third party advice should always be sought.

The focus of this report is on the UK but, where appropriate, reference is made to developments in other countries.

Construction details, where shown, have been chosen to represent best practice specific to the material in question. However, certain generic design considerations are common and these are indicated.

1.2 Background

Cellulose – commonly known as cellulose fibre – is a complex carbohydrate which is insoluble in water. It is the chief constituent of the cell wall of plants, and gives them their strength and rigidity. Important natural sources of cellulose include jute, hemp, straw and wood. It has a high tensile strength and is a relatively low density material. The fact that cellulose is grown and therefore renewable, has made it attractive to manufacturers of composites. According to the National Non-food Crops Centre (NNFCC), hemp shiv (hemp's woody core) and lime-based binders can be used to produce materials which can be applied as a casting, sprayed into place and pre-cast into forms; therefore they can be adaptable in application in a similar manner as concrete.

However, the growing attraction of cellulose-based materials can be attributed to two key qualities:

- its ability to provide a combination of thermal mass and insulation when compared with more conventional building materials, which tend to perform well in one or other of those functions
- their low embodied carbon/energy.

Table 1 reviews the main uses in construction of cellulose-based materials.

Table 1 Review of cellulose-based materials currently used in construction^[1]

Material	Application
Flax	<ul style="list-style-type: none"> ■ Roofing insulation
Hemp fibres	<ul style="list-style-type: none"> ■ Insulation ■ Medium density fibre board ■ Oriented strand board
Hemp shiv	<ul style="list-style-type: none"> ■ Monolithic construction of walls, floors and roofs ■ Insulation ■ Panel construction
Jute	<ul style="list-style-type: none"> ■ Carpet ■ Plastering mesh ■ Scrim
Paper	<ul style="list-style-type: none"> ■ Recycled and shredded for insulation ■ Mixed with cement to form blocks
Reed	<ul style="list-style-type: none"> ■ Thatching
Reed mats	<ul style="list-style-type: none"> ■ Plastering base (like laths)
Sisal	<ul style="list-style-type: none"> ■ Carpet (mixed with reinforced cement in some countries)
Straw	<ul style="list-style-type: none"> ■ Bales as building blocks ■ Wall panels ■ Thatching

1.2.1 Use of cellulose-based materials

In the UK

Historically in the UK, cellulose-based materials have been used extensively in the construction of houses and farm buildings. Materials such as straw and reed, and even heather, broom and flax have been used for thatching. Cob (a walling material made from a combination of clay loam, straw and water) has also been used, with regional variations and techniques. English Heritage has estimated that there could be as many as 500,000 cob or earth buildings in the UK and 40,000 buildings with thatched roofs.

For a long time, the use of traditional cellulose-based materials was very much in decline in the UK for new build and they were mainly used for the repair, maintenance and renovation of older existing buildings. However, the past decade has seen a number of innovations as the construction sector has looked for ways to combine modern building techniques with a renewed interest in the use of traditional-based materials for walling and roofing new homes.

The use of hemp in buildings is a more recent development, mainly due to the fact that it was illegal to grow hemp in the UK between the years 1928 and 1993 because it is a member of the cannabis family, even though the varieties grown contain only low levels of the active drug, tetrahydrocannabinol. Since the law was repealed in 1993, the establishment of licensed production and contract growing has meant that a number of processing companies, such as Lhoist, Lime Technology and Hemp Technology have pioneered the development and use of a range of hemp lime formulations in both housing and larger scale non-domestic applications.

The use of straw bale construction in the UK has been advocated by manufacturers since the mid-1990s. One company, Amazonails, has been involved in a range of straw-based projects, including an auctioneer premises in Essex, the largest straw bale building in the UK. Another company, ModCell, has used straw bales in a panel and modular format to construct large educational and commercial projects, and are now developing housing projects.

A chronology of projects associated with cellulose-based building materials in the UK is summarised in Table 2.





Table 2 Projects that have used cellulose-based building materials

Type	Project	Date completed	Application details	
Hemp lime	Adnams Brewery, Suffolk (© Tom Woolley)	2006	Commercial warehouse	
	Clay Field, Elmswell, Suffolk (© Nick Jones)	2008	26 housing units	
	WISE Building, Centre for Alternative Technology (CAT), Wales	2009	Educational, hybrid construction. Earth and hemp.	
	The Renewable House, BRE	2009	Social housing demonstration project test house to Code Level 4 equivalent	
	Private house, Reigate	2010	300 mm Tradical Hemcrete cast on site.	

Table 2 (continued) Projects that have used cellulose-based building materials

Type	Project	Date completed	Application details	
Hemp lime	The Triangle, Swindon	2011	42 units, mixed housing	
	Denmark Lane, Diss, Norfolk (© Christopher Gaze)	2011	114 units, housing at Code Level 4. Over 300 mm of Tradical Hemcrete cast on site.	
	Private house, Hertfordshire	2011	300 mm cast on site	
	Marks & Spencer Cheshire Oaks, Ellesmere Port	2012	Sustainable learning store, BREEAM 'Excellent'. Hemclad wall panels.	
	Private house, Lincolnshire	2012	Hembuild panel system. U-value 0.15 W/m ² .K	

Table 2 (continued) Chronology of projects associated with a number of cellulose-based building materials in UK

Type	Project	Date completed	Application details	
Hemp lime	Enterprise Centre, University of East Anglia (© UEA)	2014	Building targeting BREEAM 'Outstanding' and Passivhaus certification. Thatch (reed and wheat) and hemp batts.	
Modular straw bale panellised system	Eco Depot, York (© Sarah McCarrick)	2006	Commercial building	
Straw bale	Sworders Auction House, Essex (© Nick Jones)	2010	Commercial building	
Prefabricated straw and hemp panels	The BaleHaus, Bath University	2009	Research building	
Cob	500,000 estimated by English Heritage	Historical	Cob barn	See Figure 11 for an example
Thatch	English House Condition Survey recorded 34,000 in 2005	Historical	Conservation area work	See Figure 12 for an example

Internationally

There are many examples of the use of cellulose-based materials in construction from around the world.

Historically, due to a shortage of conventional building materials, straw bale construction was used in the US state of Nebraska. Around 30 structures including houses, farms and churches were built up until the 1940s, with the oldest surviving building dating from 1887.

In Europe, the oldest known structure built using straw bales is the timber framed *Fuilette Maison* dating from 1921; in Denmark there is a history of straw bale construction, with testing having been undertaken on the technique by the Danish Building Research Institute. More recently there are examples of straw bale buildings in Pakistan, Egypt, China and Eastern Europe.

The use of hemp and a lime binder to form hemp lime for use in construction was pioneered in France in the 1980s. As the potential of the material became known, it was used in a number of projects, either as a render during refurbishment, cast around a frame or as an infilling block, such as in the seven-storey office building at *Clermont Ferrand*, shown in Figure 1.

Thatched buildings are well represented in Japan and China, as well as in South Africa where there are some companies specialising in large projects such as the 6800 m² Nelspruit International Airport. A comprehensive history of thatch and other vernacular materials in New Zealand and Australia is given by Miles Lewis^[2].



Figure 1 Hemp lime blocks were used in this seven-storey office building in *Clermont Ferrand* (© Lhoist UK)

1.3 Potential benefits

Figures 2 and 3 show typical sections of wall forms that achieve U-values of $0.25 \text{ W/m}^2\text{K}$, or better.

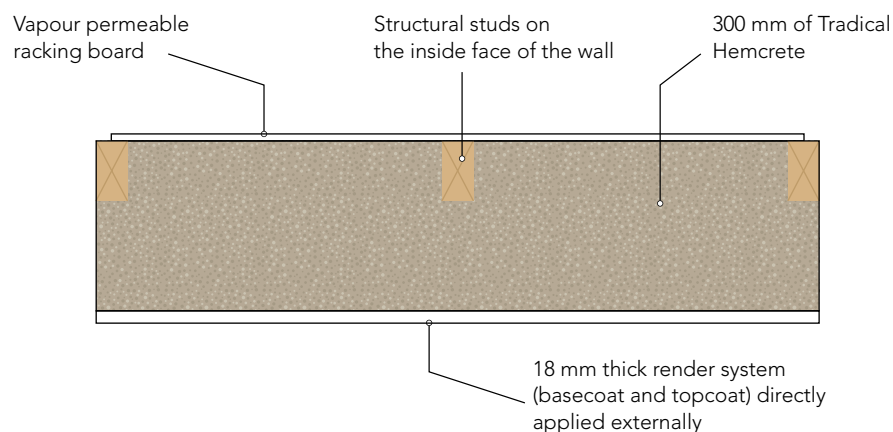


Figure 2 Plan view of a frame on the inside of a face hempcrete wall, U-value $0.25 \text{ W/m}^2\text{K}$

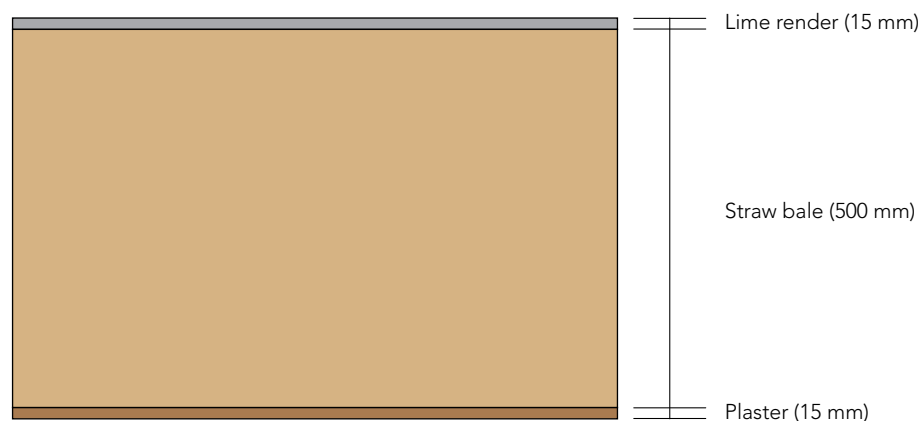


Figure 3 Plan view of a straw bale wall of standard bale thickness, U-value $0.15 \text{ W/m}^2\text{K}$

Cob is, however, a different type of material; a 900 mm thick cob wall, comprising 860 mm of cob and 20 mm thick layers of lime-based render and plaster on each face, will typically achieve a U-value of $0.45 \text{ W/m}^2\text{K}$ ^[3].

