

Straw bale

Straw has been used as a building material for centuries for thatch roofing and also mixed with earth in cob and wattle and daub walls. Straw bales were first used for building over a century ago by settlers in Nebraska, USA, shortly after the invention of baling machines.

Straw is derived from grasses and is regarded as a renewable building material since its primary energy input is solar and it can be grown and harvested.

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Straw is the springy tubular stalk of grasses like wheat and rice that are high in tensile strength. It is not hay, which is used for feeding livestock and includes the grain head. Straw is composed of cellulose, hemicellulose, lignins and silica. It breaks down in soil, so waste straw can be used as mulch. Different grasses have slightly different qualities: rice straw for instance has a significant amount of silica, which adds density and resistance to decomposition.

Strawbale walls are surprisingly resistant to fire, vermin and decay. The Australian straw bales suitable for domestic construction have two strings (American how-to books often show three-string bales) and are typically 900mm long x 450mm wide x 350–400mm high, and weigh 16–20kg. Agribusiness produces large round straw bales that are no use for building purposes but rectangular 'jumbo bales' are available (2,400mm x 1,200mm x 1,200mm) which can be used for large structures and require mechanical lifting.

Performance summary

Appearance

Finished strawbale walls are invariably rendered with cement or earth so that the straw is not visible. The final appearance of rendered straw bale can be very smooth and almost indistinguishable from rendered masonry, or it can be more expressive and textural.

Structural capability

The structural capability of straw bales is surprisingly good. In the loadbearing ('Nebraska' style) strawbale



Photo: Paul Downton

A 'truth window' is a common feature in strawbale homes, providing a glimpse of the material that is otherwise completely rendered over and hidden in the finished building

method, walls of up to three storeys have been constructed. Most strawbale construction uses a frame of timber or steel for the building structure to comply with the Building Code of Australia (BCA). (see *Construction systems*)

There are many examples of multi-storey buildings in framed strawbale construction.



Photo: Paul Downton

Straw bales in the city. There is no location that strawbale building cannot adapt to.

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Thermal mass

Straw bales have very low thermal mass, being composed, by volume, mostly of air. However, the cement and earth renders typically used on straw bales result in finished walls having appreciable thermal mass in the masonry 'skins' either side of the insulated straw core. With earthen renders a thick render skin of up to 75mm can be achieved, providing significant thermal mass. (see *Thermal mass*)

Insulation

Straw bales have excellent insulation properties, among the most cost effective thermal insulation available. (see *Insulation*)

- Centimetre for centimetre, straw has similar insulation value to fibreglass batts.
- A typical strawbale wall has an R-value greater than 10.
- Dollar for dollar, the insulation value of a strawbale wall exceeds conventional construction.

The design goal in any structure must be to complement the insulation performance with the performance of the rest of the building. Thus, it is essential to insulate roofs and windows to maintain the overall performance of a strawbale building. (see *Design for climate; Orientation; Passive solar heating; Passive cooling; Glazing*)



Straw bales can accommodate any window shape and occasionally be used for internal walls.

Sound insulation

Straw bales also provide cost effective sound insulation, which contributes to the liveability of this kind of construction and can be quite marked. Even walking into the space created by an unfinished strawbale structure, one can appreciate the quietness and hear the difference from conventional buildings. (see the appendix *Noise control*)

Fire resistance

Straw bales are tightly packed and covered with a skin of render. Fire can't burn without oxygen, and the dense walls provide a nearly airless environment, so the fire resistance of compacted straw is very good. Laboratory fire tests conducted at the Richmond Field Station in 1997 by students at the University of California Berkeley rated a strawbale wall at two hours. Strawbale homes survived Californian bush fires that destroyed conventional structures. A fire that started in a Whyalla strawbale building did not take hold, as it would have in a conventional structure, and the damage caused was repaired with the cost covered by insurance.

Because the dense walls provide a nearly airless environment, the fire resistance of compacted straw is very good.

Tests undertaken by the CSIRO on behalf of Ausbale and the South Australian fire authority in July 2002 on three kinds of standard size rendered straw bales (earth; lime and sand; lime, sand and cement) produced a two hour fire rating. Samples were subjected to a simulated bushfire front with a maximum heat intensity of 29kW per square metre — an accepted standard under AS 3959, Construction of buildings in bushfire prone areas. Since the 2009 Victorian bushfires new standards have been set for testing materials for bushfires.

Straw bales can burn (slowly) but the potential for fire to take hold can be minimised. Try to cap walls by continuing render over the top of the bales and plates so that an inadvertent flue effect does not support combustion by bringing in air to fuel the fire.

Strawbale structures attract interest: sometimes that interest is not positive. Maintain vigilance during construction and ensure that loose straw and sawdust or other combustibles are not left in or around the structure at any time. Some trades use fire, such as oxy cutters and welders. Take special care to manage activities that are of high fire risk.

Vermin resistance

A completed wall has excellent resistance to vermin and the normal termite protection measures required in the BCA are generally sufficient. However, prevent infestation of mice during construction when the bales are relatively unprotected. Most strawbale construction is coated with plaster or render which is adequate to keep animals out, and if they do manage to get inside, densely packed straw makes it hard for them to navigate through the space. During construction, consider using traps and baits to ensure the finished structure is sound and vermin-free.



Photo: Paul Downton

Laying straw bale.

Durability and moisture resistance

Provided the straw is protected and not allowed to get waterlogged, strawbale buildings may have a lifetime of 100 years or more (Amazon Nails 2001).

The most detrimental factor affecting strawbale wall durability is long term or repeated exposure to water. After two or three weeks the fungi in bales produce enzymes that break down straw cellulose if the moisture content is above 20% by weight. The best way to prevent rot in a finished structure is to create a waterproof, breathable wall. The survival of historic strawbale structures in Nebraska and Alabama demonstrates their durability in climates with variable moisture and temperature.

Rice straw can make more durable bales than wheat straw because its high silica content improves rot resistance. Rice straw bales are slightly denser, and therefore heavier, but can otherwise be treated the same as straw bales.

Toxicity and breathability

The natural materials of strawbale construction are safe and biodegradable. Some people are allergic to the dust created during strawbale building. No toxic fumes are

released when straw burns and there is no toxic end to the strawbale construction cycle. Strawbale walls have good breathability, allowing air to slowly permeate the structure without moisture penetration. Earthen and some earth-lime renders may allow walls to 'breathe' better than cement render, especially renders that have a high cement to sand ratio.



Photo: Alex Makayev Photography

Straw bale in the bush. Strawbale walls provide good insulation against cold nights and hot days.

Environmental impacts

Straw is a waste product; it cannot be used for feed, like hay, and much of it is burned at the end of the season. Using straw for building reduces air pollution and stores carbon. The straw left over from building can be used as mulch so that, overall, there is minimal waste from using the material. (see *Waste minimisation*)

Straw bales contain a high level of renewable material. Straw has a six month growing cycle and is biodegradable. To be sustainable in the long term, straw would need to be grown in a way that maintained the soil quality and ecological integrity of its provenance.

Fertilisers and pesticides associated with industrial farming practices increase the environmental impact of straw bales, as does the use of baling twine made from petroleum products.

Straw bales are inherently low in embodied energy but most are produced by fossil-fuelled machinery, tied together by plastic twine and transported long distances – increasing their embodied energy. Strawbale walls often require concrete footings that add further to the energy cost of their construction.

Rice straw is a by-product of irrigation agriculture that changes the flow and water balance of catchments in Australia's major river systems. Wheat straw is less water-intensive.

Greenhouse gas emissions associated with straw bales are very low. One tonne of concrete requires more than 50 times the amount of energy in its manufacture than

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straw. Using straw for building stores carbon that would otherwise be released but the amount sequestered per dwelling is relatively small.

Straw's primary value is as an insulating material that enables houses to use less energy and have lower carbon dioxide emissions over the building's life.

Buildability, availability and cost

Strawbale construction rates highly for buildability because it can be very straightforward and is well suited to workshop and volunteer based building programs. Many volunteer and workshop-based bale raisings happen around Australia. The very active and informed network of straw balers constantly explores ways to improve and quantify bale building technology. In 2002 the non-profit association Ausbale was formed to develop and provide information on strawbale building techniques and performance.

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The general availability of straw bales is good, with many settled parts of Australia being within an hour or so of wheat or rice straw supplies. Straw bale is a low cost material but requires labour-intensive construction techniques. Projects that incorporate some volunteer or workshop-based construction can deliver cost savings. A large detached dwelling, with a high standard of fittings and finishes and built through conventional building contractual arrangements, costs about the same as if it were in double brick, but with a better cost-saving thermal performance.

Typical domestic construction

Construction process

Strawbale construction methods are all variations on ways of achieving good bale compression to minimise settlement and movement.

