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THE PROBLEMS OF BUILDING AN IGLOO IN THE SAHARA DESERT!

or

A CAUTIONARY TALE OF HOW A PERFORMANCE-BASED BUILDING CODE CAN BE EFFECTIVE BUT MUST BE FULLY IMPLEMENTED WHEN BUILDING IN A MATERIAL TAKEN FROM ONE ECO-CLIMATE TO ANOTHER.

Abstract

This paper uses straw bale construction to outline the problems of taking the technology of building from one country and using it in another. It explains how the New Zealand performance based Building Code works and then discusses the process of analysing the performance of straw bale construction in New Zealand and of resolving the problems arising from the difference between climatic conditions in New Zealand and those where it was developed.

Keywords

Straw bale, performance-based building codes, eco-building

INTRODUCTION

It is understood that straw bales were first used by the early North American settlers who had slowly settled from the east to the west of America, building cob or turf buildings as they went, using what came to hand on the plains. When they arrived at the sand hills of Nebraska, however, they found that the turf crumbled when dry and their shelters disintegrated. With no trees for timber or stone for solid walls they were obliged to use whatever other material they could find. At the same time the straw baler machine became commonplace. The bales were stacked up like giant bricks and plastered for protection against fire and the depredation of stray cattle[1].

More recently, clean air laws[2] have left farmers in California with waste rice straw, which they had previously burnt causing large-scale air pollution. Straw bale construction is an ecologically friendly way of using the waste product. It has several other advantages:
- It is light and easy to handle,
- Its thermal resistance is extremely high,
- Once plastered, it is very fire resistant,
- It is a natural material

Thus its uses have been adopted by those who are interested in an ecologically friendly building material, particularly in the drier States of the US such as Arizona and New Mexico.

Straw bale construction has probably been used in New Zealand in only the last ten years, about the same time as the performance-based New Zealand building code. In a country that regards straw as something used for bedding animals, or putting on the garden as mulch there has been a lot of scepticism about such a method of construction, and perhaps rightly so.

The sand hills of Nebraska have a very low annual rainfall. Parts of New Mexico and Arizona have less than 8 inches. Most of New Zealand has over 36 inches annually. What is more, that rainfall is not only spread throughout the year (albeit more in winter than summer), but it is accompanied by a high relative humidity, rarely below 60% with 90% or more experienced in some parts of the country for days on end. Often the rain is accompanied by wind. This blows moisture through the cracks in the protective plaster caused by the inevitable earthquakes that occasionally shake New Zealand. The high humidity slows down the drying out of moisture that has entered creating the right conditions for the growth of moulds and the decay of straw.

Is it like trying to build an igloo in the Sahara Desert?

Moisture is the major enemy of straw bale construction, presenting an interesting problem when using straw bale in New Zealand. The Maori name for our country, Aotearoa, translates as the Land of the Long White Cloud, and not without reason. Is New Zealand the right place to be using straw bale construction? Can a performance-based building code deal with a construction system that on the face of it seems inappropriate for our conditions?

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[1] Welsch R L, 1973, *Baled Hay*, Shelter, Shelter Publications, p 70

[2] California State Building Standards Law, Health and Safety Code Div 13 Part 2.5 Chapter

THE NEW ZEALAND REGULATORY SYSTEM

The New Zealand Building Act 1991 introduced the New Zealand Building Regulations 1992 and a six-month lead-in period saw the full introduction of the building code (NZBC) as the First Schedule of the Building Regulations in January 1993. This national building code, which is performance-based, was introduced to give consistency to an industry that was previously governed by a myriad of acts, regulations and local by-laws riddling the country's building regulatory regime. Obtaining a building permit to construct a straw bale house would have been dependent on the persuasiveness of the applicant and the attitude of the local building inspector.