Research suggests that, as well as providing good thermal performance, cellulose-based materials can be used within a well designed building to offer good sound insulation properties, thermal mass and good vapour permeability. These attributes have the potential, when designed and detailed correctly, to dampen temperature fluctuations, buffer high humidity and lead to lower instances of condensation.

The use of cellulose materials has the potential to offer buildings with relatively low embodied carbon content; the emissions associated with the manufacture and construction is partly offset by the atmospheric carbon dioxide locked into the cellulose during the growing cycle. Although such benefits do not currently

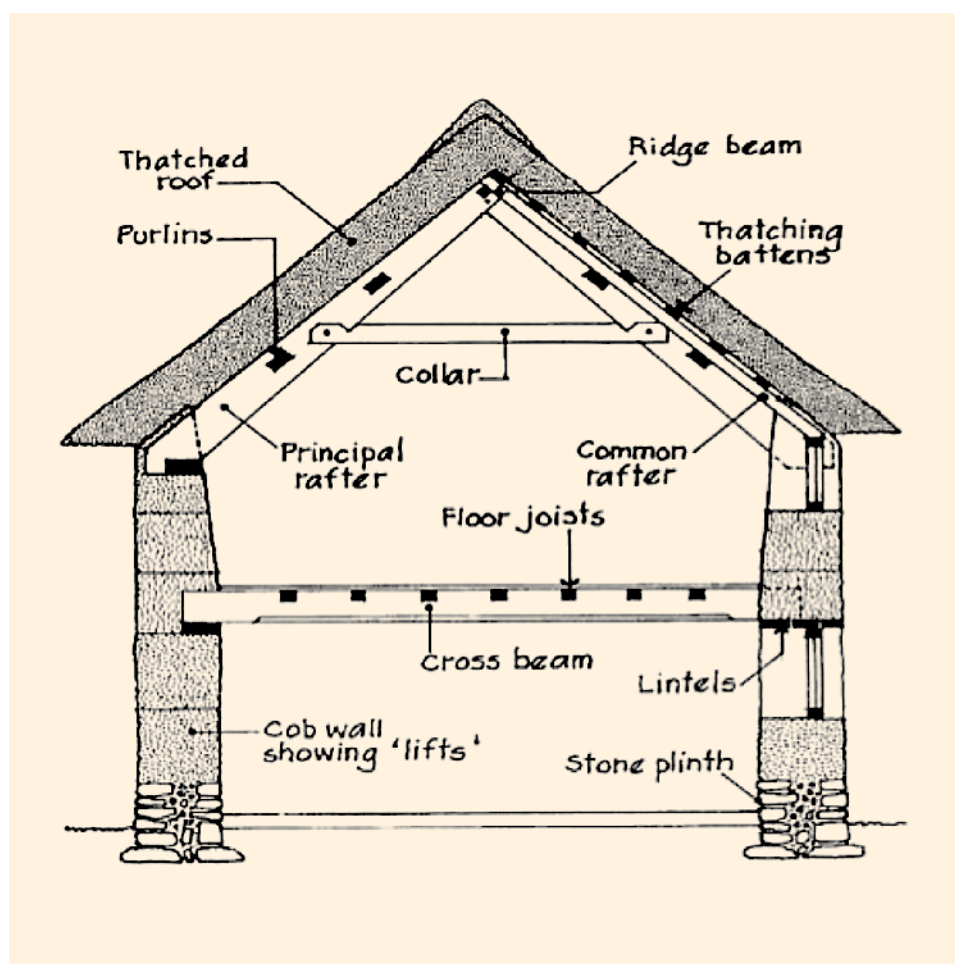


Figure 4 Cob construction

contribute towards a higher rating in either the Code for Sustainable Homes, or other low carbon standards, low embodied carbon materials are becoming more in demand. Embodied carbon can be of particular importance in low energy buildings built of conventional materials as, although less energy may be required to heat them than is needed in less thermally efficient homes, additional energy is perhaps required to manufacture both the increased quantities of insulation required and the additional technologies installed such as renewable energy. Generating this additional energy increases that amount of carbon dioxide.

NHBC Foundation report NF 34^[4] looks at the question of embodied carbon in a range of energy efficient housing and notes that the proportion of embodied carbon in masonry construction is higher than in equivalent timber construction. However, this difference is relatively marginal, the maximum difference being 4%. This is put down to the fact that, with the exception of the walls, the majority of building elements are similar in both the masonry and timber constructions modelled.

The materials specified, and the technologies used in the construction of a building, greatly influence both its overall embodied energy and the carbon dioxide emitted during construction. A University of East Anglia (UEA) study^[5] suggests that an average new house made with conventional materials contains the equivalent of 50 tonnes of CO₂ as 'embodied carbon'. It suggests that this could be reduced to 38 tonnes CO₂ with greater use of timber and modern methods of construction. It is also suggested that this can be further reduced to approximately 25 tonnes by using cellulose-based materials, such as hempcrete, a material made from hemp and lime, and straw bales.

1.4 Risks

1.4.1 What are the risks?

As with all building materials, there are a number of risks associated with their use. Table 3 lists the main risks associated with the use of cellulose-based building materials.

Table 3 Risks commonly associated with cellulose-based building materials and management strategies

Risk	Risk management
Biological degradation	Biological degradation is avoided by minimising the risk of moisture getting into the cellulose-based materials. Appropriate detailing, good construction practices and maintenance regimes will avoid circumstances that would lead to biological degradation. (The elevated pH of some lime formulations such as Hemcrete is understood to inhibit biological degradation.)
Fire	Construction should be in accordance with relevant fire safety certification.
Infestation	For many cellulose-based materials, their outer surfaces need to be protected by breathable products that are resistant to animal access, such as lime renders or lime plasters. The importance of timely construction will help prevent infestation of standing material. (The elevated pH of lime formulations such as Hemcrete, is understood to discourage infestation.)
Presence of moisture	Appropriate detailing, good construction practices and maintenance regimes should be adopted to avoid circumstances that would lead to moisture ingress. Areas to focus on during construction include appropriate onsite storage of materials and weather protection of works in progress. For both construction and maintenance, training of the construction team in appropriate skills and practices is essential.
Structural degradation	Load-bearing applications need to be independently assessed and certified.

The presence of moisture is a risk that needs the greatest care; Section 1.4.2 focuses on the general issues concerning moisture management.

In regulatory terms, these risks are managed through Building Regulations and standards. There are a number of routes to Building Regulations approval including compliance with the Approved Documents and BSI Standards, and certification and approval systems. Similar arrangements are in place in Scotland and Northern Ireland.

The Building Regulations, and their equivalents in other parts of the UK, also cover such items as a building's structural and fire performance and how the building performs both thermally and acoustically.

For innovative materials that currently lie outside the scope of both the existing regulatory support documentation and standardisation, independent certification can provide a route to compliance.

1.4.2 Moisture management

Water occurs as a liquid, a solid (ice) or a gas (steam or vapour) and can occur:

- inside a building: as a result of habitation, condensation, leaks and/or direct penetration
- within the structure: as a result of penetration, absorption and/or capillary action
- outside: as a result of rain, surface water runoff, splashing; and/or flooding.

Moisture can move within the fabric of a building in a number of ways:

- by diffusion: from wetter areas to drier areas
- thermally: from warm areas to cooler areas
- in reaction to pressure: from areas of high pressure to low pressure
- by capillary action: within the pore structure of the material.

Accidents, blocked or leaky gutters and external flooding can all have a major impact on the moisture content of a building.

It is always important to:

- keep a building dry
- dry out the structure, if it gets wet, and remove the cause of the wetting
- assess what, if any, damage may have occurred to the building
- repair it as soon as is reasonably possible.

However, it should be appreciated that in any typical 'dry' building moisture is always present within its constituent materials. This moisture is in a state of dynamic equilibrium with the surrounding conditions and in most situations it does not detract from the use of the building. Indeed, it is typically the result of habitation and general use of the building.

A building made with cellulose materials is not fundamentally different from any other and as such there are no special requirements for dealing with water or moisture content, after all timber is often used which is cellulose based.

However, using materials containing cellulose does mean that the consequences of excessive moisture getting into the fabric can be more extreme and occur more quickly than with more commonly used building materials. As a result it is even more important to ensure that the detailing of the building excludes water from the fabric as effectively as possible.

Under certain circumstances the ability of a material to take up moisture and subsequently release it back into the environment can be beneficial to the performance of a building. But it is essential that the moisture content of the material does not reach the level where it becomes detrimental to either the fabric of the building or the health and comfort of the occupants.

In a house built using a combination of timber frame and hemp lime, the hemp lime is alkaline and this alkalinity is understood to inhibit the growth of wood-degrading fungi. Even though, hemp lime's alkalinity will fall over time as the lime binder carbonates, the breathability of the hemp lime and residual alkalinity should inhibit the circumstances of sufficient moisture within the walls to allow the wood-degrading fungi to become established.

