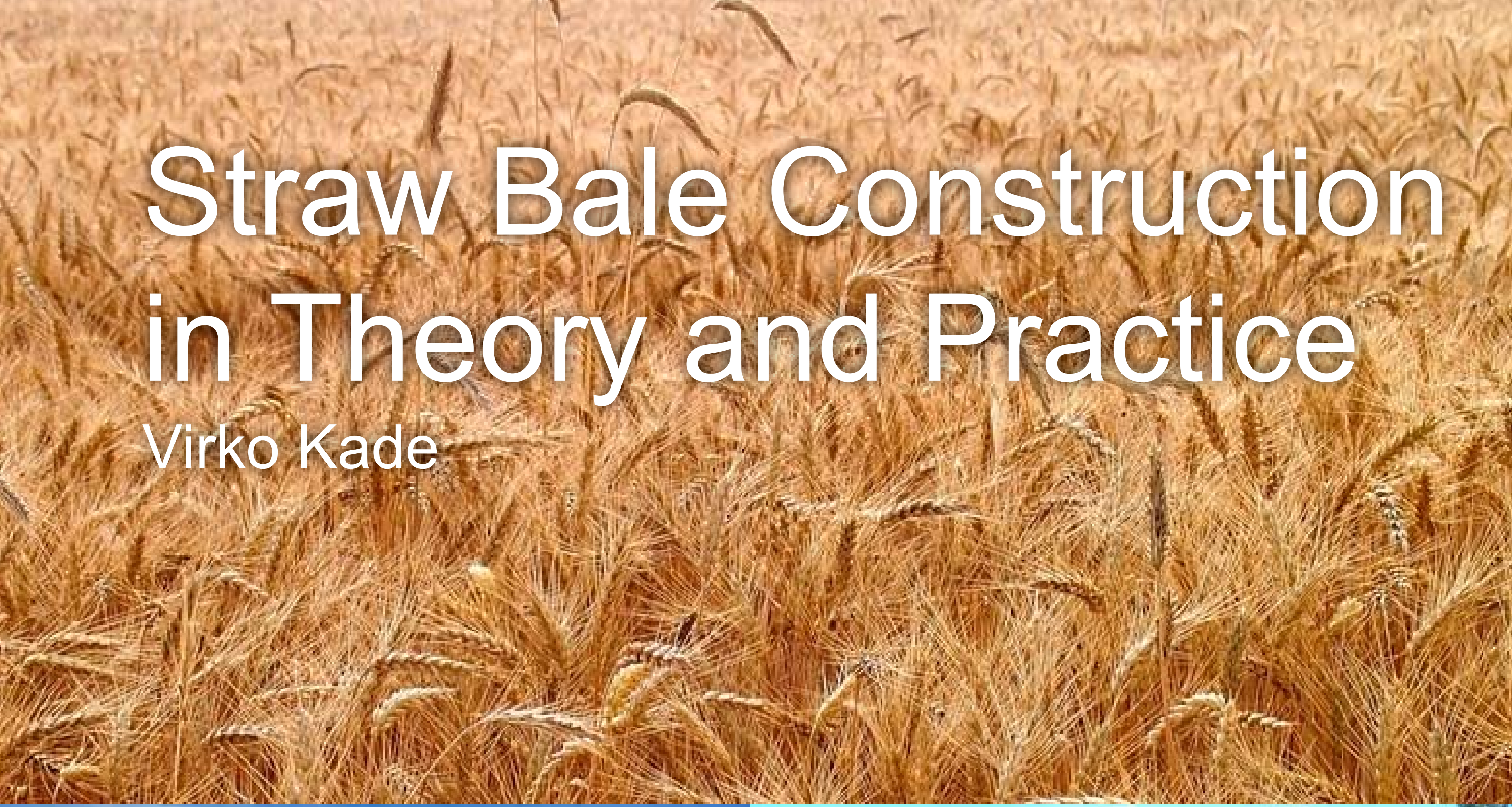

Straw Bale Construction in Theory and Practice

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FFG
Österreichische Forschungsförderungsgesellschaft

FH Salzburg
Smart Building

ReBuMat

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Foreword

Humanity is living beyond its means worldwide; we consume too much energy, produce too many greenhouse gases, and do not consider the wasteful use of finite resources and land.
The „Smart Building: Energy-Efficient Building Technology and Sustainable Construction“ degree program at the Salzburg University of Applied Sciences has not only been dealing with high-tech building solutions for years, but also focuses specifically on a counter-trend to the abovementioned situation: that is, ecological and sustainable building using renewable materials and raw materials.
Three years ago, I met Virko Kade, an expert in the field of sustainable construction using straw as a resource. He has been organising straw bale workshops with students on the Smart Building course since 2016. The students‘ enthusiasm for building with straw prompted us to publish this book as part of a project funded by the Austrian Research Promotion Agency (FFG).
In this book, we aim to provide an overview of the history of straw bale construction as well as information on the various construction methods and special features of planning.
My thanks go to Virko Kade, who has made his practical experience available to the degree program and has been inspiring our part-time students on this topic for years!