Traditionally, building regulations have been prescriptive, saying what must be done and how to do it. By their nature such systems of governance are very restrictive because they cannot cover every foreseeable circumstance and certainly they cannot cover unforeseeable circumstance. In recent times, as regulatory authorities search for more flexible, less time-consuming and cheaper methods of regulating building, they have been leaning towards performance-based building codes. Performance-based building codes simply state what must be achieved and are therefore by nature very broad and versatile. New Zealand was one of the first countries in the world to fully adapt performance-based building codes. In theory, any material or system can be used as long as it meets the performance criteria demanded by the NZBC.

The New Zealand Building Code
The NZBC has 37 clauses covering all aspects of building. These are the mandatory clauses and are all performance-based. Each clause has a 3-tiered system of sub-clauses as follows:

1. Objective – states the purpose of that clause, usually based on health, safety and accessibility
2. Functional Requirement – states what has to be achieved,
3. Performance – states how to achieve the Objective in either a qualitative or quantitative form.

All building elements, materials and system must meet the Performance criteria. The Objective and Functional Requirement are referred to when any doubt arises over assessment of a building element, material or system.

Proof of compliance
Compliance with performance-based building codes can be difficult to prove on a day by day basis and so needs to be supported by prescriptive methods. In New Zealand prescriptive documents (the Approved Documents) have been produced as one (but not the only means) of compliance with the building code. The Approved Documents consist of Verification Methods, which are usually calculations or tests, and Acceptable Solutions, which are "cookbook" methods. Verification Methods and Acceptable Solutions meet the Performance criteria of each code clauses.

As mentioned, the Approved Documents are not mandatory, and owners or designers are entitled to use alternative solutions that can be shown to comply with the performance requirements of the building code.

The most common form of proof that an alternative solution complies with the building code is a demonstration that the building element, material, or system is similar to an Approved Document. If the proposed alternative solution is not sufficiently close to an Approved Document, proof that the proposed alternative solution will comply with the Performance criteria must be produced.

Straw bale construction has very little in common with standard New Zealand construction as the only things that straw bales have in common are that they are of a cellulose material as is timber, and they are stacked like giant bricks. These are the only base on which we can compare with the Approved Documents, so a detailed examination of how straw bale construction complies with the code clauses is necessary.

CLAUSES RELEVANT TO STRAW BALE CONSTRUCTION

The main clauses that are relevant to straw bale construction are B1 “Structure”, B2 “Durability”, and because the main enemy of straw is moisture, all of the three clauses that deal with moisture, E1 “Surface water”, E2 “External moisture” and E3 “Internal moisture”. The full text of these clauses are contained in the Appendix.

Durability
All building elements or systems must comply with clause B2. The durability requirements of the Performance Clause B2.3.1 are summarised in the following table:

Ease of Access	Ease of Replacement	Detection of Failure	Structural function	**Durability requirement**
Difficult *or*	Difficult *or*	Unable to detect during normal maintenance and normal use *or*	Provides structural stability	**The life of the building being not less than 50 years**
Moderately difficult *or*	Moderately difficult *or*	Able to detect during normal maintenance *and*	Does not provide structural stability	**15 years**
Easy *and*	Easy *and*	Able to detect during normal use *and*	Does not provide structural stability	**5 years**

If the straw bale construction is used as part of the building envelope only, ie as non-structural exterior walls, it must have a durability of not less than 15 years because it is moderately difficult to access and replace and failure can be detected during normal maintenance.

If the straw bale construction is used to provide structural stability, perhaps by holding the roof up, it must have a durability of the life of the building being not less than 50 years.

The Building Act allows for the intended life to be less than 50 years. This has been done for temporary buildings, or if the durability of a building is uncertain or experimental. It could equally be specified for more than 50 years and Te Papa, New Zealand’s national museum, is an example, having a design life of not less than 200 years. A short term specified intended life might have been the safest way to deal with straw bale houses because then checks at the end of the intended life would be mandatory.

Note that maintenance can be taken into consideration when assessing the durability of a building material, element or system and therefore information on what is considered normal maintenance is part of the information necessary when considering compliance of straw bale construction.

Moisture

The majority of failures of building elements are caused by water[3]. Thus compliance with clauses that deal with moisture is greatly related to the durability requirements. Evidence of ability of the construction to keep out water, the necessity for protective coatings, and/or the method of getting rid of any water that does get in is vital to the assessment of the performance of materials. Also vital is the ability to detect failure before damage becomes widespread.

Moisture, as is obvious from the previous example of straw as garden mulch, is the enemy of straw bale construction. In order to have the durability required by clause B2, straw must be kept dry.

Keeping the water out is the best and first solution. A useful analogy is to treat the building like a person who needs to have a good rain hat, coat and gumboots for protection against a storm. The second line of defence is to allow any moisture that does get in to either dry out again, requiring a skin that breaths, or drain to the bottom and to the outside, requiring a clear path for that moisture to follow, and ventilation for any that is trapped.

Moisture is dealt with in three different clauses within the NZBC.

Surface water

E1 “Surface Water” requires as a performance criteria in clause E1.3.2 that:
Surface water, resulting from a storm having a 2% probability of occurring annually, shall not enter buildings.

Buildings must be designed to prevent surface water from entering the building in the 50-year flood. Collection and drainage of stormwater from the roof and surrounding grounds is required. Some or the entire means of compliance could be part of the Approved Documents. An alternative method could possibly be as extreme as surrounding the building with a moat, or include collection for reuse but in all cases would have to show that the surface water in an extreme flood would not damage the building. At a different level of detail, the replacement of a downpipe by a hanging chain would be singularly inappropriate unless it was well clear of the walls of a straw bale building because wind blows water off the chain on to adjacent walls.

External moisture

.E2 “External Moisture” requires as its performance criteria that:

- Roofs shall shed rain and melted snow,

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[3] Porteous W A, 1992, *Classifying Building Failure by Cause*. Unpublished PhD thesis

- Roofs and exterior walls shall prevent the penetration of water that could cause undue dampness, or damage to building elements,
- Walls, floors and structural elements in contact with the ground shall not absorb or transmit moisture in quantities that could cause undue dampness, or damage to building elements.

This is the most important clause in terms of moisture and compliance must be carefully checked in order to provide proof of durability for 15 or 50 years. The following is a list of critical points that need to be checked to show compliance with the code:

- A roof that doesn't leak,
- A good plaster system over the straw to protect it from wind blown rain and normal wear and tear,
- Control joints in the plaster to prevent cracking through shrinkage,
- A protective coating over the plaster that resists moisture in order to seal the surface and any small cracks that will occur in spite of all due care, but is permeable to vapour that may form inside,
- Adequate flashings at all openings, ie windows, doors and other penetrations big or small,
- Sloping window sills to shed rainwater, with a water proof membrane under the plaster for any moisture that does penetrate,
- A roof with wide overhangs to shelter the walls below,
- An efficient damp proof membrane (DPM) under the floor and foundations. When the floor slab is of concrete, conventional methods such as in the Acceptable Solution E2/AS1 can be used,
- Low moisture content in the bales (this can be checked with a moisture meter using a long probe used by farmers when stacking hay),

And to ensure the durability requirement of B2

- A good maintenance programme.

Internal moisture

E3 "Internal moisture" is divided into three parts:

- An adequate combination of thermal resistance and ventilation shall be provided to all habitable spaces, bathrooms, laundries, and other spaces where moisture may be generated.
- Accidental overflow from sanitary fixtures or laundering facilities shall be constrained from penetrating to another occupancy in the same building
- Surfaces of space containing sanitary fixtures or laundering facilities or adjacent to them shall be impervious and easily cleaned, and prevent water splash from getting into hidden spaces.

Complying with the requirement for prevention of condensation is not a problem with straw bale construction because the walls will have a very high R-value. It is necessary to ensure that ventilation requirements are met and that minimum insulation requirement are met to prevent condensation under the roof.

Protection of floors in wet areas and walls next to sink benches, laundry tubs and wash hand basins is important to prevent damage to building elements being caused by the use of water inside the building. In the bathroom, wc, laundry and kitchen the junction between the floor and the wall is likely to be occasionally wet and should either have coved protective floor coverings or the base of the wall lifted up 6 inches or so by supporting the straw bales on a concrete or treated timber nib. Because of the vulnerability of straw to moisture, and because joints between tiles are not sufficiently impervious, an impervious membrane behind tiles is essential.

Even preformed shower cubicles require careful detailing at the edges to prevent penetration of condensation or steam. An alternative solution suggested has been a shower curtain that formed a complete shower box. Someone talked about covering the straw bales with glass like a large “truth window”[4] (with waterproof joints between the glass panels of course).

Structure
The performance criteria required in clause B1 “Structures” include taking account of all physical conditions likely to affect the stability of buildings, building elements and sitework, including:

- Self-weight,
- Imposed gravity loads arising from use,
- Earthquake,
- Snow,
- Wind,
- Fire,
- Impact, and
- Differential movement.

Additionally due allowance must be made for

- the consequences of failure,
- the intended use of the building,
- variation in the properties of materials and the characteristics of the site,
- and accuracy limitations inherent in the methods used to predict the stability of buildings.

The straw house built by the 3 little pigs in the children’s story is very different from the straw bale construction that originated from the sand hills of Nebraska. The baling machine has been around for one and a half centuries so it is not new technology. Structurally, straw bale construction could be considered to be a bit like building with giant bricks. The modular building bricks are of tightly baled straw and are not likely to blow away.

This technology has proved itself in Nebraska and other parts of the USA including California. Rods from foundation to roof ensure non-structural straw bale construction can resist lateral loads on claddings while the post and beam construction is braced to take wind and earthquake loads. A combination of tie beams and tensioned rods ensures that a structural straw bale construction will resist wind and earthquake loads. The engineer needs to provide documentary evidence of the calculation methods used and the comparison between Californian and New Zealand practices, but a solution is obtainable.

[4] Steen, Steen and Bainbridge, 1994, *The Straw Bale House,* White River Junction, Vermont,

WHAT IS GOING WRONG

There are anecdotal reports of some disasters in straw bale construction in New Zealand although the number constructed is not high. A few proud homeowners are in denial surrounded by an odour of rotten straw. One home that started off as a structural straw bale construction ended up as piles of compost before the roof could be put on. What has gone wrong? Is it the performance based code, or the difference in climate? Are we trying to do the equivalent of building igloos in the desert?

The following are perhaps contributing to less than successful straw bale construction.

- Rain is usually accompanied by wind,
- Gabled ends do not have eaves in the right place,
- Plaster is not a material that anyone can apply. It needs skill and understanding,
- High wind and earthquake means that movement causes cracking in plaster,
- Moisture can and does enter around windows doors and other penetrations of the plaster.

Clause E2 requires the prevention of penetration of moisture that causes undue damage. Should straw bale be treated with more caution because it is more sensitive to decay than the traditional building material of timber, ie the quantum of moisture that can cause undue dampness or damage may be a lot less for straw than it is for timber? Can decay be detected during normal maintenance and if not should we be requiring a form of truth window, tubes into the straw bales at discrete points from the interior to detect a rise in moisture content in vulnerable places? Or should we introduce requirements such as a verandah as deep as the height of the walls, or strapping and cladding of the exterior with a barrier?

CONCLUSION

The performance-based building code is now well established in New Zealand, and the industry is becoming more confident and competent in dealing with it, gradually realising the versatility that it provides. When finished, a straw bale building may not look that different from conventional construction in New Zealand, but in our climate there are plenty of ways in which it can fail. Adherence to the performance criteria of the building code will ensure that this will not happen. A combination of an advanced and versatile building code, and careful detailing should ensure that we do not end up with heaps of compost on the ground, like pools of water from an igloo built in the Sahara Desert.

APPENDIX

B2 DURABILITY

OBJECTIVE

B2.1 The objective of this provision is to ensure that a *building* will throughout its life continue to satisfy the other objectives of this code.

FUNCTIONAL REQUIREMENT

B2.2 *Building* materials, components and *construction* methods shall be sufficiently durable to ensure that the *building*, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the *building*.

PERFORMANCE

B2.3 From the time a *code compliance certificate* is issued, *building elements* shall with only normal maintenance continue to satisfy the performances of this code for the lesser of; the *specified intended life* of the *building*, if any, or:

(a) For the structure, including *building elements* such as floors and walls which provide structural stability: the life of the *building* being not less than 50 years.

(b) For services to which access is difficult, and for hidden fixings of the external envelope and attached structures of a *building* : the life of the *building* being not less than 50 years.

(c) For other fixings of the *building* envelope and attached structures, the *building* envelope, lining supports and other *building elements* having moderate ease of access but which are difficult to replace: 15 years.

(d) For linings, renewable protective coatings, fittings and other *building elements* to which there is ready access: 5 years.

E1 SURFACE WATER

OBJECTIVE

E1.1 The objective of this provision is to:

(a) Safeguard people from injury or illness, and *other property* from damage, caused by *surface water*, and

(b) Protect the *outfalls* of drainage systems.

FUNCTIONAL REQUIREMENT

E1.2 *Buildings* and *sitework* shall be constructed in a way that protects people and *other property* from the adverse effects of *surface water*.

PERFORMANCE

E1.3.1 Except as otherwise required under the Resource Management Act 1991 for the protection of *other property, surface water*, resulting from a storm having a 10% probability of occurring annually and which is collected or concentrated by *buildings* or *sitework*, shall be disposed of in a way that avoids the likelihood of damage or nuisance to *other property*.

E1.3.2 *Surface water*, resulting from a storm having a 2% probability of occurring annually, shall not enter *buildings*.

Limits on application

Performance E1.3.2 shall apply only to *Housing, Communal Residential* and *Communal Non-residential buildings*.

E1.3.3 Drainage systems for the disposal of *surface water* shall be constructed to:

(a) Convey *surface water* to an appropriate *outfall* using gravity flow where possible,

(b) Avoid the likelihood of blockages,

(c) Avoid the likelihood of leakage, penetration by roots, or the entry of ground water where pipes or lined channels are used,

(d) Provide reasonable access for maintenance and clearing blockages,

(e) Avoid the likelihood of damage to any *outfall*, in a manner acceptable to the *network utility operator*, and

(f) Avoid the likelihood of damage from superimposed loads or normal ground movements.

E2 EXTERNAL MOISTURE

OBJECTIVE

E2.1 The objective of this provision is to safeguard people from illness or injury which could result from external moisture entering the *building*.

FUNCTIONAL REQUIREMENT

E2.2 *Buildings* shall be constructed to provide *adequate* resistance to penetration by, and the accumulation of, moisture from the outside.

> **Limits on application**
>
> Requirement E2.2 shall not apply to *buildings* in which moisture from outside would result in effects which are no more harmful than those likely to arise indoors during normal use.

PERFORMANCE

E2.3.1 Roofs shall shed precipitated moisture. In locations subject to snowfalls, roofs shall also shed melted snow.

E2.3.2 Roofs and exterior walls shall prevent the penetration of water that could cause undue dampness, or damage to *building elements*.

E2.3.3 Walls, floors and structural elements in contact with the ground shall not absorb or transmit moisture in quantities that could cause undue dampness, or damage to *building elements.*

E2.3.4 *Building elements* susceptible to damage shall be protected from the adverse effects of moisture entering the space below suspended floors.

E2.3.5 *Concealed spaces* and cavities in *buildings* shall be constructed in a way which prevents external moisture being transferred and causing condensation and the degradation of *building elements*.

E2.3.6 Excess moisture present at the completion of *construction*, shall be capable of being dissipated without permanent damage to *building elements*.

E3 INTERNAL MOISTURE

OBJECTIVE

E3.1 The objective of this provision is to:

(a) Safeguard people against illness or injury which could result from accumulation of internal moisture, and

(b) Protect *household units* from damage caused by free water from another occupancy in the same *building*.

FUNCTIONAL REQUIREMENT

E3.2 *Buildings* shall be constructed to avoid the likelihood of:

(a) Fungal growth or the accumulation of *contaminants* on linings and other *building elements*,

(b) Free water overflow penetrating to an adjoining *household unit*, and

(c) Damage to *building elements* being caused by use of water.

PERFORMANCE

E3.3.1 An *adequate* combination of *thermal resistance* and ventilation shall be provided to all *habitable spaces,* bathrooms, laundries, and other spaces where moisture may be generated.

Limits on application

Performance E3.3.1 shall not apply to *Communal Non-residential*, *Commercial, Industrial*, *Outbuildings* or *Ancilliary buildings.*

E3.3.2 Accidental overflow from *sanitary fixtures* or laundering facilities shall be constrained from penetrating to another occupancy in the same *building*.

E3.3.3 Floor surfaces of any space containing *sanitary fixtures* or laundering facilities shall be *impervious* and easily cleaned.

E3.3.4 Wall surfaces adjacent to *sanitary fixtures* or laundering facilities shall be *impervious* and easily cleaned.

E3.3.5 Surfaces of *building elements* likely to be splashed or become contaminated in the course of the *intended us*e of the *building*, shall be *impervious* and easily cleaned.

E3.3.6 Water splash shall be prevented from penetrating behind linings or to *concealed space*s.

B STABILITY

B1 STRUCTURE

OBJECTIVE

B1.1 The objective of this provision is to:

(a) Safeguard people from injury caused by structural failure,

(b) Safeguard people from loss of *amenity* caused by structural behaviour, and

(c) Protect *other property* from physical damage caused by structural failure

FUNCTIONAL REQUIREMENT

B1.2 *Buildings*, *building elements* and *sitework* shall withstand the combination of loads that they are likely to experience during *construction* or *alteration* and throughout their lives.

PERFORMANCE

B1.3.1 *Buildings, building elements* and *sitework* shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during *construction* or *alteration* and throughout their lives.

B1.3.2 *Buildings, building elements* and *sitework* shall have a low probability of causing loss of *amenity* through undue deformation, vibratory response, degradation, or other physical characteristics throughout their lives, or during *construction* or *alteration* when the *building* is in use.

B1.3.3 Account shall be taken of all physical conditions likely to affect the stability of *buildings*, *building elements* and *sitework*, including:

(a) Self-weight,

(b) Imposed gravity loads arising from use,

(c) Temperature,

(d) Earth pressure,

(e) Water and other liquids,

(f) Earthquake,

(g) Snow,

(h) Wind,

(i) *Fire*,

(j) Impact,

(k) Explosion,

(l) Reversing or fluctuating effects,

(m) Differential movement,

(n) Vegetation,

(o) Adverse effects due to insufficient separation from other *buildings*,

(p) Influence of equipment, services, non-structural elements and contents,

(q) Time dependent effects including creep and shrinkage, and

(r) Removal of support.

B1.3.4 Due allowance shall be made for:

(a) The consequences of failure,

(b) The intended use of the *building*,

(c) Effects of uncertainties resulting from *construction* activities, or the sequence in which *construction* activities occur,

(d) Variation in the properties of materials and the characteristics of the site, and

(e) Accuracy limitations inherent in the methods used to predict the stability of *buildings*.

B1.3.5 The demolition of *buildings* shall be carried out in a way that avoids the likelihood of premature collapse.

B1.3.6 *Sitework*, where necessary, shall be carried out to:

(a) Provide stability for *construction* on the site, and

(b) Avoid the likelihood of damage to *other property*.

B1.3.7 Any *sitework* and associated supports shall take account of the effects of:

(a) Changes in ground water level,

(b) Water, weather and vegetation, and

(c) Ground loss and slumping.