It remains important to both understand the impact of moisture on cellulose materials, such as an untreated timber in conventional buildings. It is also important to have a strategy for controlling the ingress of moisture into a building from the design stage through construction and throughout the building's design life.

It should also be noted that it is good practice, even with a treated timber frame, to maintain a low moisture content in the fabric of a building; otherwise this can result in problems including fungi and their spores which can be harmful to human health. Cellulose-based building materials inherent breathability can passively manage the humidity in buildings, and reduce moisture content which may result in reduced incidence of fungi and their spores.

1.4.3 Environment and design

Environment and exposure zones

It is important to design and construct a building with consideration to the environmental conditions pertaining to its location.

In the UK, the most important environmental characteristic is the frequency of periodic wetting and drying, and the aggressive effects of wind driven rain. BS 8104 *Assessing Exposure of Walls to Wind-driven Rain*^[6], provides guidance on the nature of exposure, the distribution of rain wetting on a wall and the effectiveness of render and roof overhangs in avoiding water penetrating into walls.

BRE's Report BR 262 *Thermal Insulation: Avoiding Risks. A Good Practice Guide Supporting Building Regulations Requirements*^[7] provides a map showing the National Exposure Zones for the UK which defines the country's exposure zones as being categorised as:

- sheltered
- moderate
- severe
- very severe.

It also provides guidance on the appropriateness of using the various traditional wall forms in these exposure zones.

While it does not include any of the cellulose materials contained in this report, the information it does contain is indirectly relevant in that it should be considered very carefully whether and with which type of cellulose materials it would be appropriate to build in 'very severe' or perhaps even 'severe' exposure zones. The use of a drained cavity in the wall construction is a sensible precaution and affords a greater degree of protection, allowing certain cellulose-based building materials to be used in such circumstances.

Detailing

The detailing of a building is very important, not only to provide good weather tightness but also to provide a building with a low air leakage rate and without any cold bridge issues. These factors will contribute to the long term satisfactory in-service performance of the building.

The key elements for consideration are the:

- foundations and damp proof course(s)
- walls
- roof
- openings, windows and doors
- interfaces between the elements of the building.

Cellulose-based materials are always particularly vulnerable to degradation as a result of moisture which is why, careful consideration needs to be given to protecting the:

- tops of walls: using effective roof overhangs
- wall surfaces: ensuring that the surface finishes are appropriately specified

- openings: detailing that is designed to ensure that water cannot get round the frames
- bottom of the walls: using appropriate damp proof course detailing
- interfaces between elements: appropriate detailing.

Appropriate guidance on detailing in relation to air tightness can be found in the various parts of BRE Good Building Guide 67^[8,9,10]. One of the key messages is that particular attention needs to be paid to the potential for shrinkage, settlement or movement of the materials around openings.

1.4.4 Performance

The performance of a building element built using the cellulose materials can be measured in a number of ways:

- thermal performance
- acoustic performance
- weather tightness
- durability
- resistance to fire
- airtightness.

Although these are very important characteristics, they do not depend solely on the cellulose-based material for their overall performance. For example, both the acoustic performance and the airtightness of a building depend on the building's design and how it is put together rather than on the presence of cellulose-based materials, attention to detail is everything. For that reason, while comments have been made about the properties of a number of these materials, they should be taken as being indicative of the potential performance of the material in the context of the whole building. When looked at in that context, stability and robustness are also important parameters for assessing the performance of a building.

1.4.5 Construction

By their general nature, all cellulose-based building materials require protecting from moisture during the construction process. They are often bulky and storage onsite can be difficult, but the typical solution adopted onsite usually includes wrapping materials in plastic for extended periods of time, which can result in condensation problems and potentially lead to degradation of the materials.

A better solution would be to provide a properly ventilated and covered area. But it should also be considered that each of the cellulose-based materials has its own requirements in this respect, which are considered in the following sections. Some cellulose-based building material systems are produced in factory conditions and arrive at site already dry and should be protected in temporary storage in a similar manner to conventional building materials.

2 Cellulose-based building materials and systems



2.1 Hemp and lime

2.1.1 Example buildings

Several buildings have been built in the UK using hemp lime, an example of which is the Renewable House at BRE shown in Figure 5. This house uses a timber frame and hemp lime-based wall form and meets Level 4 of the Code for Sustainable Homes.



Figure 5 The Renewable House at BRE, Watford

Other examples of hemp lime construction can be seen in Table 2.

2.1.2 Materials

Industrial varieties of the hemp plant are grown mainly in the East of England under licence from the UK Government. It is used as a fast growing break crop between other crops being sown in the spring and harvested as little as 10 weeks later.

The fully grown hemp plant has three commercial parts:

- the seed
- the fibres
- the woody core known as the shiv.

The fibres and the shiv can be used in construction, but it is the shiv mixed with a binder that is currently used in walls.

The shiv needs to be mixed with a binder that can use the insulation and hygrothermal properties of the hemp and, to date, use in construction has focused on the following three binders:

- high calcium lime (CL90)
- natural hydraulic lime (NHL)
- formulated limes (FL).

Formulated limes are high calcium limes blended with additives which may include Portland cement.

This mix of hemp and lime is known generically as hemp lime or hempcrete. It may also contain some sand. For clarity this report refers to hemp lime although it is appreciated that proprietary products such as Hemcrete are also available.

The role of the binder in hemp lime formulations is to hold the cellulose together in a way that allows the resulting material to be worked as a building material, by being either sprayed, cast or moulded into blocks. The binder should also facilitate the insulation and hygrothermal properties of the hemp shiv.

The ratio of binder to shiv can vary depending on the properties required. For example, if less binder is added the density decreases and the thermal performance improves.

2.1.3 Use

There are two main ways to use hemp lime in walling either in situ construction or factory-produced panels. The two ways for in situ construction, neither of which are intended to carry the structural loads of or applied to the building, comprise a:

- lightweight timber frame with the frame being placed centrally within the hemp lime
- lightweight timber frame with the timber frame separate from, and inside, the hemp lime wall.

In addition to use in walls, hemp lime can be mixed with an aggregate for floor slabs and screeds, at low density for roof insulation, renders and plasters.

Hemcrete currently has a BBA certificate for the method of construction shown in Figure 6.

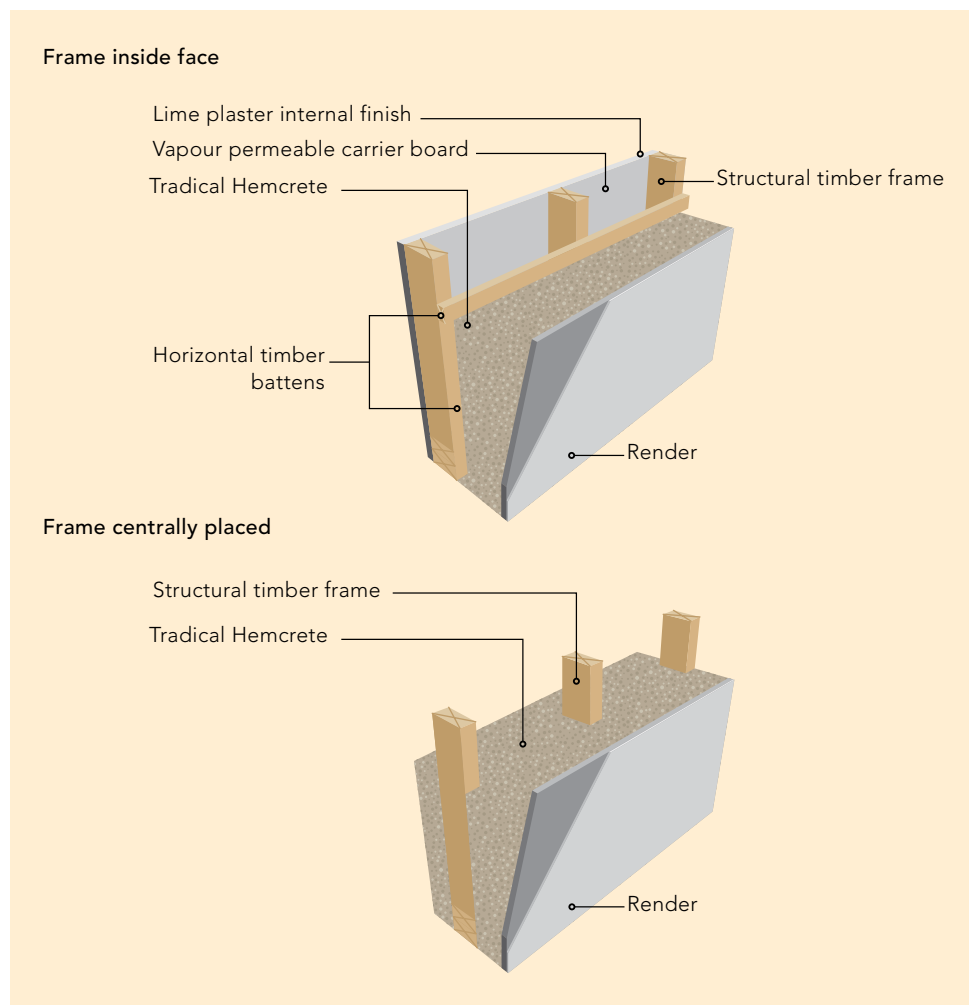


Figure 6 Two recognised ways of building walls with hemp lime – in this case using Hemcrete (© BBA, certificate 10/4726 (redrawn from an image © Lhoist UK))^[11]

There are other similar wall products available in the UK including variations involving constructing walls by tamping hemp lime into temporary or permanent shuttering.

Factory-produced panels are also available. These can be designed and manufactured to either provide a cladding panel for an independent structural frame or as structural panels that provide the structural frame of the building. The hemp lime is fully dried in the manufacturing process before delivery to site. The panels can be wholly filled with hemp lime or can include hemp fibre insulation as well as hemp lime depending on the thermal properties that are desired.

Finishes

The finishes applied to hemp lime walls both externally and internally are an important part of the wall construction.

The external finish should be breathable as it needs to allow the hygrothermal properties of the hemp lime to deliver their benefit so that trapped moisture can dissipate. External finishes, including render and proprietary cladding, should be breathable and can incorporate a drained and ventilated cavity if required.

Internal finishes are also required to be breathable paints, but lime or earth-based plasters should be used along with lime washes and water-based or mineral paints.

2.1.4 Performance

Thermal

The U-values for a wall made from hemp lime will depend on the wall's dimensions, the applied finishes and density of the mix. An example of the thickness of materials in a wall needed to achieve a U-value of 0.25 W/m².K as shown in Section 2.3. Tests carried out at the National Physical Laboratory have established a direct link between hemp lime's thermal conductivity and density. The hygrothermal performance of hemp lime can enhance the conventionally measured thermal conductivity by the phase change of moisture vapour, providing temperature and humidity buffering functions.

Acoustic

Testing carried out by BRE has shown that hemp lime construction can be detailed to meet the acoustic requirements of the Building Regulations.

Weather tightness

Hemp lime shrinks as it dries, so the weather tightness of walls made from hemp lime relies on a combination of the external finishes, their time of application relative to the hemp lime installation and the detailing of the roof and the openings. It is always prudent to leave the walls to dry out for as long as possible before applying those finishes, so that as much drying shrinkage as possible has already occurred. The pre-dried panels are manufactured taking shrinkage into account prior to delivery to site.

If the walls subsequently become very wet, eg as a result of flooding, then the hemp lime itself has the potential to dry quickly, but replacement finishes are likely to be required.

Durability

The durability of the finishes applied to, or protecting, the hemp lime wall relies on the weathering resistance of the hemp lime and on the structural performance of the timber frame. The pore structure of the hemp lime mix is sufficiently open to prevent frost damage and there is currently no evidence that the physical properties of the hemp lime change with time.

The protection of the structural timber frame relies on the applied finishes and is aided by the lime binder, which has a high pH and wicks away moisture from the timber, to prevent high moisture levels and fungal growth. However, as the lime binder carbonates, the protection of the timber becomes increasingly reliant on the ability of the finishes to keep moisture out of the building.

Resistance to fire

Hemp lime has the required resistance to fire through both spread of flame and combustibility testing both with and without finishes applied. Several fire tests have been carried out on unfinished hemp lime and the material has been found to have inherent fire resistance characteristics and insulation performance that would reduce the spread of fire. Hemcrete panels tested to BS EN 1365-1:1999^[12] and BS 476-22:1987^[13] passed the 60 minute minimum test when fully loaded. In a separate test with a factory-produced panel construction including both Hemcrete and hemp fibre insulation, a three-hour test to BS 476-22:1987 was passed.

2.1.5 Construction

Training

Building with hemp lime is a relatively new method of construction and therefore it is important that designers, construction managers and operatives are correctly trained, follow the manufacturer's instructions and have a strict quality assurance regime.

Mixing

The current method of hemp lime production onsite involves the use of bagged dry products being put into a pan mixer and a recommended amount of water being added. This has the potential to lead to errors, especially if the workforce is unfamiliar with both the material and the process, and it is not yet clear what the working tolerances are with the material, in relation to its stated performance. The problem is that of hemp lime's two constituents, the shiv and the lime, the shiv absorbs water more quickly during mixing. This can lead to insufficient water being available for the lime binder to set adequately, and adding more water in an uncontrolled manner can result in an unduly wet mixture.

As a result, guidance should be sought from the manufacturer on the most appropriate way to mix the materials prior to the construction commencing onsite.

Day joints

During construction it is recommended that vertical day joints are avoided or minimised by working up to the sides of openings. Horizontal day joints should be lightly wetted prior to the application of more hemp lime.

Alterations

Hemp lime is generally very easy to alter if changes are necessary. Within the first few hours it can simply be removed with a trowel, the shuttering altered and then recast. Even cured hemp lime is relatively easy to remove using simple hand or power tools. Care should be taken not to alter structural timbers without assessment and design approval for the alteration.

Fixings

It is essential to use structural fixings for use within the hemp lime that are either stainless steel, non-ferrous or painted with red oxide or bituminous paint to keep any risk of corrosion to a minimum.

2.1.6 Risks

Environment and exposure zones

Testing has suggested that hempcrete, with a reasonable and well applied external finish, has the potential to resist extreme weather. A 96-hour water penetration test on 200 mm hemp lime blocks showed some water penetration up to 40 mm from the rendered face but not through the wall. This is reflected in the current BBA certificate (Figure 6), where its use is not restricted to sheltered or moderate exposure zones.

During construction

Both the air tightness and the thermal performance of a hemp lime building are helped by the presence of wet applied finishes, including plaster, to the inside and render to the outside. Good air tightness figures are only achieved through meticulous attention to detail during the construction phase. In this context, it is interesting to note that it is recommended that hempcrete is cast around any service penetrations to reduce the risk of air leakage.

2.1.7 Benefits

An environmentally friendly material, hemp has a number of advantages over traditional building materials:

- hemp has the potential to be a widely available, renewable local material
- hemp offers good insulation properties, with some thermal mass effect
- hemp's relatively low density means that houses built using it are of a lightweight construction, reducing loads on foundations
- depending on the finishes, the construction envelope is vapour permeable.

2.2 Straw

2.2.1 Example buildings

A number of buildings have been built in the UK using straw bales – an example can be seen in Figure 7, Sworders Auction House. This building uses a timber frame to provide the main structural support, with some of the load being transferred to the infilling straw bales, providing the walls with essential racking resistance.

Other examples of straw bale construction can be seen in Table 2.



Figure 7 Sworders Auction House, Essex (© Nick Jones)

2.2.2 Materials

Straw bales can be used either structurally or non-structurally, with two distinct methods being recognised for each. Structurally, the Nebraska Method and the Lightweight Compressive Frame System, and non-structurally, panelised solution and simple infill.

Particular care needs to be taken when building with straw in the UK. Buildings should be designed and detailed to ensure that water is kept out of the walls, and during the building process all efforts should be made to ensure the building is constructed exactly as detailed.

The bulk and moisture sensitivity of straw bales means that careful planning is required throughout the building process, right from procurement, delivery to the site, storage onsite, site construction and finishing.

2.2.3 Use: structural applications

A straw bale building typically consists of:

- a raised footing or foundation
- a moisture barrier or capillary break between the bales and their supporting platform
- stacked rows of straw bales placed on top of the footing
- wooden pins, fitted inside the bales or on their faces, or surface fixed wire mesh to hold the bales together
- a stucco or plaster external finish.

The straw bales need to be dry, precisely formed and well bound. It is also important to ensure that the bales do not get wet during the construction process. This can be achieved by the provision of a covered and ventilated store onsite.

A typical wall section is shown in Figure 8.

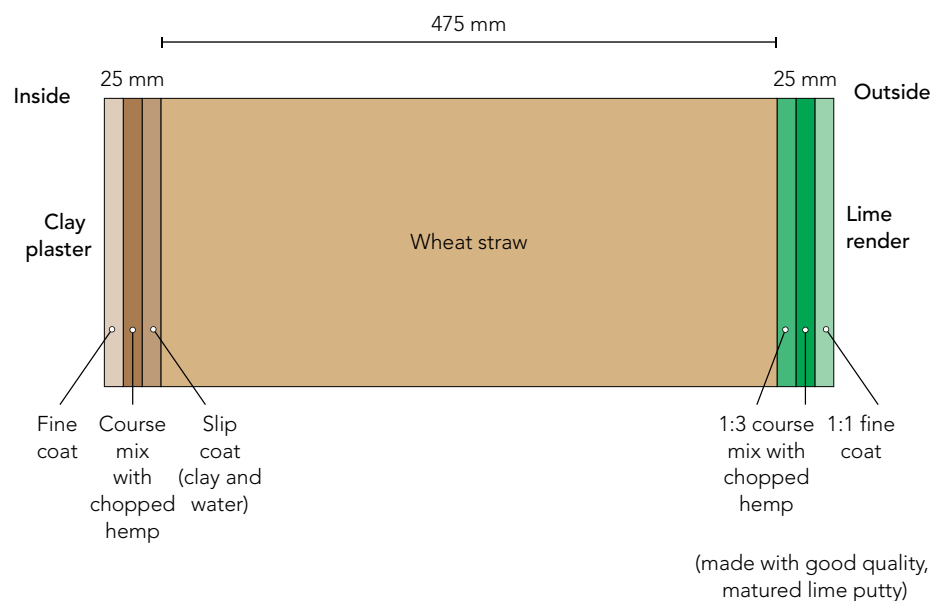


Figure 8 Cross-section through a typical completed straw bale wall from Atkinson^[14]. This example also incorporates chopped hemp in the plaster and render base coat.

The Nebraska Method

The Nebraska Method takes its name from the original approach taken in the mid-western US and is the simplest and cheapest option. The bales take all the structural loads, including the roof loads, without the need for structural framework (Figure 9). In practice, the roof is triangulated to ensure the lateral loading applied to the top of the walls is minimised.

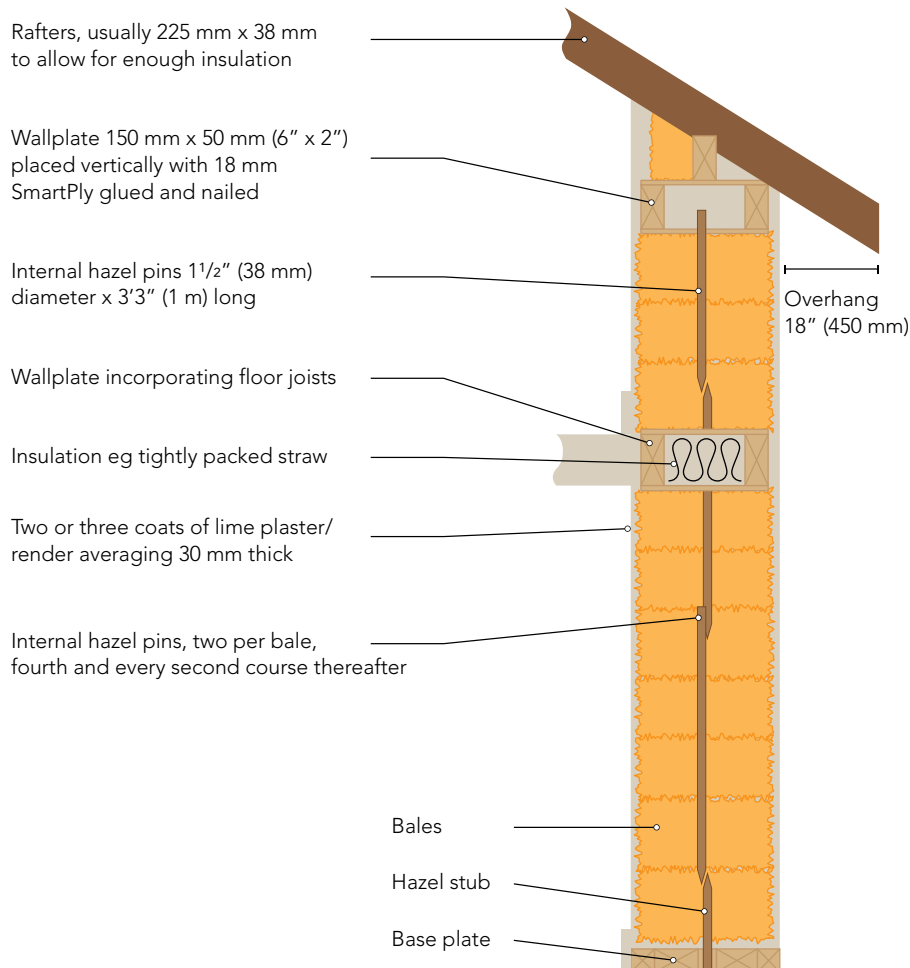


Figure 9 Section through a Nebraska System, straw bale wall^[15]

Lightweight Compressive Frame System

This method uses a lightweight timber frame and shares the loads between the straw bales and the frame. The advantage it offers over the Nebraska Method is that the presence of the frame allows the roof to be constructed earlier, which means that the straw bale walls can be protected during construction.

With the exception of the frame, the build process is the same as for the Nebraska Method.

Points to note are that the timber posts are located at the corners and at either side of window and door openings. These are designed so that the timber wall plate at first floor and/or roof level can either be slotted down into the posts or screwed down with a threaded rod once the straw is in place, allowing the bales to be compressed and thereby aiding stability. To increase stability further, the bales can be pinned externally, with the pins being secured to the base and wall plate of the framework once the settlement of the walls is complete.

In addition, the roof is attached to the timber frame and is located roughly 100 mm above what will be the finished level of the straw walls – with the roof plate in place. Once the walls are built up, the roof's bracing can be removed and the roof allowed to drop down onto the walls. This has the effect of loading them in compression, increasing their resistance to lateral loading. This process can be problematic and one technique to ease the position is to strap the roof to the foundations and pull it down onto the walls using ratchet straps.

2.2.4 Use: non-structural applications

Non-structural applications result in the main vertical loads applied to the building being carried by either a frame or structural panels, typically manufactured from timber. The straw is used to form the walls that fill in the space between the frame members. In this type of application, the straw resists the lateral loads applied by the wind.

Panelised and infill systems

An alternative method for constructing walls using straw bales is the use of prefabricated load-bearing wooden frames filled with compressed straw bale panels.

Straw bales can also be used as infill for a pre-constructed load-bearing timber frame (Figure 10). As with the lightweight frame, the timber frame is constructed and the roof finished before the straw bales are installed. The difference in this case is that the timber is designed to take all the vertical loads and the straw is used as an infill.

These forms of construction can be used to provide both larger plan and multi-storey buildings.

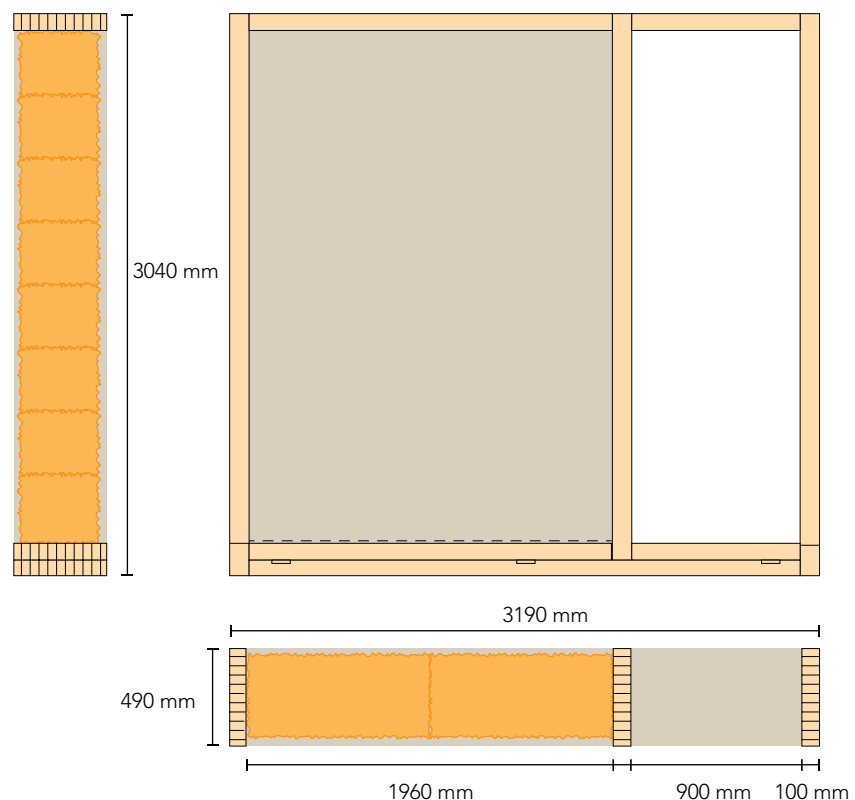


Figure 10 An example of a panelised straw bale system manufactured by ModCell

2.2.5 Performance

Thermal

The thermal performance of a wall made from straw will generally depend on the density of the straw and the wall's dimensions and make-up. Tests have indicated that a 500 mm thick structural straw wall with finishes has a U-value of around 0.15 W/m².K, as can be seen in Section 2.3.

Acoustic

No results for the acoustic testing of straw bale buildings are currently available for the UK. However, to give an indication of the relative performance of straw bale construction, limited data from the US suggests that a 500 mm thick rendered wall made from wheat and rye grass straw bales has an acoustic performance roughly comparable to a 180 mm thick solid wall made from concrete blocks, with a wet plastered finish.

Clearly, these figures will be dependent on which materials are used, their thickness and the quality of workmanship in a building's construction, so this result should only be seen as being indicative of straw's acoustic performance.

Weather tightness

Accelerated weather testing carried out on Bodmin Moor has shown that, with a 35 mm thick lime render, the moisture content of the straw can rise to above 20% and be lost back to the atmosphere quickly because the system is breathable.

However, in very exposed locations it is recommended that the inner face of a panelised wall is dry-lined, to ensure that any moisture that gets into the wall can readily pass through, and out.

Durability

The durability of straw bale buildings relies heavily on excluding moisture from the structure and the straw itself. If the moisture can be excluded, then the examples from the US that date back to the 19th Century show that these buildings can perform well for in excess of 100 years. It should always be appreciated that straw, like all other construction types, requires regular maintenance.

Concerns have been expressed that both insects and vermin could gain entry to the walls and degrade them. To date there have not been any reports of vermin infestation, probably because the straw is compressed and then fully enclosed within lime render or sheathing boards. There have, however, been two incidents of insect infestation reported, in both cases psocid bloom linked to sporing on the surface of the timber in a panelised system and not on the straw itself.

Resistance to fire

Straw bale walls have passed fire tests in the UK, US and Canada. In the UK, tests carried out at BRE showed that straw bales, finished with 12 mm of plaster, when tested to BS 476-20:1987^[16], withstood the test conditions for in excess of two hours.

2.2.6 Construction

The same detailing principles apply here as apply to any building; details should be carefully designed and built to avoid moisture ingress into the building.

Building off a plinth

In order to ensure the weather tightness of straw bale walls, the building needs to be constructed on a raised plinth, perhaps 300 to 450 mm above ground level, and be protected externally with lime render or timber cladding.

Openings

With solid straw bale walls it is important that openings are:

- carefully detailed on the working drawings to ensure that the appropriate membranes are used correctly throughout
- built in accordance with the design which will help to ensure that moisture is kept out of the walls.

For example, wherever possible, a window should be set back to reduce the risk of water ingress around the window reveal.

The alternative, cutting through the walls to create a window-sized opening, needs to be carried out very carefully, and is never as satisfactory. However, wall plates are in place at each storey height and they will act as beams if some support is removed from below – spreading the vertical loads around an opening, so long as it is not too large. The presence of the pins will also act to hold the straw bales together.

Once the opening has been created, a structural box frame can be fixed into the space to form the space for the window frame to be fitted.

External finishes

The whole external surface is normally sealed with a wet finish. These surface finishes are an important part of the structure as they contribute greatly to its weather tightness. Wherever possible, lime-based renders and plasters should be used with straw as they allow the passage of moisture through the fabric of the walls; cement or gypsum-based renders and plasters – and non-breathable paints and surface finishes – should be avoided as they tend to act as more of a barrier to the passage of moisture. For the same reason, where lime or clay plasters are used, the walls should not be wrapped in chicken wire or metal lathing, as the slightly elevated moisture content of the straw associated with these finishes can affect their long-term durability.

Loading

It should always be the intention, when building a load-bearing straw bale building, to ensure that the loads are distributed as evenly as possible throughout the whole building, as this will avoid the creation of any point loadings.

Accommodating creep

A building constructed with load-bearing straw is subject to vertical settlement as the straw creeps under the applied vertical loads, including self weight. This should be designed for in the construction process by leaving suitable gaps above doors and windows. In practice, this means that time must be set aside for this creep to have fully occurred before the surface finishes can be applied, otherwise there is the risk that the finishes will crack allowing a path for water ingress into the bales.

Site storage

The straw bales should be stored inside a ventilated and covered building or onsite store and the partly finished building needs to be protected to avoid water ingress.

Onsite care

The following basic minimum standard of care has been put forward^[17] for straw construction to ensure it maintains a high standard:

- The traceable provenance of the straw should include a documented history of the straw's harvesting and its storage prior to delivery to site.
- The fibre length should be checked, as this affects compactness.
- Any bale with signs of mould or discoloration should be discarded.
- Vulnerability to moisture, during both site storage and construction, should always be considered.
- If the bales are pre-compressed, for example during delivery, it should be expected that they will expand once untied.
- Where possible natural permeable materials should be used with straw, such as clay and limes.
- The first course of bales should be raised up from the ground by perhaps 300 to 450 mm and a 450 mm (18") roof overhang should be used to protect the walls from rain and moisture.
- Avoid using metal in the walls if at all possible, since it is a material that can result in warm, moisture-laden air from the inside of the house condensing on it, leading to dampness in the walls.

2.2.7 Risks

Environment and exposure zones

The use of straw bale construction remains in its infancy in the UK and so the performance of the material has not been proven by time.

The oldest Nebraskan examples of straw buildings are in a part of the US that experiences low humidity levels. Investigations carried out in areas with higher humidity levels have identified excessive levels of moisture in some straw bale buildings.

In Canada, the Canadian Housing and Mortgage Corporation has studied moisture control and measurement in straw walls and floors in high humidity and precipitation environments^[18]. They identified a number of instances where straw became wet enough to rot, particularly on north facing elevations. They concluded that, if a wall sees an abundance of moisture through plumbing leaks, surface water or a lack of rain protection, some straw will begin to rot. Similar concerns have been expressed about straw building in the east of the US^[19].

2.2.8 Benefits

An environmentally friendly material, straw, has a number of advantages over traditional building materials:

- straw is a widely available, renewable local material
- straw bales have good insulation properties
- straw's relatively low density means that straw bale houses are lightweight construction, which reduces loads on foundations
- depending on the finishes, the construction envelope is vapour permeable.

2.3 Cob

2.3.1 Example buildings

Many buildings have been built in the UK using cob construction, an example of a combination of an older building that has been rebuilt and extended can be seen in Figure 11.

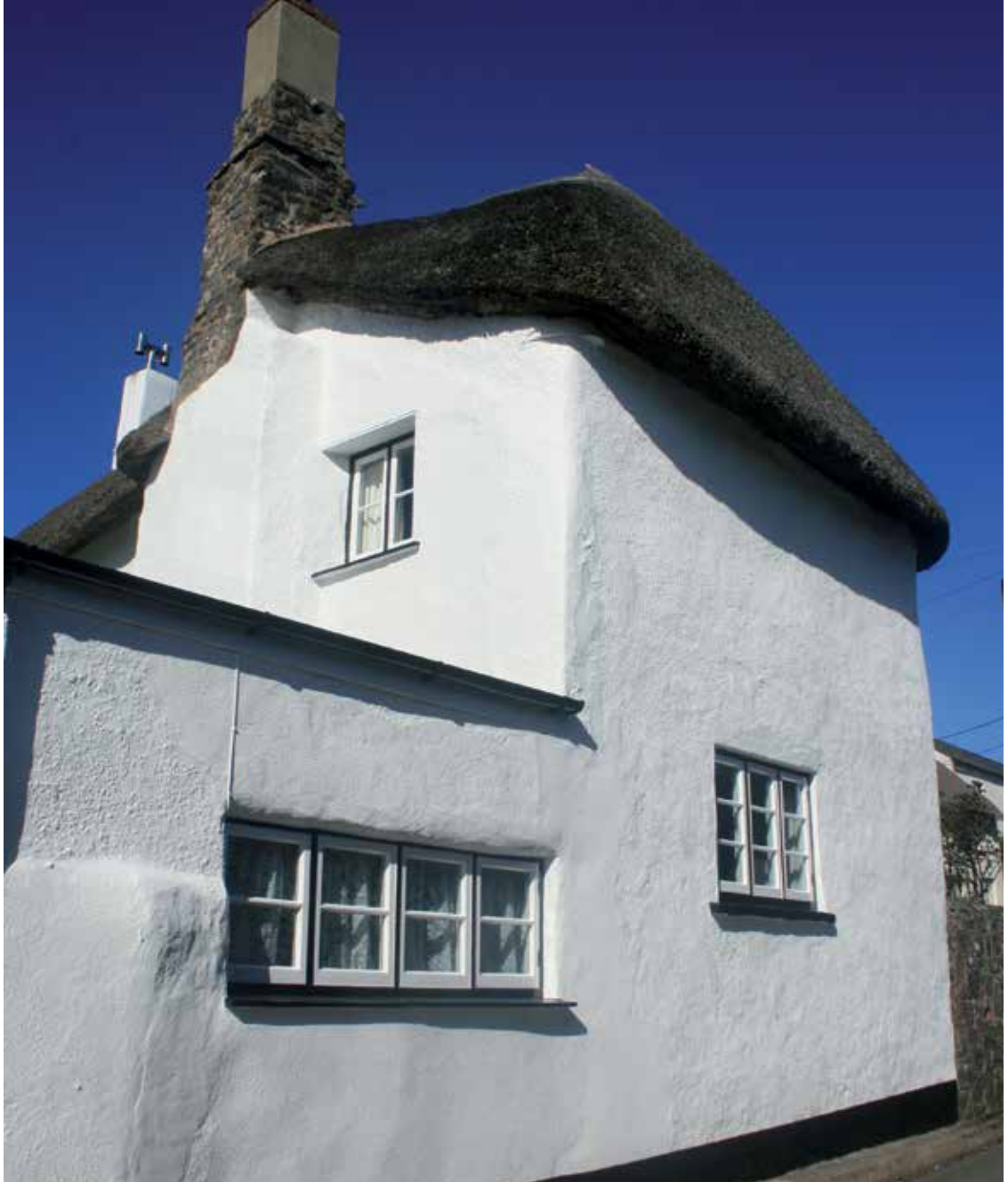


Figure 11 Lime-rendered cob building, Devon (© Paul Jaquin)

2.3.2 Materials

Cob is a traditional building material that comprises a mixture of:

- clay or sub-soil
- straw
- water.

Plain cob consists of clay mixed with straw which is then well watered and mixed to achieve the required consistency. A typical chalk-cob mix is one part clay and straw to three parts chalk lump. As well as site-mixed cob, ready-made cob bricks for use predominantly in repair work are available, although they can also be used for new build.

There are a number of regional names and variations for this material which is known as cob in the South West, clunch in Hampshire, clom in Wales and whitcirt in the Oxford/Aylesbury area. Historically, large numbers of buildings were built, particularly in the West Country, with an excess of 50,000 in Devon alone^[20].

2.3.3 Use

Figure 4 shows a section through a traditionally built cob house. This shows the stages in the building process, the arrangement of the first floor and the general principle of keeping the cob walls above ground level protected by a roof overhang.

An early report by the Building Research Station^[21] led to the building of several test houses in Amesbury, Wiltshire, using rammed chalk and clay. This period also saw local authority houses being built of the material – for example clay lump in East Anglia, where, in more recent years, work has been undertaken on technical standards^[22].

In Devon, a considerable amount of research and development work has been carried out on the contemporary use of cob, leading to publications on the history of building methods, modern designs to comply with Building Regulations^[20], and repair and maintenance methods.

At present there is no formal testing or accreditation for cob, with performance being based on historical custom and practice. However, a renewed interest in earth construction has led to some testing and performance data that can be applied to cob construction becoming available and examples of this can be seen in the References section in this report^[21, 22, 23, 24]. Further reference to cob construction can be found within the Bibliography.

2.3.4 Performance

There is very little information currently available on the thermal performance of cob although, as an indication, the U-value for a 900 mm thick wall made with cob is around 0.45 W/m².K^[3]. The nature of the material and the sheer scale of a cob wall should mean that, if correctly detailed, its acoustic performance and fire resistance will be satisfactory.

Its weather tightness will, in part, be dependent on the finish applied to the external surfaces of the wall. Historically, not all walls were rendered, for example in the south west only those elevations facing the prevailing winds were. Nowadays, however, it is recommended that all external surfaces are rendered.

