Evaluation of sustainable materials for rainscreen claddings on straw bale houses

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Abstract

Straw bale construction is potentially an energy efficient building method. Straw bales have both very low embodied energy and excellent insulating properties [3][10]. With good solar access straw bale buildings can have low energy cost in use. In maritime climates however, where wind driven rain events are frequent, it is essential to keep rain off straw bale walls [1][9]. It is therefore generally recommended that large overhangs be used as a primary weather protection measure [2][11]. This has direct implications for solar access. A simple straw bale house layout is presented and modelled using the thermal simulation software SuNREL. The house is modelled with and without overhangs on all elevations, as well as with rainscreen cladding on all facades as an alternative means of weather protection. Results show the adverse effect of large overhangs on energy use. The embodied energy of the rainscreens is calculated as a portion of total energy. This paper presents a case for rainscreen cladding as an alternative means of weather protection for straw bale houses as a means of reducing both energy for heating requirements and embodied energy for straw bale buildings.

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Tables and Figures

1 Introduction

Over the last decade, straw bale houses have become more popular as a construction method in many parts of New Zealand [9]. Characterised by thick walls and deep window recesses, straw bale buildings can express unlimited architectural forms and can be found in inner city contemporary designs as readily as in rural settings [6]. This construction method has many advantages including:

- Uses materials with high insulating properties, with a thermal resistance up to $8m^2{}^\circ C/W$.
- Construction can be carried out by laypersons and in many cases can be built by the homeowners themselves.
- Low cost of materials, as straw is generally regarded as a waste material.
- Materials are abundant and readily available in most countries, and is thus seen as a sustainable form of construction [11].

Disadvantages of using straw bale construction include:

- Careful consideration of construction process is required to ensure water is kept off bales, as a moisture content of greater than 17% will result in the straw rotting.
- Lack of specific guidelines for contemporary designs or complex design details
- Lack of expertise of the construction method within local authorities

1.1 History

It was shortly after the introduction of baling machines in the 1850s that straw bales began to be considered a building material. The first significant use of bales as a building material occurred in the Sandhills of Nebraska. An abundance of wild grasses, combined with the lack of timber and good building soils, provided incentives to devise new building techniques using unconventional materials. Some of the first patents for straw bale walls date back to the 1880s in Indiana, USA. The oldest bale building on record is a school built in Scott's Bluff County in 1886 or '87 which was ultimately devoured by cattle [10].

Previously constructed in drier climates, straw bale houses are now being used in many parts of the world including maritime tropical climates. New Zealand, for example, has adopted the use of straw bale construction where weather conditions are prone to strong winds and heavy rain. Regions such as the Wairarapa, in the North Island and Marlborough, Nelson and Abel Tasman in the South Island are experiencing a growth in the use of straw bales as structural walls or fill for timber framed structures. Both regions are prone to periods of heavy rain accompanied by strong winds, making almost any structure susceptible to high levels of moisture.

1.2 The Problem

Straw bale construction can be extremely stable and last for hundreds of years, however, like many construction methods that use natural products for the building elements, straw bale houses are susceptible to rot if exposed to moisture. Bales exposed to excess moisture should not be used and the recommended maximum moisture content is <17% [1].

Current practice includes the use of large overhangs to keep rain off walls, however the amount of solar gains allowed through the windows is then compromised. If overhangs are minimised to allow solar access, the walls are then susceptible to overexposure to moisture such as wind driven rain.

1.3 Case Study: House in Wairarapa

While large overhangs are recommended, they are not always used in practice. Currently there are no standards for straw bale construction in New Zealand and builders rely on documented cases of previous work. Many tend to follow the original examples from Nebraska and build with hipped or gabled roofs with small eaves [1]. Figures 1 shows a house in the Wairarapa region where little or no overhangs have been used on an exposed façade of a modern straw bale building. The west face of the house began to show signs of water damage within a relatively short time. (Note the holes on the lower section of the wall drilled to test moisture content of the bales.) In this house, moisture content reached up to 30% in lower areas of the exposed face.

This house has recently been fitted with a rainscreen cladding to prevent further damage to the bales. In many cases, materials used for the rainscreen cladding are corrugated iron or fibre cement board (Harditex or similar product) and other materials, which are not considered sustainable, contradicting straw bale construction principles.

Figure 1: Plastered wall of straw bale house

1.4 Aim

The aim of this research is to find an alternative to large roof overhangs in the form of a sustainable solution for rainscreen claddings for straw bale construction. In doing so the aesthetic quality of straw bale housing may also be enhanced by providing solutions which allows more flexibility of design, even in harsh climates. A successful solution will thus increase energy savings, made possible by increasing solar access to the building, while at the same time, providing design alternatives for the appearance of the building.

1.5 Hypothesis

To achieve this aim, this research will attempt to prove the following hypothesis:

A rainscreen cladding can be created from sustainable materials to prevent wind driven rain ingress while allowing maximum solar access into the building.

1.6 Conclusion

Investigation of this hypothesis begins with a background study of the problems associated with straw bales and excess moisture in Chapter 2. Existing solutions for rainscreen claddings for conventional construction are explored to determine whether these principles can be successfully transferred to straw bale buildings. The research method in Chapter 3 will outline thermal simulations used to determine the energy in use of a straw bale building. Chapter 4 will discuss the embodied energy of the rainscreen claddings evaluated. Finally, an analysis of the research will be discussed in Chapter 5 along with any acceptable solutions found. Chapter 6 reviews the research method and presents conclusions to the study.

2 Background

This chapter will attempt to address the principles of water penetration in regards to straw bale construction. Current solutions for the protection of straw bale walls are discussed along with the introduction of rainscreen principles for conventional construction.

2.1 Moisture and straw bale construction

It has been shown that straw bale buildings can survive in humid climates, but less is known about the interaction of the bales and the humid air. It is obvious that bales must be protected from direct exposure to moisture. Damage to the bales can result in problems ranging from development of mould and mildew to disintegration of the bales [11].