FH-Prof. Dr Thomas Reiter

Forword for the international edition:

Agricultural “waste”, often burned on the fields and causing air pollution, greenhouse gas emissions,environmental harm and health impairments, is now turned into valuable building material. It replaces conventional materials, which themselves immensely impact the environment and consume our limited resources in production. Local bio-based materials cause less transport and more local business and employment. Straw is available year-by-year in large quantities everywhere around the world where grain is grown for food production.
In this guideline Virko Kade shows how buildings with straw can be built, and he shows examples of successful cases. Careful design and execution based on engineering principles of durable and functional buildings create trust in such “innovative” technologies. In the REBUAMT project it was our objective to exchange experience and research on sustainable building techniques in exchange between German and Vietnam. We thank Virko for his valuable contribution and support in our endeavor and hope that many people worldwide are inspired by this brochure.

Prof. Dirk Schwede, Technical University of Applied Science Lübeck

Disclaimer:
Although the research in this book was done most carefully, the authors assume no liability for the specific nature, quality or reliability of the information compiled here and no liability for the completeness and accuracy of the information content.
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1. Introduction

1.1 Current situation

Over 50,000 residential units are built in Austria every year, around two thirds of which are single-family homes (according to Statistics Austria 2016). We are one of the leaders of the EU, and the trend is rising. The demand for living space is also increasing: the usable space per resident has been rising for years, and reached a value of 44 m² per person in 2016 (according to Statista).

What does this ongoing construction boom mean from a long-term perspective? Resource consumption in the construction industry is extremely high in terms of primary energy requirements and non-renewable raw materials (share of total resource consumption in Germany: 50%, energy consumption: 40%). The main reason for this lies in the production of building materials. The production and subsequent processing of the materials accounts for a considerable proportion of the total amount of waste (in Germany, construction waste represents 60% by weight and 80% by volume of the total waste). Huge quantities of hazardous waste are produced every year (for sources, see Chapter 18: Appendix).
A sustainable, ecologically justifiable form of disposal (end of lifecycle) is not possible for large proportions of the building materials used, or is only possible with large amounts of energy and high corresponding costs, which are rarely included in current calculations of construction costs. For this reason, the issue of material disposal is often passed on to the next generation. In addition to the aspect of sustainability, there are also direct effects from the construction methods and materials that are currently used. An increasing tendency towards allergies in many people and even lasting damage to their health can be attributed in part to so-called „indoor toxins“. These refer to the inorganic compounds from building materials that are released into the indoor air.

1.2 Perspective

As a topic, „sustainable construction“ encompasses the entire life cycle of a building, which includes the selection of the building materials used. As a regionally available and renewable material, straw bales can offer a variety of possible solutions, and these can and should have a pilot effect on other building materials and their production. The universal usability of straw bales as an insulating material in various structures, as a plaster base, and as a structural element means that a number of significantly less sustainable building materials can be replaced.
At present, there are hardly any opportunities for sustainable and ecological building that are not significantly more expensive than conventional construction methods, making sustainability a luxury rather than a necessity that must be implemented on a large scale.
Straw bales can be a realistic option as a building material if the project is planned and executed correctly. In most cases, they provide components that are suitable for passive houses, and fulfil the requirements for fire protection, sound insulation and building physics. In terms of primary energy consumption, CO_2 balance and other ecological factors, few building materials can keep up. With careful planning, the costs of the components made with straw bales can be comparable to those used in conventional construction methods.
As building materials, straw bales (both small and jumbo bales) can be used as pure insulating materials in various wall, floor and roof structures. Straw bales are a very good plaster base for interior and exterior applications, and under certain conditions can also be used to support structural loads.

What is the actual potential for implementing straw bales in the construction sector? According to a study by AgrarPlus, the annual straw harvest in Austria is around 1.9 million tons. Around 900,000 tons of this is used for bedding, trade and re-fertilisation in the field, and the amount of unused straw is therefore around 1 million tons per year. With an average straw bale requirement per detached house of approximately 12 tons, this gives a potential total of 83,300 units per year. If we assume that there is a significantly lower insulated façade area per unit in a multi-storey residential building, we can probably build twice as many units per year using only straw bales compared to those that are currently being built almost exclusively using conventional methods! (For sources, see Chapter 18: Appendix) .

1.3 Intention of this guideline

As straw bale construction is currently still a niche product in Austria and other countries, and no large manufacturing groups or other special interest groups are bringing more comprehensive certification with detailed construction catalogues onto the market, there is a great need for the transfer of knowledge into practice.

In addition to specific aspects of planning and building law, this brochure also deals with practical procedures and possible technical details for implementation. Straw is now offered by some manufacturers in chopped form, or as blown-in insulation (the details of this process largely correspond to those for the processing of blown-in insulation in timber construction, and are therefore not dealt with here). The topic of straw bale usage as a replacement for conventional insulation in timber construction is reviewed in this brochure, and the use of straw as insulation in roof and floor structures is explained in detail. The thematic focus of this brochure is on the multiple uses of straw bales as insulation and as plaster base. In some cases, this results in significantly simpler structures with correspondingly fewer material layers and transitions; this can help to reduce potential construction errors and ensure that the building functions properly in the long term, which is only guaranteed to a limited extent with the use of vapour barrier films and adhesive tapes, for example. The details and structures presented here have been proven in practice and are confirmed by building physics simulations. However, from straw bale houses built over the last 100 years, we see that building physics lags somewhat behind practice, even though simulation programs such as WUFI now provide quite good results (the Glaser method is unsuitable here). Accordingly, the structures presented here are recommendations, without any claim to liability. The selection of the appropriate details or structure also depends on the respective building situation, and should be made accordingly. Straw bales should only be used as building material by experienced straw bale building specialists, or under their supervision.

2. Straw bales and their properties

2.1 General overview

Straw bales are compressed blocks made of left-over stalks of cereal plants that are threshed and then field-dried. These should not be confused with dried grass, which is known as hay, and has a much greater tendency to decompose in damp conditions, since, among other things, it contains significantly less air and therefore has a poorer insulating effect. The chemical composition of straw is similar to that of wood, which is why this combination works very well in the construction sector. The equilibrium moisture content of both materials is in the range 13–15 mass%.

Straw essentially consists of cellulose, lignin and silica. It is coated with a waxy layer which, in combination with the high silicate content, makes it highly resistant to moisture. A decomposition process therefore only starts after weeks of increased moisture content, and even in this situation, a straw bale retains its volume and releases the moisture on its own, provided the structure allows for this. The stalks initially absorb little or no moisture, as this is stored in the air spaces and can escape again through capillary action. Many alternative insulating materials, such as mineral wool, start to clump as soon as a certain moisture content is reached, and have difficulty releasing the absorbed water again.

Tests by the author have shown that even a completely soaked, mouldy bale retains its volume and dries out again. Loose straw in fields, which is ploughed under, aerates the soil for a long time, until the slow rotting process gradually enriches the soil with nutrients. These properties also play an important role in the use of mulch, bedding or manure as fertiliser.

Straw from domestic cereals is mostly wheat straw (approximately 45%) followed by barley (35%), oats (6%), rye (4.6%), triticale (4%) and spelt (1%) (for sources, see Chapter 18: Appendix). Wheat, rye and spelt are the most relevant to the construction sector; however, in Italy and the USA in particular, rice straw is often used in the construction sector.

The total volume of straw produced in Austria in recent years has been around 2 million tons per year, of which around half was actually used for agricultural purposes.

2.2 Production

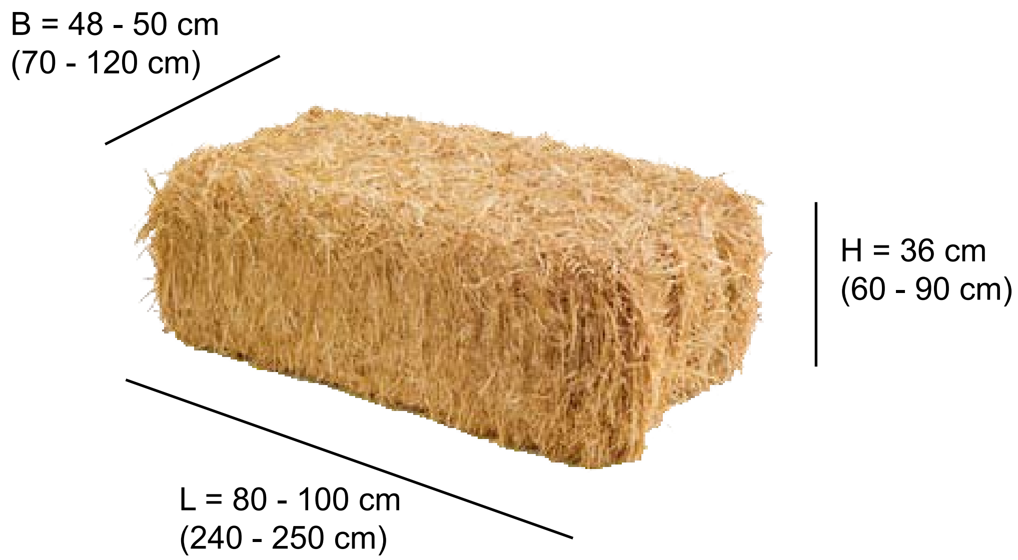
Straw bales are usually produced by a hydraulic press, which is pulled by a tractor directly over the grain field after threshing and drying. The straw stalks lying in a swath are picked up by the reel, pressed together in layers of 5 cm, and tied together with an adjustable length using two (or for large bales, up to eight) strings.

In addition to the length of the bale, which can be adjusted in 5 cm increments, the density of the bale can also be varied. For small bales, the maximum achievable density is approximately 130 kg/m^3 (Welger), although in practice, this rarely reaches more than 120 kg/m^3, and 100 kg/m^3 is sufficient for approval as building material. The bale density for large bales is usually above 150 kg/m^3, with high density (HD) baling machines giving values of above 200 kg/m^3 .

The density, length and sharpness of the edges, which should be as constant as possible, depend on the quality of the straw (strength and stalk length), the swath density in the field, and the corresponding driving speed. If the swath is thin (with few stalks and low density), the tractor must be driven faster, and correspondingly slower if the density is very high.

The so-called 'channel dimensions', which refer to the width and height of the opening in the baler through which the loose straw and then the finished bale are pressed, is not variable. For most small balers in Austria and across Europe, the channel dimensions are 50 x 36 cm (W x H), although in some cases, the opening is only 42–45 cm wide and 30–34 cm high, while large bales can reach widths of 70–120 cm and heights of 60–90 cm. Most straw bale traders produce small bales that are between 80 and 100 cm long, and large bales that are between 240 and 250 cm long. In practice, this results in total weights of 12–25 kg for small bales and 200–300 kg for large bales.

Usual dimensions for a small bale, horizontal position
(dimensions for large bales shown in brackets)



Selection of straw balers with channel dimensions and bale density

	Manufacturer	Model	Bale Size w/h/l	Density kg/m³
Small Bales	Welger	AP 53	36/48/50-120	<130
		AP 530	36/48/50-120	<110
		AP 630	36/48/50-120	<110
		AP 730	36/49/50-120	<120
		AP 830	36/49/50-120	<120
	John Deere	349	36/46/30-130	<100
		359	36/46/30-130	<100
		459	36/46/30-130	<115
	Massey Ferguson	MF 1835	36/46/31-132	
		MF 1837	36/46/31-132	
		MF 1839	36/46/31-132	
	New Holland	BB900	38/56/31-132	<270
Big Bales	Welger	D4006	70/80/90-250	<150
		D6006	70/120/90-250	<150
	Krone	890	80/90/100-270	<150
		1270	70/120/100-270	<150
		1290	90/120/100-270	<150
		1290 HDP	90/120/100-320	<220
		12130	130/120/100-270	<150
	Claas	1150	50/80/70-240	<170
		2100R	70/80/120-250	<190
		2200R	70/120/90-300	<200
		3400	100/120/100-300	

2.3 Straw bales in the construction sector

In Europe, when we talk about straw bales in connection with house construction, we are usually referring to small cuboid bales (length 60–110 cm, height 30–35 cm and width approx. 50 cm, lying flat) The density is between 70 and 130 kg/m³, depending on the baler and the settings. When used as insulation material, a density of 95–100 kg/m³ is ideal, whereas for load-bearing construction, the value should be between 110 and 130 kg/m³. A small bale for load-bearing construction should therefore be approximately 18–25 kg with a length of 1 m. Jumbo bales are also used for load-bearing construction in many houses, and especially for the construction of halls or large buildings. Typical sizes here are 240 x 80 x 70 cm and 240 x 120 x 70 cm, and the density is usually above 150 kg/m³. Due to their weights (approx. 300 kg), these bales can only be moved by machines. Special attention must be paid to the bale length when planning. Re-binding a large bale requires considerable effort over 20–30 minutes, unlike a small bale, which is ready after just a few minutes.

In Austria and Germany, wheat, rye, spelt or triticale are generally used in straw bales for construction. Oats or barley have a somewhat poorer insulating value; they are also softer, and therefore unsuitable as a plaster base and especially not for structural purposes. They can be used as insulating material in some cases.

2.4 Material properties

As a building material, straw bales have a multitude of desirable properties that can be matched by hardly any other material:

- Very good insulating properties (U-values for components made with small bales between 0.1 and 0.14 W/m²K; for large bales, usually below 0.05 W/m²K)
- Very low energy consumption in production and hence real savings in heating costs (a conventional passive house has already consumed a significant amount of energy in production compared to the energy saved for heating.)
- Ecological and renewable
- Often available locally
- