

STRAW BALE

An introduction to low-impact building materials

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This Information Paper provides a broad view of the benefits and limitations of straw bale for those considering its use in construction projects.

Straw is a renewable material offering good thermal insulation properties and a much lower environmental impact than many current mainstream construction materials. Straw bale is very suitable as infill insulation for timber-frame buildings with either an external render or timber rainscreen finish. Straw provides a vapour-permeable wall construction using a locally sourced, low-impact material, although it does need careful detailing and construction to avoid the ingress and retention of moisture.

This is one in a series of five Information Papers and parallel case studies on low-impact building materials. The others cover hemp lime, unfired clay masonry, cross-laminated timber and natural fibre insulation.

Straw bales may be used in both infill (non-loadbearing) and modest loadbearing wall applications. Non-loadbearing straw bale walls are mainly used for external infill above the damp-proof course level in moderate or sheltered environments. They can be constructed either on site or as prefabricated panels delivered to site already enclosed in a protective outer finish, such as lime render. Detailing requirements for both approaches are similar, although construction sequences are different.

In addition to the other general benefits of offsite construction (speed of construction, reduced waste), straw bale is particularly well suited to prefabricated construction, as the risks of water damage during construction, and of fire associated with loose-cut straw, can be minimised. Over the past 10 years, different prefabricated straw bale systems have been developed in the UK and elsewhere. These typically use an engineered



Figure 1: Sworders' auction rooms, Stansted Mountfitchet, Essex – a single-storey 1100 m² building, constructed in 2008 using straw bale wall construction (Courtesy of Mike Beckett/Collins & Beckett)

timber framework that is infilled with straw bales and covered by either lime render or timber screens off site. While the timber is often imported, the straw itself is readily abundant throughout the UK, minimising transport costs. Prefabricated panels can be made and used throughout the year and require minimal specialist machinery – primarily adequate lifting equipment. Rendering and initial hardening can be carried out off site, with final finishes applied on site as necessary.

Straw bales can also be used for lightly loaded structural walls (up to two storeys high). While compressive strength is very low (governed by displacement rather than material failure), 450 mm-thick bale walls are capable of supporting 0.8–1.0 tonnes/m length, sufficient for domestic-scale buildings and loadings. The render plays a significant structural role, increasing resistance and improving stiffness (limiting movement) as well as protecting the straw from decay and enhancing fire resistance. Weather protection to loadbearing walls during construction can be more problematic than when straw bale is used as infill. To



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Box 1: Why specify straw bale?**Advantages**

- Avoids thermal bridging and provides good airtightness with simple detailing
- Good insulation qualities
- Lightweight material with simple construction details and processes
- Light weight reduces load on foundations, reducing the need for materials with high embodied energy (eg concrete)
- Low-cost renewable material, widely available from local sources, that stores carbon throughout its life
- Simple building skills suited to self-build and community projects
- Suitable for in situ and prefabricated approaches
- Vapour-permeable construction envelope

Limitations

- As an agricultural co-product, inconsistent properties (eg dimensions, density and moisture content) can be problematic during construction
- Details restricted by need to protect the straw from water ingress; careful detailing needed for exposed areas
- Limited to relatively lightweight fixings
- Limited water resilience (giving rise to concerns over flood damage) and problems for repair if water-damaged (especially loadbearing walls)
- Requires shelter before finishes can be applied
- Suitability of rendered external finishes limits application in some areas
- Use limited to above damp-proof course or equivalent level

overcome this, systems have been developed in which the permanent roof structure is supported temporarily during wall construction and then lowered onto the walls. Other options include temporary tarpaulins or erecting a temporary external shelter structure.

Straw bales provide lightweight, large building blocks that are ready to use. Basic site skills for straw bale construction can be learned quickly, and are probably most readily suited to carpentry and woodworking trades. Once constructed, the bales form a robust wall infill that can receive a vapour-permeable lime render finish internally and externally, although external walls can be finished instead with a timber rainscreen cladding. Any waste from straw bales is entirely biodegradable.

Straw is perhaps best known as a roofing material for thatched roofs. Straw bales can also be used in vertical or lateral (racking) load-carrying capacities in walls. However, as these uses are not covered in this Information Paper, further information should be sought (see 'Further reading and sources of information').

Straw is a co-product of cereal production and has no value as animal feed, although it can be used as bedding or ploughed back into the ground as a soil conditioner. Its use as a construction material currently has no direct impact on food production or other uses of straw (eg for animal

bedding or mushroom production), although much larger-scale use may eventually have some consequences. For straw construction in the UK, wheat or barley straw is preferred. This can be sourced from local farmers, or specialists in straw bale construction may source the materials. In either case, it is important to ensure that bales are tightly bound and relatively consistent in dimension and density. Typical UK dimensions for straw bales are 990 × 500 × 375 mm, although some straw-baling machines have the capacity to bale 'to order'. Straw bale density for construction should normally be no less than 110 kg/m³ to provide robustness in transport, stability and fire resistance. The integrity of straw bales in the long term partly depends on the binding used to form the bale: bales used should be bound with robust, non-degrading twine such as polypropylene.

When using straw in construction, both the unique properties of the material and the method of working with it need to be considered from the beginning of the design process. This different approach can initially seem complex, but ultimately straw bale construction is a comparatively simple and straightforward process once its unique nature has been understood.

Perhaps most importantly, straw is a stable structural material provided that, like timber, moisture does not reach levels of ingress over time that might compromise its stability. This is of particular relevance during construction, when the components are most exposed, but applies throughout its usable life. Like all other building materials, straw bale requires appropriate detailing, planning, protection and maintenance. Straw bale walls are most vulnerable around openings (windows, doors) and at the base of walls, which should be protected from damp and excessive rain splash by use of a brick or stone plinth, for example. Figure 2 provides an example of a section detail of straw bale construction.

Straw bale walls should normally be finished with a vapour-permeable render (such as lime) both internally and externally. The wall head and external face are often further protected by a good roof overhang to prevent driven rain saturating the render. In order to minimise the risks associated with water penetration around sill details, windows and doors will probably be fitted towards the outer face of the wall. It is also important to ensure that miscellaneous penetrations through the walls are detailed to ensure that they do not allow moisture to build up (Figure 3). It is generally recommended that thermal bridges and cold elements within the straw are avoided, as these may allow water vapour present in the straw to condense. For this reason, metal framings or fixings are often avoided or at least wrapped in sackcloth to separate them from contact with the straw.

Box 2: Typical properties of straw bale

- minimum recommended bale dry density: 110–130 kg/m³
- thermal conductivity: 0.055–0.065 W/mK (density 110–130 kg/m³)
- recommended initial moisture content: 10–16%
- recommended maximum in-service moisture content: normally not to exceed 20–25%

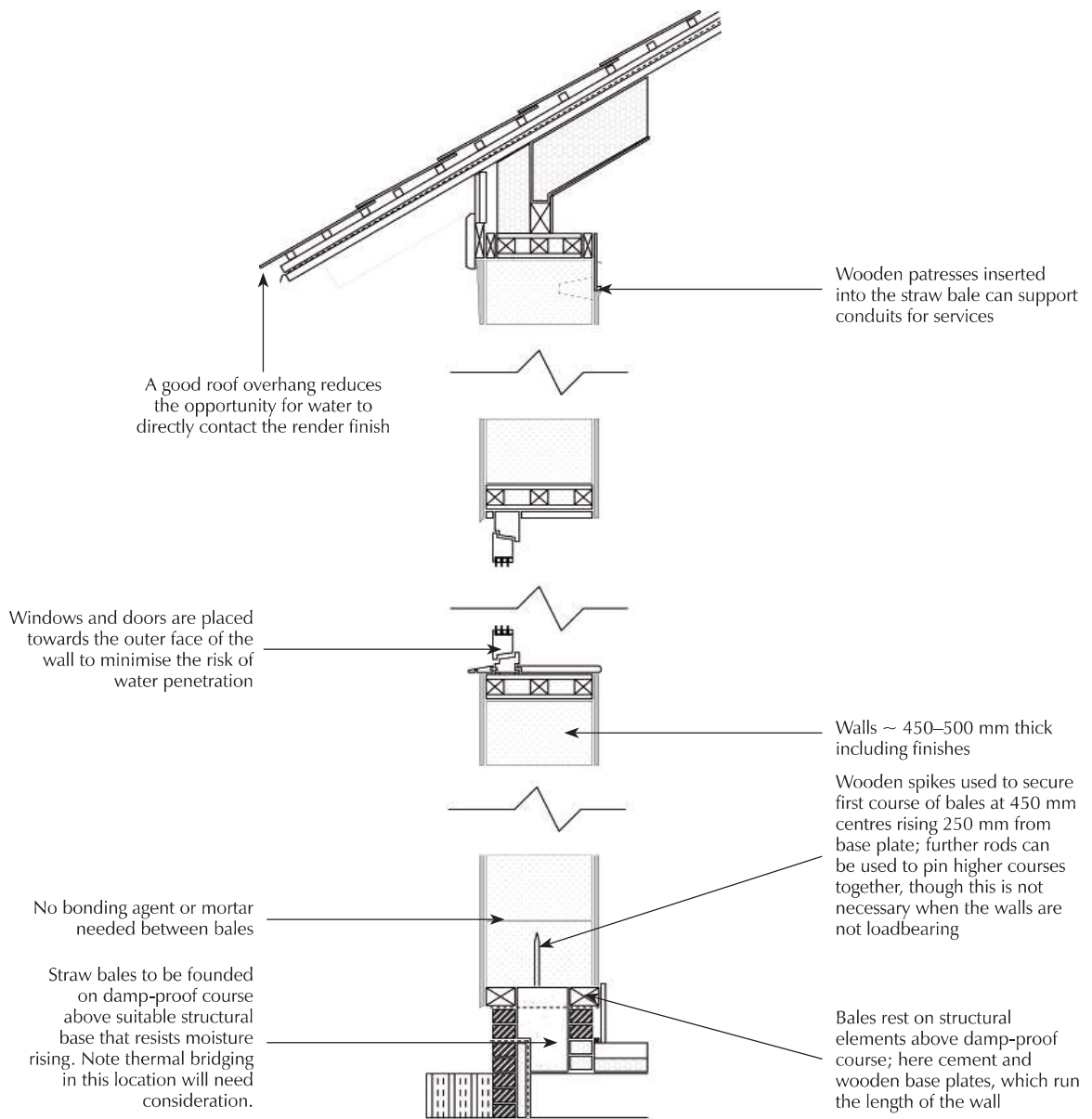


Figure 2: Section detailing of an example straw bale wall construction

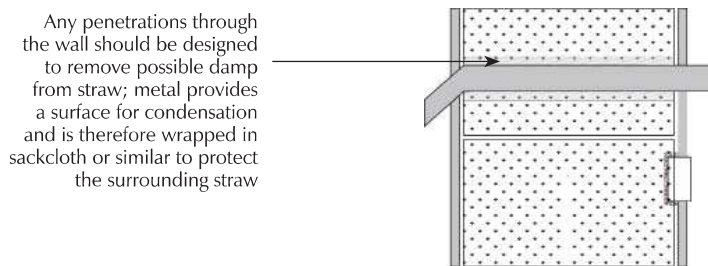


Figure 3: Penetrations must eliminate the risk of condensation or damp ingress

Straw bale construction also features a unique structural building solution. Figure 4 illustrates the construction sequence. In the UK, for walls up to 2.5 m high, it is usual practice for the first course of bales to be initially secured onto wooden spikes at approximately 450 mm centres rising about 250 mm from the base plate of the wall. The timber spikes ensure that the foot of the wall does not slip. While it is not necessary to continue the process of spiking or pinning for subsequent courses, this does add additional stiffness and robustness to the resulting wall construction.

Bales are normally laid flat to form walls 450–500 mm thick once finishes have been applied. However, bales can also be laid ‘on edge’ to form walls around 100 mm thinner, although this would provide a corresponding reduction in insulation value. Once the first course of straw bales has a secure footing, the bales are stacked without any bonding agent or mortar using a stretcher bond format, ie each bale centred on the bale joint beneath (Figures 5 and 6). The stretcher bond format will inevitably require some bales to be cut, which is easily done by inserting a long needle at the desired point to bind the bale at the required length, with the extra bale then trimmed off (Figure 7). As it can be time-consuming to cut bales, even for someone with experience, detailing of wall sizes, and especially window and door openings, should seek to minimise the amount of bale cutting required. Similarly, any gaps that form can be filled with tightly hand-packed loose straw.

Most commonly in the UK, bales are secured by pinning and compression, for example using timber spikes and wall plates (rigid beam components that sit on top of the bale wall), and tied with straps onto the surrounding framework (Figure 8). Compression can be achieved by designing the structural frame to allow the wall plate to be lowered and tightened once the final course of straw bales has been inserted. Alternatively, the fixed frame is completed first and the bales are compressed by applying pressure to the penultimate layer of bales, allowing the final layer to be put in place before release. Once the pressure is released, the remaining bales expand to hold them all firmly in place. Whichever method is used, the straw bale wall should be left in a state of compression. The compression of the wall not only provides some stability, but also mitigates later wall settlement. Rendering further stiffens and strengthens the wall.

When the straw bale wall is in place, it is possible to install pattress boxes (containers behind electrical fittings) for future lightweight fixings. These may be installed by hammering a timber spike and block into the bale. Heavier fixings will need to be integrated into the framing system. Electrical conduits can be hidden on the surface of the straw behind the render.

Once the wall is complete, a lime render (or other vapour-permeable finish) can be applied internally and externally (Figures 9 and 10). The surface of the straw is normally prepared by trimming. The first render coat is applied directly to the straw, and is firmly thrown or sprayed to achieve a good bond with the straw. Where desired, flexible plastic corner and stop beads can be used (avoiding the risk of condensation from metal fixings). This rough coat should be applied to both sides in succession, as leaving the wall unevenly rendered for any significant period can cause minor deflection. Once the base render is ready, a second coat to finish is applied and allowed to cure in accordance with good practice. A final third skim or finish coat is normally applied. Total render thickness on an external, weather-exposed face should normally be around 35 mm (depending on materials). As a lower-carbon alternative, earth- (clay-) based finishes may be used, especially in internal faces, as they too are generally vapour permeable.

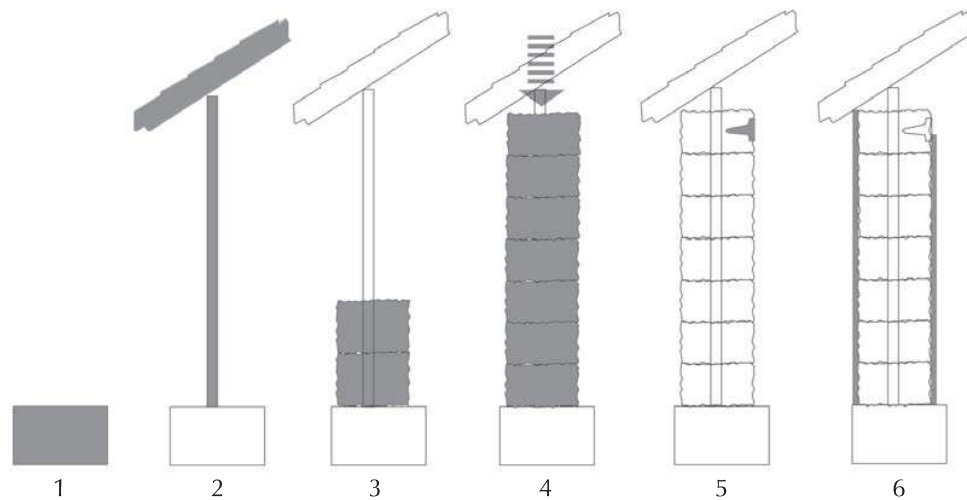
On site, straw bales should be kept in dry conditions until used to ensure no ingress of moisture, with protection provided against rising water from the ground or very high levels of humidity. Construction on site can be quick, dry and straightforward, requiring little training for site carpenters. The primary concerns on site are preventing excessive moisture ingress and minimising the risk of fire through proper management of loose straw. While the finished straw bale wall has surprisingly good fire resistance (the charring rate is similar to that of timber), loose straw from any cut bales presents a notable fire risk and the site should be swept clear regularly.