Studies in Canada checked humidity levels of the walls of a straw bale house at 3 year intervals. Despite fluctuations in humidity levels of the environment around the walls, levels remained low in the bale walls. These studies also showed that the moisture content of the bales remained low enough, at 13%, to still have good thermal resistance [11]. The results of these studies show the importance of allowing the walls to breathe and release vapour when air is humid.

The most common problem associated with straw bale construction in New Zealand is excess moisture on the face of the walls. Driving rain is one of the more problematic conditions from which a straw bale house must be protected [1]. The "do it yourself" nature of New Zealand homeowners has translated into experimental design methods being tested in many locations that feature exposed sites susceptible to wind driven rain (Figure 2). With the desire to keep building costs low, a natural progression has lead to verandas and large overhangs being dispensed with [1] and consequently, more buildings experiencing water damage due to excess moisture.

Figure 2: Modern application of straw/earth house near Nelson. Note exposed façade on upper level.

Other areas susceptible to moisture damage are the top and bottom of the walls. Even a minimal overhang can help prevent water reaching the join at the roof and wall, reducing risk of moisture damage. Recommended practice includes a barrier, or damp proof membrane, placed between the bottom of the bales and the footing to prevent moisture from seeping into the bales [11] (Figure 3).

Figure 3: Footing of brick for straw bales.
Note layer of bitumen to prevent moisture seeping into the bales.

2.2 Current solutions for moisture protection

To prevent damage due to excess moisture, several methods are recommended.

2.2.1 Plaster renders

To prevent deterioration of the bales, renderings are used to coat the straw on the interior and exterior walls [8] (Figure 4). In an attempt to form an impermeable render, extremely rich cement mixes or renders with very fine aggregate are applied which are subject to excessive shrinkage and eventually form cracks. Because the renders are mixed with water and therefore are subject to shrinking, cracks are a natural feature of straw bale construction. In addition, compression of the bales due to self and imposed loads can result in deformation and cracking of the render. Once the render has been compromised, water penetration increases leading to rotting of the bales [1].

Figure 4: Plaster being applied to exterior wall in Abel Tasman region.
Note the minimal overhang on this exposed wall.

2.2.2 *Vapour barriers*

Splashes and wind driven rain are common and a moisture barrier under the stucco on the lower third of the wall is recommended in some drier climates, such as the Southwest of the United States. There are differing opinions on the use of vapour barriers on straw bale walls. In their book *The Straw Bale House,* Bill and Athena Steen advise against the practice and explain, "It is thought by many that the use of any type of building paper, vapour barrier, or other non-breathing material is not a good practice for bale walls [11]." As vapour flows from warm to cold, and walls need the ability to dry, an impermeable barrier or coating can be detrimental. The Steens recommend, "making the finish on the warmer side of the wall semi-permeable so that it slows the flow of vapour in the wall, while the finish on the cooler side of the wall should be permeable so that vapour can flow through." A bale wall that is able to release water vapour to the exterior may be the best insurance against potential problems with moisture [11].

2.2.3 *Overhangs vs. Solar Gains*

An additional design feature includes large overhangs to protect the external walls (Figure 5). Large verandas, at least 1/3 the height of the wall, are recommended to ensure even heavy, wind driven rains are prevented from reaching the walls [1]. However, due to the large overhangs, solar access into the building is compromised, which negates some of the advantages of a solar designed house. By finding a solution that allows minimal overhangs, underlying solar design principles inherent in straw bale houses are not sacrificed.

Figure 5: Large veranda included on exposed wall.
Note small overhangs used on wall in foreground.

2.3 *Water penetration through joints*

When considering the problem of excess moisture, how water enters the wall should be considered. Water penetration between joints can occur through five different processes:

- *Kinetic energy*
  Drives rain through joint by force of wind.
- *Surface tension*
  Cause water to adhere to and run along the underside of horizontal surfaces.
- *Gravity*
  Pulls water down and across surfaces.
- *Capillary*
  Draws water into narrow passages which are bounded by wet surfaces.
- *Air pressure differentials*
  Water is drawn through small gaps due to cavity pressures which are less than external pressures.

Capillary action and pressure differentials are the main sources of water penetration to straw bale walls through cracks in the exterior render [1].

2.3.1 Pressure differentials

Wherever wind strikes a building surface, an air pressure differential is created between the higher pressure of the exterior and the interior surfaces. Any water present in a joint in the wall can be carried into the building by the force of moving air. Sealants are an option however any imperfections or deteriorations would allow a stream of moving air to bring water into the building [4]. In the case of a straw bale wall, sealants are impractical due to the organic nature of the render and the resulting number and size of cracks that can occur. It may be easier to minimise the amount of water reaching the building or to ensure that any water that does get in can find an exit to the exterior quickly, avoiding leaks altogether [12].

2.4 **Rainscreen principles**

To reduce the incidence of water penetration through joints in the wall, a "screen" can be attached to the wall to stop any wind driven rain reaching the wall. Rainscreen walls are generally divided into two categories:

2.4.1 Pressure-equalised wall

A pressure-equalised wall system has an airtight inner section and a chamber between inner and outer wall sections [13]. Pressure-equalised walls use mechanical means to keep out water rather than sealants and gaskets. Usually the wall is divided into sections so that each section is equalised and independent of the whole wall, which ensures that no pressure differentials exist to allow siphoning of water around the envelope [7]. Due to the non-uniform surface of the straw bale wall and the fact that the plaster cracks thus reducing airtightness, this type of rainscreen wall is not suitable.

2.4.2 Drained cavity wall

The term "rain screen" is often loosely used to describe a wall system that has an outer water barrier and inner vapour barrier but which is not actually pressure-equalized [13]. This system controls only some of the forces acting to drive moisture into a building by supplying a cavity to drain any water that penetrates the exterior surface. This ventilated cavity would encourage vapour release from within the bales [13].