2.3.5 Construction

Mixing

Cob is composed of both organic and inorganic materials and should be mixed correctly and laid in the recommended way. In addition, it should be noted that enough material should be mixed to allow the completion of each lift; adding newly mixed material with a different consistency can affect the integrity of a finished wall.

Weather tightness

Any wall material that does not contain an active binder is likely to be susceptible to damage if it is exposed to water for any length of time. For that reason, particular attention must be paid to ensuring that the outer surface of the cob is protected by an appropriate finish.

Traditionally in cob construction, keeping water out of the walls is achieved by the following:

- building the walls off an impervious plinth
- using relatively short floor-to-eave heights, so reducing the external wall area
- having a substantial roof overhang
- using a lime-rendered external finish.

These measures minimise rising damp, and the effects of wind-driven rain, and in addition using a lime-rendered external finish also facilitates vapour transfer to the atmosphere.

Openings

Openings for doors and windows can be prepared in timber and worked into the walls during construction, ensuring that the openings are both secure and well-sealed.

Repairs

Small repairs simply require filling with freshly made cob. However, when repairing larger areas, there is always the risk that the new cob will fall off the building before the area has dried. For that reason, larger repairs are best carried out using pre-made cob bricks, as they increase the stability of the repair.

Extending existing buildings

When extending an existing cob building, all the detailing associated with the walls should be in accordance with local custom and practice.

Good sources of information on this aspect include:

- *The Cob Buildings of Devon 2: Repair and Maintenance Guide*^[23]
- BRE Building Elements *Walls, Windows and Doors: Performance Diagnosis, Maintenance Repair and Avoidance of Defects*^[24]
- Dorset Building Control Technical Committee^[25].

2.3.6 Risks

Environment and exposure zones

Cob walling has been used extensively in the West Country which, ironically, is a part of the UK that is designated as having Severe or Very Severe exposure according to BR 262^[7]. The traditional walls themselves are very thick and so are likely to absorb and then release moisture, even if they are not rendered.

On that basis, if new cob walls are built with similar wall thicknesses following similar practices as used traditionally, satisfactory performance can be achieved, although they would need to achieve the minimum U-values required in the Building Regulations.

2.3.7 Benefits

An environmentally friendly material, cob has a number of advantages over traditional building materials:

- the materials are cheap and easily acquired, although they do require a suitable subsoil
- straw, or other vegetable fibre, is readily available
- embodied energy is low, particularly so as the walls are handmade.

2.4 Thatch

2.4.1 Example buildings

Thatch is a roof material that has been used for many centuries, and an example of a typical use can be seen in Figure 12.



Figure 12 Thatched cottage

2.4.2 Materials

There are many regional variations and different materials that are used for thatching:

- Varieties of straw including different wheat, rye and wheat/rye hybrids. Durability is typically around 20 to 25 years, with maintenance.
- Water reed is more durable than straw, perhaps lasting for up to 50 years, subject to periodic maintenance. However, supplies of Norfolk reed (the UK's water reed) can be uncertain and this has resulted in imports from Eastern Europe which has introduced some uncertainty about likely durability.

2.4.3 Use

Thatch is a roofing material of particular historical interest that is used in various parts of the UK. It is a natural material and needs to be maintained.

Thatch comprises two coats:

- the undercoat, which typically is always left in place
- the top coat, which is replaced on a cycle, depending on the thatching material.

The top coat (also known as the wearing coat) is stripped away and replaced once it starts to degrade. This process means that the thatch undercoat may be of considerable age in older properties.

2.4.4 Performance

Currently there is very little in the way of performance data for thatch and its acceptance and expected performance tend to rely on experience, custom and practice that have developed over many hundreds of years. This sets thatch apart from hemp lime and straw bale where there is not the same history and experience of use.

Control of the quality of thatching is achieved by requiring membership of the National Society of Master Thatchers, which is overseen by the National Council of Master Thatchers Associations. Some regional work has been undertaken on standards and the Dorset Model is seen as complying with the Building Regulations^[25].

2.4.5 Construction

Thatch construction must be in accordance with established custom and practice, subject to local and regional variations.

Good sources of information on thatching include:

- *The Complete Thatching Guide*^[26]
- The Dorset Model^[27]
- *Thatching* (Advice note 14, Broadland District Council)^[28]
- BRE Report 504: *Roofs and Roofing*^[29].

2.4.6 Risks

Environment and exposure zones

The long history of thatching in many exposed areas of the UK has led to a substantial body of knowledge on the impact of different environments and different exposure zones. As a result these risks are managed through the understanding of materials and by the use of the right material and regular maintenance of the wearing coat.

It has also been found that, the further west, the less durable thatch becomes as it is exposed to the wetter Atlantic weather.

2.4.7 Benefits

An environmentally friendly material, thatch has a number of advantages over traditional building materials:

- Where available, thatch is a local material that does not need to be transported far.
- Thatch maintains the traditional appearance of the house on which it is fitted.

3 Maintenance and repair



All buildings require regular and appropriate maintenance of the external envelope to ensure the anticipated design life is achieved. In structures built with cellulose-based materials, the emphasis is on keeping the external envelope weathertight to reduce the risk of moisture ingress that could lead to decay and deterioration.

Areas requiring particular attention include:

- the condition of roof and walls
- the integrity of the down pipes and other rainwater goods
- avoidance of a build-up of the external ground adjacent to the building, which could result in penetrating damp
- checking for cracking of the external render layer, which could allow the ingress of either driving rain or runoff
- carrying out all repairs with compatible materials.

BRE Good Repair Guide 35^[30] provides guidance on the inspection and repair methods for earth, clay and chalk walls and so provides guidance that is particularly relevant to cob walls.

The render layer in any cellulose material is always a potential weak point in the system and regular checks are needed to ensure its integrity is not compromised. The settling of walls made of cellulose-based materials may mean that some cracking will occur, in both the render and the structure of the wall.

This can be avoided, to some extent, by:

- delaying the application of a final finishing render for as long as possible to allow any shrinkage associated with moisture movement to have occurred, and/or
- ensuring that a visual inspection, followed by remediation, is part of the post-occupancy guidance.

Thatch has its own needs in respect of maintenance and a suitable programme must be put in place to ensure it has a reasonable longevity. Repairs must be carried out promptly.

Specific maintenance and repair needs vary depending on the thatching material, but typically include:

- a yearly inspection after the winter
- dressing up: the periodic 'knocking up' of the material ends to ensure that the thatch stays in place and has an even thickness across the roof
- brushing down: the removal of leaves and other organic debris
- repairing holes
- replacing the protective surface netting.

4 Accreditation and conformity

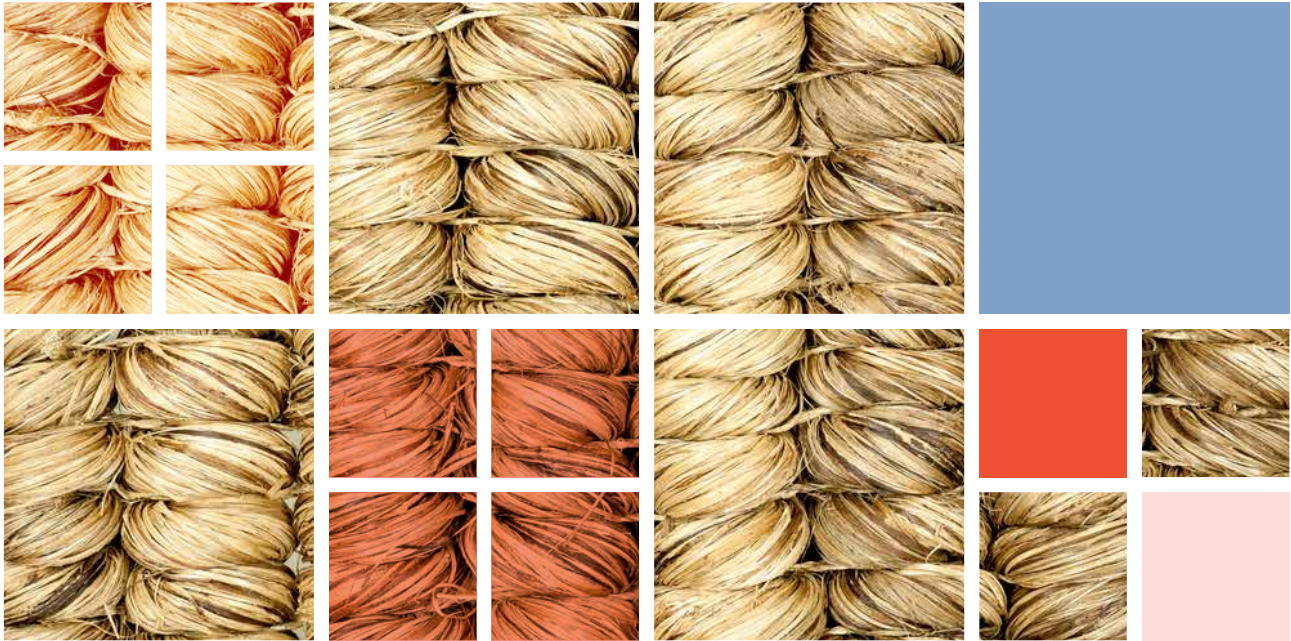


Conformity assessment, the demonstration that what is being supplied actually meets the requirements specified or claimed, and accreditation, are both important parts of the UK quality infrastructure. So, if cellulose-based construction materials are to become an accepted part of mainstream construction, it is essential that their use is assessed in the same way as for other more conventional materials. This will allow comparisons to be made between the performance of different building materials on a level playing field.

Conformity assessment can be applied to a product, system or process and includes services such as testing, inspection and certification.

Additional methods may be required for assessing cellulose-based building materials, for example the adhesion of render systems.

5 Availability of materials



5.1 Hemp

There are, at present, around 2000 hectares (ha) of hemp grown annually in the UK. It has been calculated that 1.5 ha of hemp is required per house (if using the cast onsite process), which equates to sufficient hemp producing fewer than 1500 houses per year. Production is set to increase to around 3250 ha in the near future, which equates to approximately 2166 houses. Even with the increase, current production of hemp in the UK limits the number of new-build hemp houses that could be manufactured from home-grown hemp to less than 1% of the 2010 new-build figure.

While claims have been made that converting all the current 250,000 ha of fallow land in the UK to hemp production would yield sufficient cellulose to meet current new housing projections without any loss in agricultural productivity, it is hard to see this as being a realistic expectation. However, just 10% of this production would provide sufficient hemp for roughly 16,000 houses. Given that the recently developed prefabricated panel method uses both the hemp shiv and fibre as insulations, the volume of grown material required is approximately half compared to the cast onsite methodology. The improved U-values and greater certainty these panel systems provide has increased market acceptance and it is likely that agricultural production will be able to increase with market demand if the market adopts such systems. It is considered unlikely for there to be a radical step change given the construction industry's inertia to adopt new technologies rapidly, but any rise in demand could be met by an increase in agricultural production.

5.2 Straw

As long as the UK produces wheat and barley, straw will always be available and the Government's Biomass Energy Centre gives annual straw production for wheat and barley straw as being 10 million tonnes^[31]. However, there are competing demands for straw, the main one being biomass for energy production. As a result, it cannot automatically be assumed that straw will be available for construction purposes.

As with the other crops discussed here, the potential use as a fuel source will give straw a minimum unit price. That price will vary, but it is unlikely that it will significantly fall.

5.3 Cob

As cob comprises clay, straw and water, with, or without, chalk, it is hard to envisage a time when there will not be sufficient materials to cover the demand. Considerably less straw is used in the manufacture of a unit of cob compared with a unit of straw bale.

5.4 Thatch

For thatching, a critical factor is obtaining straw of the correct length. This limits the amount of usable straw that is available. The Master Thatcher's Association gives annual thatching requirements for straw of around 12,000 tonnes. At the same time, approximately 80% of the water reed used for thatching in the UK currently is being imported.

There are many regional variations and different materials that are used for thatching. Even so, the UK does not produce sufficient materials to meet our existing needs.

5.5 Summary of availability

Overall, there would appear to be some potential for increasing the production of the raw materials used in cellulose-based construction and so increasing the potential for their use in both residential and commercial developments.

However, the viability of the use of all the cellulose-based materials in construction discussed in this report is essentially defined by the cost of fuel. All the cellulose materials can be converted into biofuels and that effectively defines their minimum price. Unless actions were taken to prevent cellulose being used in this way, it is not impossible to imagine that cellulose-based materials might be priced out of the construction sector, apart from in their traditional niches, such as thatching and cob walling.

6 Conclusions



There appears to be an increasing interest in the use of cellulose-based materials in construction which may increase further as projects are successfully completed and the evidence base in support of future projects becomes more extensive and reliable. The Renewable House at BRE, the Hempod and the Strawbale houses in Kesteven are all being monitored to quantify both their performance and any changes to the properties of the materials themselves. This research is being supported by further studies on the use of traditional materials such as cob, rammed earth and thatch, and by a renewed interest in their use both in the UK and internationally.

There are some projects currently onsite and others planned and these will provide important data as cellulose materials attempt to move towards mainstream construction. Cellulose building materials do have the potential to make a significant contribution to the low carbon building sector. For example, the Marks & Spencer retail store at Cheshire Oaks has just completed its first year in use and the use of hemp lime wall panels is seen as one of the contributing factors to the exceptional building performance^[32].

However, the move towards mainstream construction will require significant developments within the supply chain to ensure that there is sufficient capacity to meet the potential demand, and this must be a concern. The products will need to be supported by test evidence, guidance and certification, to ensure that they demonstrate satisfactory in-service performance in accordance with recognised standards, regulations and requirements.

Existing and future projects will need to be reviewed and the findings used to strengthen current guidance on good practice for both design and construction, including appropriate detailing and provision for the management of moisture.

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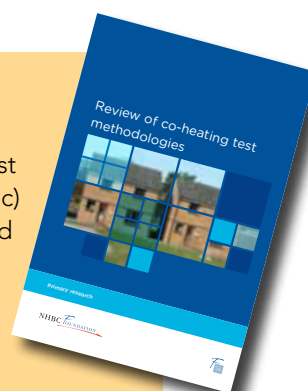
NHBC Foundation recent publications

Review of co-heating test methodologies

This report describes a series of co-heating tests undertaken by test teams from BRE and six project partners (commercial and academic) in one of BRE's test houses, with a second identical test house used as a control.

The project assessed the approaches taken by investigators undertaking the co-heating test, with particular regard to test protocols, data analysis and treatment of uncertainties.

NF 54 November 2013



Low- and zero-carbon technologies in new homes

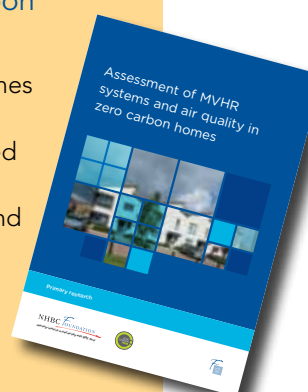
This report provides new real-world insights into the detailed, day-to-day marketing and use of homes with LZC technologies. Further, these insights inform the development and demonstration of a continuous improvement marketing approach for house builders.

NF 53 November 2013



Assessment of MVHR systems and air quality in zero carbon homes

This report is based on the experience of MVHR systems in 10 homes built by Scottish and Southern Energy at Greenwatt Way, Chalvey. Built to Code for Sustainable Homes Level 6, these homes provided a perfect test bed for the detailed evaluation of MVHR systems in practice. As well as looking at design, specification, installation, and commissioning issues, the research also gauged the use of these systems by some typical home occupants. **NF 52** August 2013



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NHBC Foundation publications in preparation

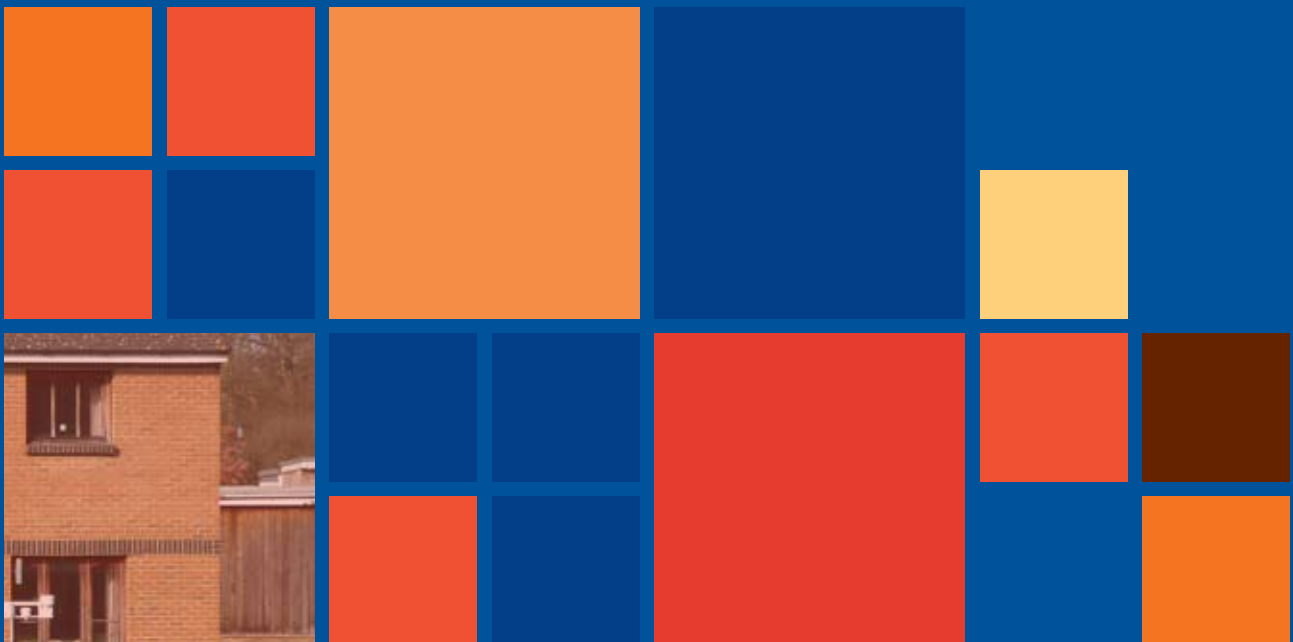
- Socio-technical analysis of microgeneration technologies in UK and France
- Garages - what do we use them for?
- Homes through the decades

Cellulose-based building materials

Use, performance and risk

There are many examples of crop-derived materials that have been used in construction – English Heritage has estimated that there could be as many as 500,000 cob or earth buildings in the UK. Recent work has seen these traditional cellulose-based building materials being re-examined as potential low impact building materials, products and systems. For such materials to become more widely accepted, it is important that they can be properly evaluated and assessed alongside other products and materials.

This report provides a brief history of cellulose-based building materials, and reviews the current developments in their use. It discusses use and performance issues and examines the potential benefits and risks associated. It also provides examples of recent projects built in the UK.



NHBC Foundation has been established to facilitate research and development, technology and knowledge sharing, and the capture of industry best practice. NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the UK's wider housing needs. NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.