Straw bale building is growing in popularity and, despite the current lack of certificated products or systems, an increasing number of successful housing, school and office buildings have been approved by local building control.

FURTHER READING AND SOURCES OF INFORMATION*

- BRE and University of Bath. Low-impact materials: case studies. Straw-bale: auction rooms. Available at: www.bre.co.uk/page.jsp?id=2669.
- Dick K and Krahn T. Straw bale building system research and ongoing research at the Alternative Village, University of Manitoba. Winnipeg, University of Manitoba, 2009.
- Jones B. Building with straw bales: a practical guide for the UK and Ireland. Totnes, Green Books, 2009.
- King B. Design of straw bale buildings: the state of the art. San Rafael, California, Green Building Press, 2006.
- Walker P. Compression load testing straw bale walls. Bath, University of Bath, 2004.

* All URLs accessed October 2011. The publisher accepts no responsibility for the persistence or accuracy of URLs referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.



1. Groundwork completed with damp-proof membrane lapped over loadbearing wall footing. Thermal bridging design detail required for this wall footing.
2. Timber structure and roof with significant overhang installed.
3. Straw bales laid in stretcher bond format with overhang pinned, rebound and cut.
4. Bales compressed (with steel jacks or similar) to required level.
5. Wooden patresses (and penetrations) installed to provide fix for service conduits.
6. Render applied inside and out.

Figure 4: Construction sequence for an example straw bale wall (using steel jacks or similar to achieve required compression)

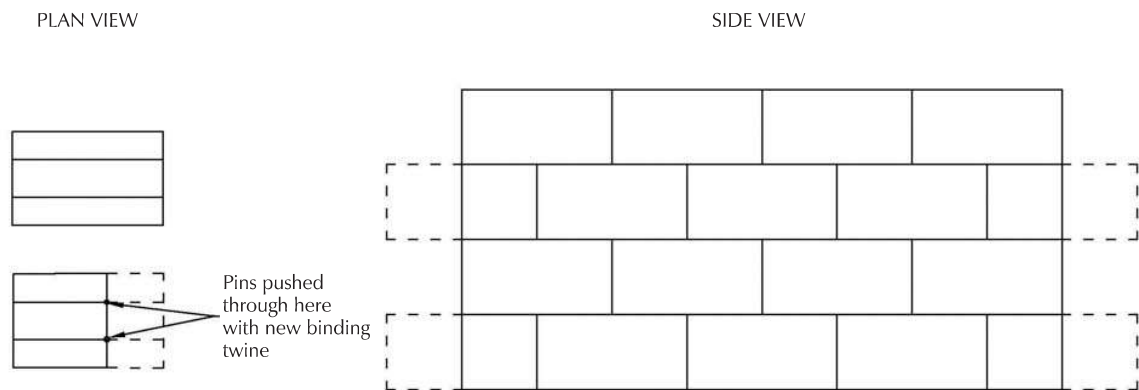


Figure 5: Bales are laid in stretcher bond and excess material is pinned, bound and cut out
(Courtesy of Mike Beckett/Collins & Beckett)



Figure 6: Six courses of straw bales laid in stretcher bond with the seventh about to be added
(Courtesy of Mike Beckett/Collins & Beckett)



Figure 7: Pinning, tying and cutting end bales
(Courtesy of Mike Beckett/Collins & Beckett)



Figure 8: A completed wall with straps connecting the wall plate to the base
(Courtesy of Mike Beckett/Collins & Beckett)



Figure 9: Vapour-permeable render being applied to exterior of straw bale surface
(Courtesy of Mike Beckett/Collins & Beckett)



Figure 10: Second coat of render has been applied
(Courtesy of Mike Beckett/Collins & Beckett)

Box 3: Carbon storage

The embodied carbon of straw bale products is very low relative to many other construction materials. As with all plant-based material, carbon is stored during plant growth and continues to be stored through its use as a building material. At the end of its life, it might either be used as animal bedding (if cleaned of any other materials such as lime render), be ploughed back into the ground as soil conditioner or possibly used as biomass fuel.



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