This back-ventilated wall is more likely to suit the type of construction techniques used for straw bale houses. A cavity is created behind the outer leaf to allow drainage and to promote the ventilation of any remaining moisture on the back of the outer wall. In this type of rainscreen construction, detailing of the joint is critical to ensure minimal moisture penetration occurs.[7]

2.5 Environmental benefits of straw bale

Straw bale houses tend to be favoured by homeowners with initiatives to reduce their energy usage and to use materials that make less impact on the environment than conventional construction. Straw has a low environmental impact. However the low density of the fibres means that the environmental impact of haulage is higher on average than other materials. This impact can be minimised if straw is taken from a local source [4]. Straw can be grown in a completely sustainable production system in less than a year. Straw rates highly as an eco-friendly choice as it bypasses much of the energy and waste required for conventional building products [11].

Calculations of embodied energy performed on traditional straw bale construction as compared to timber framed walls with equivalent fibreglass, show that straw bale walls are at least thirty times less energy intensive, minimising the financial and environmental impact of construction. There are also many examples of the durability of straw bale houses, even in tornado zones of the USA [11].

2.6 Recent Studies

2.6.1 Water penetration of straw bale walls

A recent New Zealand study by faculty at Victoria University of Wellington [1] indicates that water entry via exposed plaster walls is the main source of moisture damage to straw bale walls. This study considers buildings with little or no overhangs, which rely entirely on the plaster system to keep the bales dry, and the ability of such walls to resist water penetration. Significant findings of this research include [1]:

- Walls with cracks in the plaster reached a moisture content of approximately 16% (just below recommended levels) after only 10 minutes of exposure to water with no wind pressure
- After applying water for 145 minutes the high of 30% moisture content had been reached nearest the wet plaster, while the centre of the bale was approximately 29%

These findings reiterate the need for extra protection from wind driven rain, which can occur in many parts of New Zealand. If overhangs are reduced and the plaster is fully exposed to harsh weather conditions, the need for improved primary protection is even more crucial.

2.6.2 Sustainable rainscreen claddings

A recent study in Wales shows that common timber rainscreen technology popular in mainland Europe can be successfully transferred to suit UK conditions [7]. It is possible that these solutions could also be used in New Zealand. These timber rainscreen solutions include:

- vertical timber slats
- horizontal timber slats with plywood backing
- large planks of horizontal green oak boards attached to timber battens

Significant findings from this study are:

- Relatively large open joint cladding allows timber to dry out quickly
- Fixings on large planks needed to be carefully positioned and need to cater to movement adding to overall costs of construction
- Climatic differences may demand tighter control of joints but simpler, less expensive fixing methods are feasible.

2.7 Background conclusion

Straw bale walls can withstand the humid conditions common in New Zealand if the walls are allowed to breathe and are protected from direct moisture exposure. In many cases overhangs are minimal or are not used at all in an attempt to reduce costs. Large overhangs are recommended to ensure protection, however this reduces the amount of solar access to the interior.

To reduce the size of overhangs on a straw bale building, an investigation of rainscreen claddings is required. A rainscreen that utilises a cavity to drain any water that penetrates the screen is most suitable for application to straw bale walls due to the organic nature of the construction and the inability to provide an airtight seal characteristic of other rainscreen claddings. Due to the nature of straw bale construction, sustainable materials should be sought and evaluated in regards to environmental impact. Timber rainscreen claddings have already been proven successful in the UK, however other materials are included in the analysis in Chapter 4.

3 Research Method Part 1: Thermal simulations

To evaluate the environmental impact of a building, both embodied energy and operating energy requirements over the lifetime of a building should be considered. The choice of materials used will influence both components of total energy use [9].

The research method analyses the energy use of a straw bale house using a thermal simulation programme. The simulation will address only energy consumed for heating, due to the ability to address cooling loads in New Zealand houses through natural ventilation. The estimated heating energy will then be combined with calculations of embodied energy of the materials used to determine the total energy use of the straw bale house. Comparisons will include a house with and without overhangs as well as several rainscreen cladding alternatives.

This chapter outlines the thermal simulation programme used and the parameters of the model.

3.1 SuNREL Thermal simulation

To determine the extent of potential energy savings, a thermal simulator for domestic dwellings is used to simulate a straw bale house modelled with and without overhangs. The SuNREL model includes various properties about the dwelling including:

- dimensions of building elements
- thermal properties of the building materials
- orientation of the building on the site
- heat gains due to occupants and appliances
- schedules of heating and ventilation.

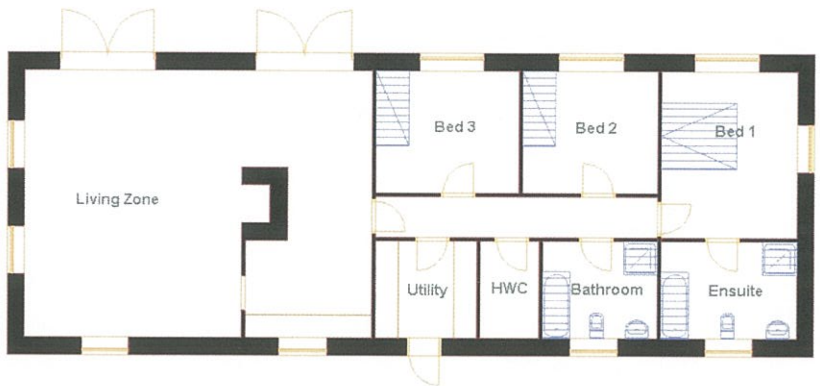
Once a "base" house is modelled and the programme produces results, the house is altered, and energy estimates recorded for each alternative. The alterations include removing the overhangs and replacing the claddings to include various types of rainscreens.

Using SuNREL, the base straw bale house was modelled. The house has the following characteristics (refer to Figure 6 for plan). The complete list of parameters used to build the model is located in Appendix A.

- Timber frame with straw bale infill with R value of $8m^2°C/W$
- 1 storey measuring approximately $150m^2$
- Cathedral ceiling in living area and ceiling cavity above bedroom areas.
- 100mm concrete floor with tiles on 100mm polystyrene
- plaster render on both interior and exterior walls
- R 3.9 value in ceiling and living room roof using fibreglass batts
- Corrugated galvanised steel on timber roof structure

- 2.1m overhangs on all sides (total of 120m^2 of overhangs)
- All windows single glazing
- Weather file for Wellington used for all runs

Figure 6: Plan of simulated straw bale house



It is noted that the house was modelled using building materials typical of current construction practice in New Zealand and not all materials are considered sustainable (roof, floors, etc).