Bales must be well compacted and have a moisture content not exceeding 15% — below 10% is preferable. Straw bales must not get wet inside but wetting the sides should not be a problem. Straw does not wick water into itself like concrete. If rain is driven into the sides of bales, the natural movement of air or wind around the bales is able to dry them out, and this cycle of wetting and drying does not damage the bale.

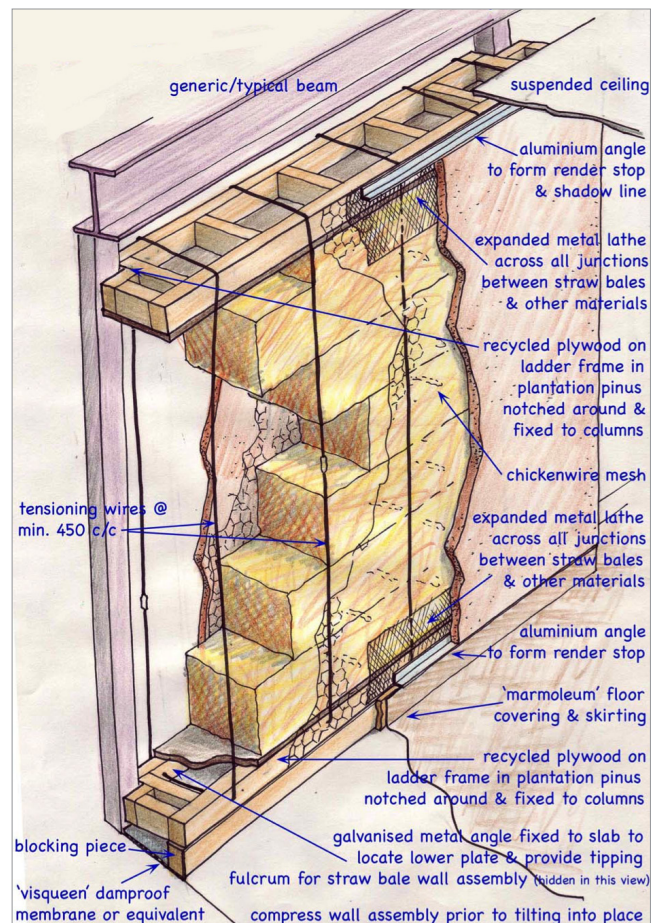
While footings are being prepared, work can proceed on other aspects of the building. Making frames and 'bucks' in advance of site works can speed up construction.

The vertical and horizontal stability of strawbale walls needs to be secured by tying bales to structural frames or pinning between bales and structural elements. There is growing consensus that the extensive use of reinforced steel bars and excessive pinning that characterised early strawbale construction is not necessary and modern practice is thus more material and resource efficient.

Bales are laid like giant bricks and, as with bricks, it is preferable to interlock the bales for a stronger and more stable wall, whether or not it is loadbearing.

Typical details

All structural design should be prepared by a competent person and may require preparation or checking by a qualified engineer. Qualified professionals, architects and designers have years of experience and access to intellectual property that can save house builders time and money as well as help ensure environmental performance.



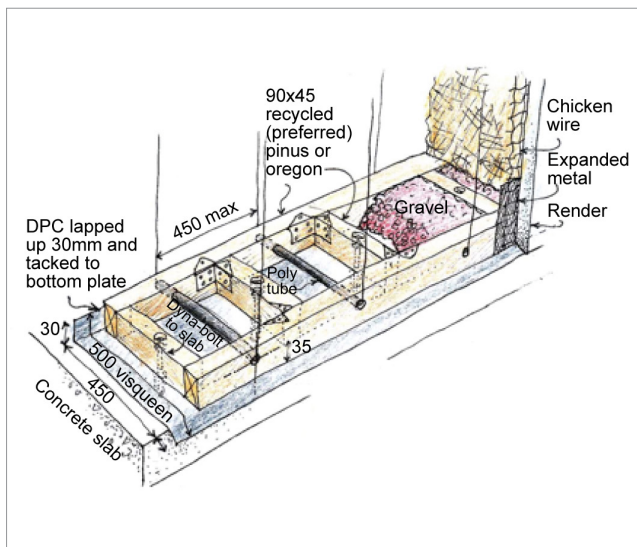
Source: Paul Downton

Strawbale wall panel — typical detail (simplified).

Footings

A strawbale wall requires footings with a similar load carrying capacity to that required for a masonry wall, although a straw wall is generally lighter (one mud brick weighs about the same as a straw bale). Footings are usually concrete strips or slabs to facilitate compliance with the BCA. The width of a footing under a nominal 500mm rendered strawbale wall is typically 450mm (subject to soil conditions); this results in approximately 2m³ of additional concrete for a 150m² home, adding a one-off emission of about 300kg of carbon dioxide (the average Australian household carbon footprint is a recurring 15 tonnes a year). (see *Embodied energy*)

There have been successful experiments with rubble trench and rubber tyre footings, and several strawbale buildings in Australia are built on piers, bearers and joists. As with mud bricks, the non-loadbearing option means a roof structure can be raised in advance of the walls to provide a protected environment for building works. (see *Mud brick*)



Source: Paul Downton
Bottom plate detail.

Loadbearing walls

The earliest strawbale buildings of over a century ago were loadbearing. Australian strawbale experts recommend a maximum wall height of 2.5m when using standard sized bales. Bales for loadbearing construction should ideally have tighter strings than normal.

Loadbearing strawbale construction employs relatively simple techniques that are forgiving to novice builders and yet have sufficient flexibility to allow the creation of



Another kind of base plate with a lower profile and no crosspieces. Note early placement of conduit to accept wiring.

design features such as curved walls. Its limitations are that openings for windows and doors should not exceed 50% of any given wall surface area and the maximum unbraced wall length is about 6m.

Bales should be laid like bricks in a 'running bond', i.e. butted end to end with joints that fall in the middle of the bale on the rows above and below. Corners should allow for at least a full bale return in each direction to give strength and stability. After the walls are laid they have to be pre-compressed before taking any structural loads. Of the variety of methods for achieving this, the most popular and practical method is gripling.

Gripling runs 2.5mm high tensile fencing wire vertically around the bale walls every 450mm. The wires are run through a bottom 'plate' (generally a ladder-frame timber structure secured to the footings) and over a top plate (similar, or as simple as a plank of wood). Grippers are proprietary soft metal clamps that hold the wires in tension. They were invented for fencing use and are available with the associated specialist tools through fencing suppliers.

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Photo: Paul Downton

Ladder frame being filled with pea gravel before frame and bale placement.

Early experiments in bale building used excessive vertical reinforcement to tie bales to footings and to each other. Good results with better economy in materials can be achieved without reinforced steel bars, and the vertical spiking of bales is largely unnecessary with the wire and gripping method.

Like giant bricks, straw bales need to be cut to fit into wall lengths, the fewer cuts the better. Design walls in strawbale length modules and calculate heights from working out strawbale dimensions and allowing for compression of 50–75mm per single storey height of bales.

Slicing a bale requires that it is first 'sewn' at the desired finished length; the original twine is then cut. The idea is to produce two short bales with the same compression as the original, held by new sets of twine. The cutting and trimming of bales can be done with hand tools, but the most popular and effective method is to use a chain saw with a blade length of at least 400mm.

Frames

Although it is possible to build strong and effective single storey strawbale structures, it is often easier to ensure BCA compliance and predictable engineering outcomes if the walls are constructed as infill elements between loadbearing frames. Non-loadbearing strawbale walls are similar to loadbearing but are generally more complex and have to be connected to the frames within which they sit. The frames allow more freedom in the design and placement of openings and a running bond is not as critical as it is with loadbearing walls. Pre-compression is still necessary to avoid problems with the bales settling over time.

Framework and posts can be constructed off site and the frame can allow a roof to be constructed in advance of the wall raising, providing shelter during the wall construction process.



A chain saw is the tool of choice for cutting and trimming straw bales.

Framed construction provides more design freedom for wall and opening placement — in the example below, a large two-storey bay structure with a partly cantilevered floor construction can be easily achieved that would not be possible in the same way in a loadbearing strawbale structure.



Photo: paul Downton

A typical frame. This two storey house uses only recycled and plantation timbers.



The use of frames makes almost any kind of opening possible in strawbale construction.

Joints and connections

Strawbale walls can be joined to almost any construction provided attention is paid to flashing details, preferably with the assistance of a competent architect or designer. When one material joins another, accommodate for differential movement and ensure there is no passage for moisture penetration.

The roof timbers or steel members can spring from the columns (particularly in the case of steel) or bear on wall plates. It is recommended that roofs have a considerable overhang to afford some protection to walls from driving rain. In more sheltered areas this requirement is less important, but take care to use a good quality render and waterproofing finish.



The middle plate and compression wires can be seen in this detail of a timber framed, three storey strawbale townhouse.

Fixings

It is possible to fix substantial loads to loadbearing and non-loadbearing strawbale walls by forming clamps made from planks of timber on either side of the bales, tied through the wall with high tensile wire and tensioned by gripling or twisting. Other methods for fixing such things as shelves and kitchen cupboards simply use elements connected to the loadbearing frame. With cement rendered interior skins that are a nominal minimum of 30mm thick, it is possible to hang pictures and other items off plugged holes in the thin masonry skin.

Openings

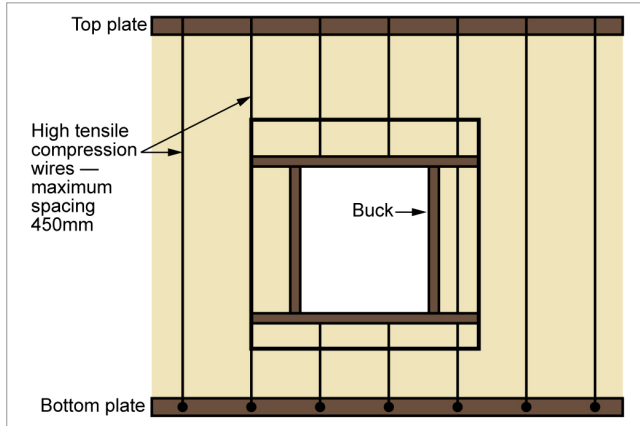
Windows, doors and other openings in strawbale walls generally have to be placed within a frame designed to withstand compression loads, unless the window or door frames are themselves strong enough to do the job. These frames are sometimes called 'bucks'. With bucks to resist distortion, almost any kind of window or door can be set into a straw wall, either 'floating' in the bales or tied to frames. Until the walls have undergone final compression, window and door frames and bucks must have adequate temporary cross-bracing.

It is best to set any frames with their faces flush to the outside face of a wall to improve weather protection. This also makes a deeper 'reveal' to the interior,

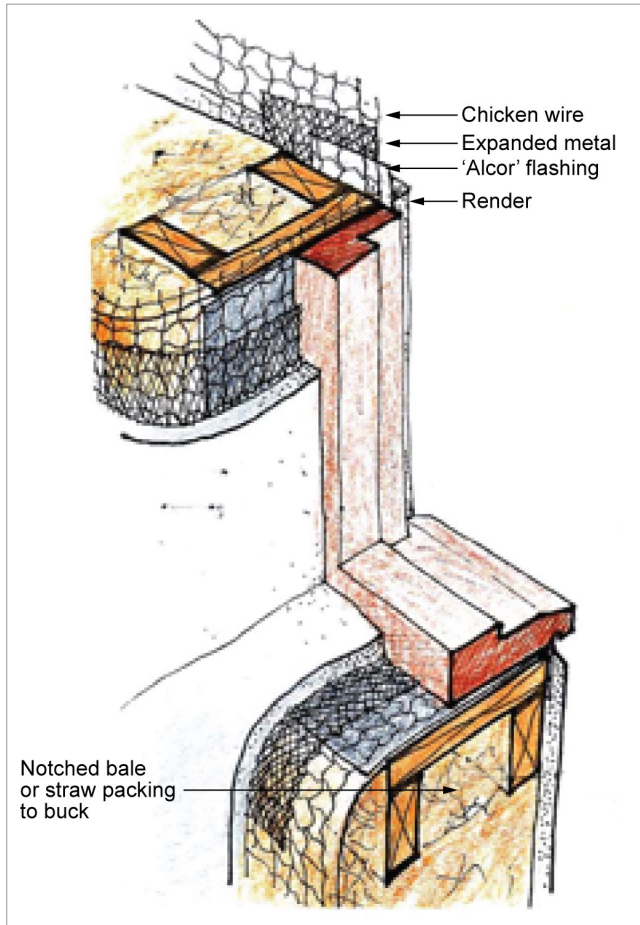
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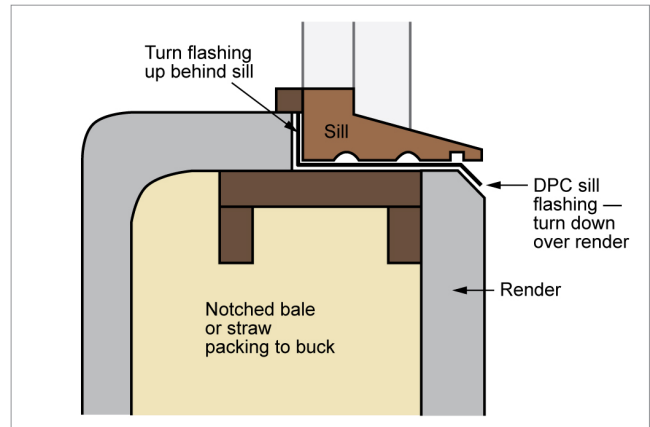
opening up possibilities for deep interior sills, window seats and angled or sculpted surrounds to the openings that can do much to improve overall daytime lighting qualities. (see *Lighting*)



Source: Paul Downton
Typical buck placement.



Source: Paul Downton
Typical window opening detail.



Source: Paul Downton
Sill detail.

Use standard flashing materials and methods to weatherproof window openings that are exposed to direct rainfall.

Niches can be cut into strawbale walls in almost any position or formation provided care is taken not to cut into the twine that binds the bales together.

Finishes

Strawbale walls need render to protect them from rain, fire and vermin. Wall claddings such as corrugated steel sheets cannot provide sufficient protection as they do not seal the surface of the bales.



Photo: Paul Downton

Window reveals can be shaped to soften the entry of light and reduce glare.

Before any render is applied, the walls must achieve final compression and licensed tradespeople must install electrical and plumbing conduits. Details of these installations depend on the design of the building. Avoid placing water pipes adjacent to unrendered bales to minimise potential problems with future leaks.

Three main kinds of render are used in Australian strawbale construction: cement, lime and sand; lime putty and sand; and earthen render (sometimes incorporating lime).

Final finishes on cement renders can range from clear acrylic-based water repellents to traditional coloured lime wash. Cement renders can be finished with a lime putty render topcoat. The three layers of render should be progressively weaker to reduce the potential for cracking caused by having too brittle an external layer. Lime putty renders resist cracking and hold coloured oxides well. Earth renders are gaining popularity as concerns about their effectiveness have been addressed. The main advantages of using earth renders are to do with minimising environmental impact and time spent in preparation and application. Earth renders significantly reduce the embodied energy of the building. (see *Mud brick*)



Photo: Paul Downton

Strawbale walls can be sharp, smooth and even sloping.

Seek advice from experienced strawbale builders wherever possible.

Render can be applied directly to the face of a strawbale wall, particularly earth renders. Cement has a long life but does not bond well with straw and requires a supporting medium. A common method has been to

fix chicken wire to the wall surfaces to be rendered by sewing lighter gauge wire through the walls at 450mm spacing and by pinning it with staples made from medium gauge wire (2mm). A number of practitioners are moving away from the use of chicken wire and emphasise working the render into the bale surface instead. There are various ways of improving adhesion and reinforcing the render skins, including the use of fibreglass netting instead of chicken wire.

Curved corners, window and door returns, and all junctions between dissimilar materials are best dealt with by having expanded metal mesh as the substrate for any render.

An increasingly popular method of applying render employs a concrete pump or spray, as used to make swimming pools. Renders should not create non-breathing skins that prevent the movement of air and encourage mould, fungus and decomposition of the straw.



Photo: Alex Makayev Photography

The use of light colours in the finishes of this living room enhances the effect of natural timber.

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Things to watch out for

There are no formally established standards for strawbale building but, like any building material, the best performance comes from following acknowledged best practice.

- Build test walls before proceeding with the final construction.
- Keep bales dry during storage and construction.
- Try to eliminate vermin: straw attracts mice and it is not unusual to find mice in strawbale deliveries.
- Keep on-site storage times to a minimum.
- Cover otherwise unprotected walls with tarpaulins or plastic sheets (which should be kept ready for easy deployment).
- Ensure moisture content of straw bales is below 15%.
- Cover any exposed straw with render to keep out water and vermin.
- Continue render over the tops of walls to minimise the potential for drawing air through the wall in the event of fire (allowing it to smoulder).
- Pick up and bag all loose straw (for use as mulch) during construction to avoid creating a fire hazard.

Although it may not be ideal, if bales do get slightly wet they can often be dried out sufficiently to be usable. Strawbale walls are very resilient and in the event of damage they can be repaired. Wet bales can be taken out and replaced and even fire damage can be repaired under insurance.

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