3.2 *Results of SuNREL simulation*

Firstly, simulations of the base straw bale house were run using SuNREL to determine annual energy use attributed to heating. Heating operated to maintain 21°C in the living areas and 18°C in the bedroom areas from 7am-11pm. Simulations were also run with continuous heating operation (24hrs). Secondly, simulations with no heating were carried out to establish temperatures and comfort levels in the main living zones.

3.2.1 Energy Use

The base model was developed with and without overhangs and energy calculated with a heating schedule in place. When overhangs are not included on the straw bale house, SuNREL estimates a 15% savings when the house is heated intermittently and 17% savings when heated continuously (Figure 7).

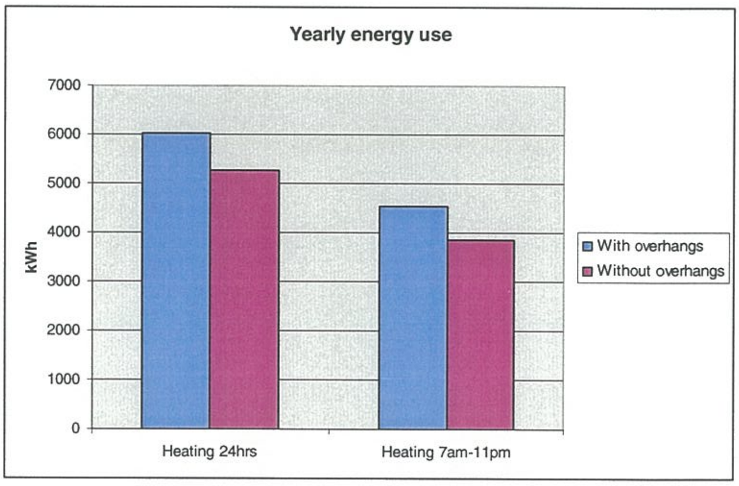


Figure 7: Comparison of annual energy use

3.2.2 Temperatures and comfort levels

The house was also simulated with no heating in the building to evaluate the performance of the building's envelope in relation to the outside conditions. The natural ventilation rate used for cooling was 5 air changes per hour when temperatures inside the house reached over 25°C.

Figure 8 graphs the results of the temperatures in the living zone. Overheating occurs when temperatures inside the house reach above 25°C during the simulation. In the straw bale house with overhangs, overheating occurred 2% of the year while the comfort zone was maintained 50% of the year and underheating occurred 48% of the year. When overhangs are removed, the incidence of overheating increases by only 1%, while underheating decreases by 10% thus increasing the amount of time the house remains in the comfort zone. This also confirms the decrease in energy consumption demonstrated in section 3.2.1.

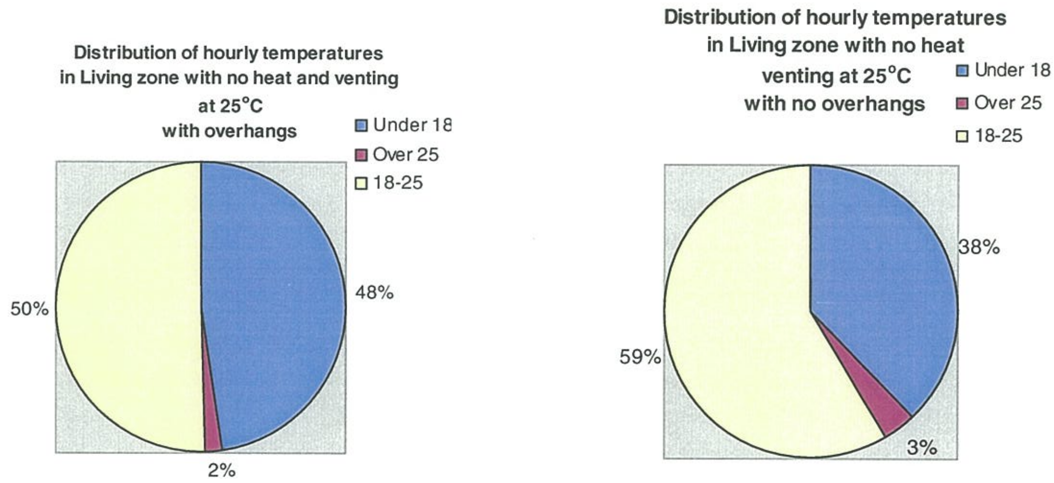


Figure 8: Results of free-floating temperature test

Using SuNREL, the solar radiation gained through the windows can also be determined. The building with overhangs gains 30GJ of solar radiation, while removing the overhangs results in 43GJ of solar radiation gained. The results show that without overhangs, the building gains more solar energy and uses less energy to heat the house.

3.3 Conclusion of thermal simulations

Results of the SuNREL simulation demonstrate that removing the overhangs has improved the thermal performance of the house. Comfortable temperatures are also maintained better when overhangs are removed. If overhangs are to minimised or removed, additional materials, in the form of a rainscreen cladding, will be required to maintain protection of the walls from the weather. The added materials will increase the environmental impact of a type of construction which traditionally seeks to keep impact environmental impact of a type of construction which traditionally seeks to keep impact at a minimum. The consideration of the investment in embodied energy of the added materials is considered in Chapter 4.

4 Research Method Part 2: Analysis of Embodied Energy

While the materials will impact the energy in use of a building, the embodied energy of the materials will determine a large portion of total energy used in the lifetime of the building [9]. Materials considered as potential rainscreen cladding will first be discussed and any existing examples given. The alternatives for rainscreen claddings will then be evaluated in regards to embodied energy. These figures will be added to energy consumption results of thermal simulations in Chapter 3.

4.1 Choosing materials for rainscreen cladding

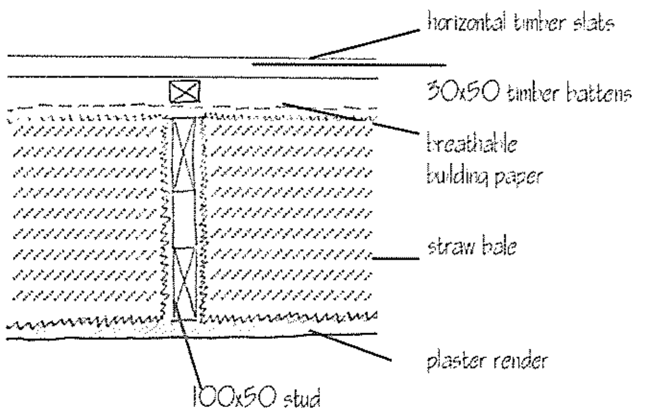
Rainscreens do not need hi-tech materials to be effective. Beautifully woven, vertically thatched screens of Juniper branches connected to timber walls are have been used by builders in Norway for centuries. In Japan, bamboo or open-jointed stone screens are used on traditional buildings, often with plants growing on them. Timber slats are a popular choice in New Zealand [12].

Ecologically responsive cladding solutions include various types of multi-layered, ventilated facades [12] and various materials could be considered as a rainscreen application. Most of these solutions require the use of a breathable building paper to keep moisture off the bales while still allowing the bales to dry out if exposed to extraneous moisture. Any water that does cross the gap should come in contact with a micro-porous membrane that deflects the water down and away through vents at the base of the cladding [7]. Therefore, building paper is included in the calculation of embodied energy except where bales are rendered with plaster.

4.1.1 Timber slatted rainscreen

This option is a natural choice due to the abundance of timber used for conventional construction in New Zealand. Figures 9 and 10 show details of this construction.

Figure 9: Rainscreen cladding of horizontal timber slats (slats to have 5-10mm gap between each)



Timber is one of the most popular cladding materials in New Zealand. It is a natural choice for rainscreen cladding in New Zealand due to its abundance in this country.

The slats can be used vertically or horizontally, however horizontal sections should be bevelled to throw off water [7].

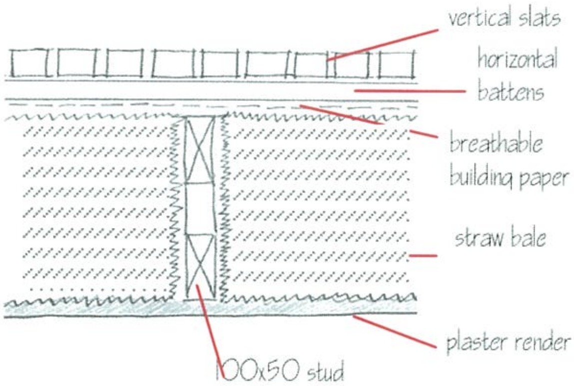


Figure 10: Rainscreen cladding of vertical timber slats (slats to have 5-10mm gap between each)

Timber is a sustainable material for many reasons. Forster, in a recent study of sustainable rainscreen claddings, lists some of the advantages of timber as a sustainable material:

- It is a renewable resource and can provide an infinite supply.
- The potential for recycling or energy production or reuse is high.
- It is waste efficient, biodegradable and non-toxic.
- As a raw material it can be converted into building products with little energy cost.

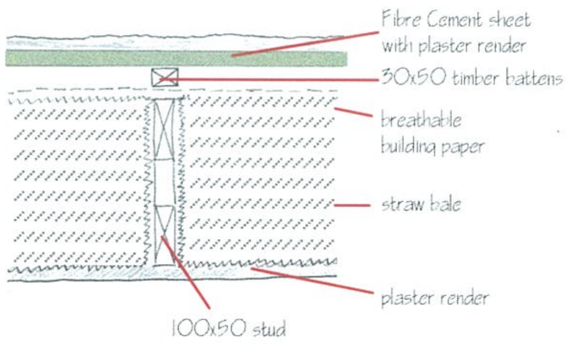
However, it can be argued that timber is not sustainable if its use results in deforestation and the loss of ecological bio-diversity. It is argued that timber is not sustainable depending on what happens to timber after sawing. Glues, treatments and finishes result in its potential to be non-waste efficient, non-biodegradable and a toxic material. The trade off is the ability of the treatment to increase the lifespan of timber. Forster, discussing sustainability in the UK claims, "These issues contribute to the argument for the use of local indigenous broadleaved timber in a green state" [7].

4.1.2 Fibrous Cement Sheet (Harditex) with plaster coating

A recent straw bale construction at Makara, Wellington has used fibre cement sheet as a rainscreen cladding on timber battens. A detail of this construction is shown in Figures 11 and 12. The timber battens are attached to the stud framing on top of breathable building paper.

Figure 11: Door detail of construction using fibre cement sheet

Figure 12: Fibre cement sheet rainscreen cladding



This product is very energy intensive due to the materials used and the processes required for binding the sheets. The product also uses toxic materials resulting in waste products which can result in environmental hazards.

4.1.3 Corrugated iron

Some straw bale houses in New Zealand utilise corrugated steel on timber battens as a rainscreen. A detail of this construction is shown in Figure 13.

Figure 13: Detail of corrugated iron rainscreen

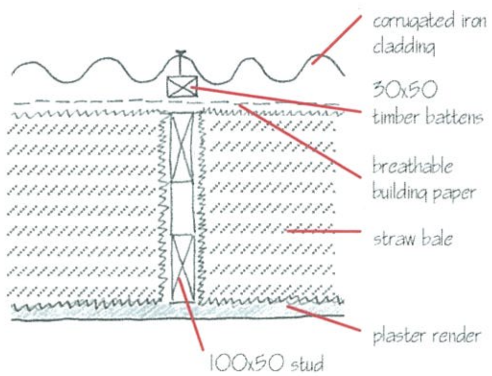


Figure 14: Corrugated steel and polycarbonate cladding on London office

This type of rainscreen can be seen on an Architect's office in urban London (Figure 14). It is constructed using profiled galvanized steel and transparent polycarbonate cladding with a 100mm air gap between a fire-resistant building paper on the bales outside face [6]. This construction is used on only the North face of the building where the bales are primarily used as infill for a timber truss system, however the architect notes that the use of the bales as a structural system was also possible [6].

Steel is highly energy intensive and is not corrosion-resistant. To protect steel from rusting it is usually treated with paint or other coatings, which will also affect the cladding's environmental impact. This rainscreen option uses galvanised steel, which undergoes the processes of zinc coating. This process uses chromate solutions and is highly toxic. The coating process itself is also very energy intensive, however this extends the life of the material [4].

4.1.4 Stone (Gabion wall)

Depending on structural applications, a narrow gabion wall could also be used as a rainscreen cladding. A detail of this alternative is shown in Figure 15. Architects Herzog & De Meuron have used this application (however with a larger cavity) in California at the Dominus Winery (Figure 16).

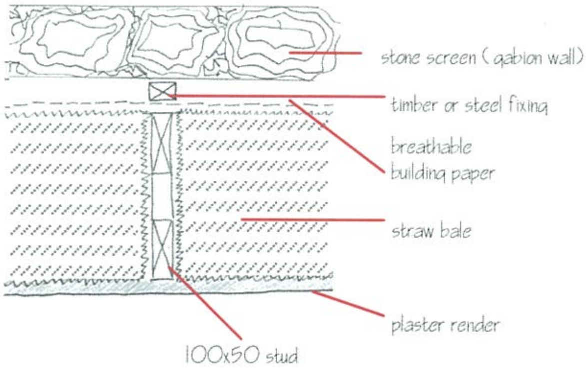


Figure 15: Detail of stone rainscreen

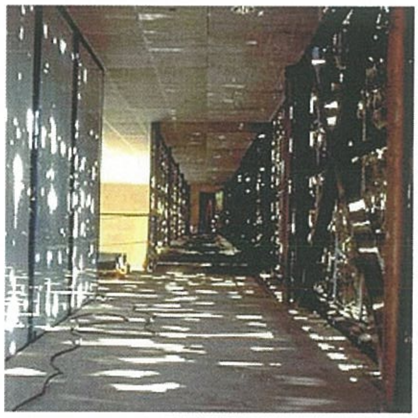


Figure 16: Inside face of stone wall at Dominus Winery

Although abundant, stone is non-renewable and the quarrying process is disruptive to natural environments. However, natural stone is useful for its strength and durability. The greatest environmental impact is due to transport costs in hauling stone and therefore local stone should be used where possible [4]. Although no example has been found by the author to date, recycled concrete could be considered in this application. Further study would be required to determine structural and aesthetic qualities of this solution.

4.2 Quantifying the embodied energy of the alternatives

Several materials can be considered for rainscreen claddings but the resulting solution should ultimately have a low embodied energy. The dimensions of the walls only in the base straw bale house were used to calculate the embodied energy of several materials.

All calculations use the same amount of straw in the walls. As timber is common to all of the alternatives in the form of framing and battens, this was not included in the calculations. Inherently the straw bale house is low in embodied energy due to the bulk of the walls being constructed of straw with an embodied energy of 30.5MJ/m^3. The embodied energy of the exterior plaster render will vary depending on the type of mix used. For this study, figures for cement mortar were used in the calculations for render. The air gap for some rainscreen alternatives, such as Harditex, were constructed as a void with a thermal resistance due to the enclosed air gap, where the alternative using timber slats was given minimal thermal properties for the vented cavity, due to the increased air flow.

Only the embodied energy of the walls was calculated for the analysis, as it is assumed that other building components, such as floors and roofs, will be identical for each alternative considered.

The embodied energy of the various rainscreen claddings is outlined in Table 1.

Table 1: Embodied energy (cladding, straw, and building paper) calculated for 150m² straw bale house. Coefficients sourced from CBPR, Victoria University of Wellington [3][15].

Material	Thickness	Embodied Energy	Per thickness	Total embodied energy for 150m² house
	m	MJ/m³	MJ/m²	MJ
Straw Bale			15.2	**2280**
Building paper			4.97	**745.5**
Cement mortar plaster	0.02	3200	64	**9600**
Galvanised Steel	0.002	273180	546.36	**81954**
Fibre Cement sheet	0.012	13550	162.6	**24390**
Hardwood Kiln dried	0.03	1550	46.5	**6975**
Hardwood Air dried	0.03	388	11.64	**1746**
Softwood Kiln dried	0.03	880	26.4	**3960**
Softwood Air dried	0.03	165	4.95	**742.5**
Plywood	0.019	5720	108.68	**16302**
Rock (gabion wall)	0.3	63	18.9	**2835**

Material	Thickness	Embodied Energy	Per thickness	Total embodied energy for 120m² overhangs
Galvanised Steel	0.002	273180	546.36	**65563**

4.3 Calculating total energy use of the alternatives

The alternatives are analysed based on an expected lifetime for the house of 50 years. The annual energy use for heating for the lifetime of the building will be added to the total embodied energy investment to determine the total energy used by the building. The energy in use is based on a heating regime from 7am to 11pm daily.

It is noted that other end users of energy should also be considered in the environmental impact of the building, such as lighting, appliances and water. However, due to the scope

It is noted that other end users of energy should also be considered in the environmental impact of the building, such as lighting, appliances and water. However, due to the scope of this research and assuming that all solutions will use the same amount of energy in these areas, energy use for these components will not be included in the calculations.

Table 2 summarises the results of the calculations:

Table 2: Calculation of Total energy use (all values expressed in MJ)

	MJ used for heating	for 50 years	plus embodied energy of straw	plus building paper	plus cladding (or render)	Total walls	Overhangs	Total energy use
Base	16330	816500	2280	0	9600	828380	65563	893943
Galvanised Steel	12512	625600	2280	746	81954	710580	0	710580
Without overhangs	13906	695300	2280	0	9600	707180	0	707180
Harditex with plaster coating	13117	655850	2280	746	33990	692866	0	692866
19mm Plywood	12431	621550	2280	746	16302	640878	0	640878
Hardwood Kiln dried	12435	621750	2280	746	6975	631751	0	631751
Softwood Kiln dried	12435	621750	2280	746	3960	628736	0	628736
Virgin rock (gabion wall)	12431	621550	2280	746	2835	627411	0	627411
Hardwood Air dried	12435	621750	2280	746	1746	626522	0	626522
Softwood Air dried	12435	621750	2280	746	743	625519	0	625519

Table 3 shows that the removal of the overhangs from the base house results in 21% reduction of total energy compared to the same house with no overhangs. The base building uses 44% more energy than the air dried timber solution and 25% more energy than the solution which uses galvanised steel. However the steel option uses more energy than the base house without overhangs.

It noted that the total energy use does not include the embodied energy from other building materials used in a typical straw bale construction. Materials for components such as concrete floors, steel roofing, and fibreglass insulation in ceiling cavities will increase the embodied energy significantly. While the total embodied energy in a New Zealand house is relatively large compared to its likely 50-year heating energy use [9], the use of straw bale construction can reduce that proportion significantly. Table 3 considers the relationship of embodied energy in relation to total energy use in the context of this research.

Table 3: Percentage of embodied energy to total energy costs

	Embodied energy of materials	Total energy use	Percentage of embodied energy to total energy use
Base	11880	893943	1.33%
Galvanised Steel	84980	710580	11.96%
Without overhangs	11880	707180	1.68%
Harditex with plaster coating	37016	692866	5.34%
19mm Plywood	19328	640878	3.02%
Hardwood Kiln dried	10001	631751	1.58%
Softwood Kiln dried	6986	628736	1.11%
Virgin rock (gabion wall)	5861	627411	0.93%
Hardwood Air dried	4772	626522	0.76%
Softwood Air dried	3769	625519	0.60%

If embodied energy of the cladding, building paper and straw are considered, the galvanised steel option has approximately 12% of its total energy use made up of embodied energy. The next highest proportion is the Harditex cladding, with 5% of its total energy being made up of embodied energy. If the embodied energy of all building components is considered, this proportion is expected to increase, however the significant difference of proportions between the rainscreen alternatives will remain.

4.4 Conclusion of energy use analysis

It is estimated that the current practice of using large overhangs to protect straw bale walls uses up to 44% more embodied energy compared to sustainable rainscreen cladding options. The common practice in New Zealand to use little or no overhangs on a typical rendered straw bale wall uses 21% less energy than those with large overhangs. This is due to the increase in solar energy stored in the building and the reduction of materials used which have high embodied energy. With the exception of the steel and fibre cement sheet, the rainscreen claddings uses less energy than those that use only render for protection of the walls, with or without overhangs.

These solutions to sustainable rainscreen cladding have been evaluated on their total energy use, including the embodied energy of the materials. It is necessary to discuss the suitability of each alternative for their practicality and durability. Issues such as product life, ease of construction and detailing are discussed in Chapter 5.

5 Discussion

Structural performance and durability of a rainscreen cladding will also affect the total energy use during the lifetime of the building. As straw bale construction is a method used by laypersons, it is also necessary to discuss the rainscreen cladding options in this context. This chapter discusses each option and its suitability to the New Zealand building environment.

5.1 The alternatives

5.1.1 Galvanised steel (Corrugated iron)

Although proven to be an icon of design for homes in New Zealand, this solution is high in embodied energy. Replacement of the galvanised sheets is likely to occur within the 50 years of the building's life, increasing the investment in embodied energy. Steel also uses finishes, such as paint which, although they extend the life of the steel, are harmful to the environment.

This option is attractive due to the ease of detailing, as it is a popular cladding for conventional construction. Sheets are available in standard sizes, come in a variety of colours, and can be easily modified to requirements. This option is easily built by the homeowner/builder.

5.1.2 Harditex

Although the second highest investment of embodied energy of those evaluated, fibre cement sheet may be more attractive initially as the construction method is very similar to conventional timber framing. Cement fibre sheets also come in standard sizes and are easily modified to requirements. Detailing of wall openings can be adapted from conventional methods using fibre cement board.

However, like many houses built using this cladding, the sheets are usually plastered, which increases the amount of labour required for this solution. The application of the plaster render is a procedure usually carried out by professionals to ensure a weathertight cladding system is achieved and not easily adapted for homeowners applying this cladding themselves. The added expense is not conducive to the low cost usually associated with straw bale buildings.

5.1.3 Plywood

The use of plywood has become a popular cladding in recent years for conventional timber framed construction. Like galvanised steel and fibre cement sheet, the adaptation of this product to include rainscreen cladding on straw bale houses would require little variance of wall opening details from conventional solutions. This product also comes in standard sheet sizes, which are easily modified to requirements.

The highest user of embodied energy from the timber options, plywood has the potential to create an aesthetic feature of the cladding. However, the plywood sheets may need extra detailing to prevent edges from de-laminating and will also need treatment, such as stains and varnishes to prevent premature deterioration, questioning its potential as a sustainable material.

5.1.4 Timber slats

Although the lowest user of embodied energy, the air dried timber is less popular as a construction material in New Zealand, while kiln dried timber is most abundant. Timber slats can be easily modified and complex fixings or detailing for large movement is not required due to the small dimensions of members [7].

Hardwoods are not considered sustainable yet they have better durability without requiring special finishes. These materials are likely to be prohibitively expensive for rainscreen applications in this context. Softwood, such as pinus radiata, is more abundant in New Zealand but treatment will have to be considered to ensure minimal environmental impact.

5.1.5 Gabion wall

This solution is naturally low in embodied energy and is an option that can ultimately be built by the homeowner/builder. The features are also conducive to the natural materials usually favoured by straw bale builders. The gabion wall is usually much deeper than the 300mm used in this example and the structural aspects would have to be researched further to determine viability. Issues with this rainscreen option will include how to detail wall openings to resolve the wide reveals while creating an aesthetic feature. There exists the potential for a unique design solution using this element if details and overall form can be considered sympathetically.

5.2 Detailing

The fixings of the rainscreen to the bale walls need not be expensive or complex [7]. Each solution will have considered fixings, especially if the screen is to be built by the homeowners themselves.

The rainscreen solutions offered in this report all utilise building paper between the air gap and the bale, allowing any water getting through the gap to be transferred out of the cavity at the base. This detail should be considered closely to ensure vapour release from bales is not inhibited allowing water to condense on the straw, leading to mould formation and eventually rotting in the bales.

5.2.1 Other sources of water penetration

Water penetration via vertical surfaces, such as walls, are only one aspect of the moisture problem in New Zealand straw bale homes. If rainscreen claddings are to be adapted for use, to negate the need for large overhangs or to reduce the incidence of moisture damage due to wind driven rain, detailing of wall openings and roof to wall junctions will need to adapt as well. Some common moisture problems in straw bale walls are [1]:

- Poor window sill detailing
- Poor detailing or design causing rising damp reaching base of walls
- Roof leaks and poor flashing details allow entry for water
- Using low permeability paints such as acrylic or oil based which cause moisture build up in walls
- Items adjacent to straw collecting condensation and wetting the bales

These problems highlight where water penetration can occur even with a successful rainscreen solution. It is even more crucial that window and door openings and roof to wall details are designed and constructed properly to avoid failure of the straw bale walls due to excess moisture.

5.3 Conclusions to Discussion

Results of the research show that two popular cladding choices in New Zealand are high in embodied energy. The choice of rainscreen cladding instead of large overhangs can reduce the embodied energy of current solutions for cladding a straw bale house in New Zealand. Not all materials which are considered sustainable are suitable for rainscreen applications in New Zealand. The use of a sustainable rainscreen cladding can include simple fixings and methods of attachment but other details, especially wall openings, must be considered carefully to ensure that poor design does not result in water damage.

6 Conclusion

This research shows that a rainscreen cladding can be used to allow maximum solar radiation into a straw bale house, decreasing the energy used for heating. All rainscreen alternatives evaluated using the SuNREL method proved to use less energy for heating when overhangs were removed, by allowing greater solar access to the building.

The results also show that sustainable materials, such as timber and stone, can be used for the cladding to ensure environmental impact is minimal. Removing large overhangs and replacing them with vertical rainscreen cladding can decrease the total energy in a straw bale house with a design life of 50 years by 31%. Given that straw bale houses have been known to last over a hundred years, the embodied energy in proportion to total energy is likely to decrease over the lifetime of the building.

Current solutions for straw bale houses in New Zealand use minimal or no overhangs but instead use rainscreen claddings made from materials with high embodied energy, such as corrugated iron. This goes against principles of sustainability inherent in straw bale construction. Embodied energy use in proportion to total energy use was highest for the galvanised steel and fibre cement board solutions, two methods currently being used in New Zealand as rainscreen cladding options.

In addition, solutions offered in this study have the potential to improve the aesthetic quality of traditional straw bale buildings due to the increased choice of cladding options which allow for more design variations, while still ensuring protection of the straw bales from excess moisture.

The research method applied was successful in identifying alternatives which use large amounts of energy. The method was also successful in breaking down that energy use to identify the proportions which make up total energy use. The method outlined several successful rainscreen alternatives which have low total energy and are suitable to the context and environment in New Zealand. The method did not attempt to address the performance of the rainscreen options evaluated.

6.1 Future research

Further investigation is required into the detailing of wall openings when rainscreen claddings are used, to ensure the prevention of water penetration due to gravity as well as pressure differentials due to driving rain.

Future studies should also consider the appropriate cavity size and detailing of the building paper next to the straw bale. It is unknown whether placing building paper on the exterior surface of straw bale walls will result in condensation between the building paper and the bale, ultimately resulting in mould formation and rotting of the bales. The use of a double cavity system, with the building paper in between two layers of battens, may be required to ensure the bales have an adequate cavity for the release of vapour within the bales.

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All detail drawings by author

Photos:

Figure 1, 2, 3, 4, 5: A Alcorn
Figure 11: by author
Figure 14: Sarah Wigglesworth Architecture website
Figure 16: Dominus Winery website

Appendix A: SuNREL parameters

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Straw Bale House


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20, 20, 0, 0
SCHDL(1,2) = 0, 0, 0, 0, 0, 0, 18, 18, 18, 18, 18, 18, 18, 18, 18, 18, 18, 18, 18, 18,
18, 18, 0, 0
/

&OUTPUT
OUTTYPE = 'building'
PERIOD = 'M'
OUTUNITS = 'M'
OUTSEASON = 'year'
FRMT = 'Y'
/

&SEASONS
NAMESEASON = 'year'
SEASTRTMN = 'Jan'
SEASTOPMN = 'Dec'
DAYOFWEEK = 'ALL'
SEASTRTDY = 1
SEASTOPDY = 31
/

&STATIONS
NAMESTATION = 'wgtn', 'auck', 'chch'
WEATHERFILE = 'R:\bbsc331\as3wthr\wgtnav.srl', 'R:\bbsc331\as3wthr\aucklav.srl',
'R:\bbsc331\as3wthr\chchav.srl'
WEATYPE = 'SUNREL', 'SUNREL', 'SUNREL'
WSTRTMN = 'JAN', 'JAN', 'JAN'
WSTOPMN = 'DEC', 'DEC', 'DEC'
SITELAT = -41, -37, -43
SITELONG = 174.77, 174.77, 172.6
ELEV = 0.0, 0, 0.0
TERRAIN = 3, 3, 3
SHIELD = 3, 3, 3
WSTRTDY = 1, 1, 1
WSTOPDY = 31, 31, 31
/

&PARAMETERS
NAMEPARAM = 'default'
ZONECONV = 0.05
TWCONV = 0.05
GLZCONV = 1.0
INFCONV = 0.05
FLWEXP = 0.5
TZERO = 18.3
HDDBASE = 18.0
CDDBASE = 30.0
DIFAN = 60.0
HGTWINDMET = 10.0
IZMAX = 50
ITMAX = 50
IGMAX = 50
INFMAX = 50
JAN1 = 1.0
WUDAYS = 10
/
```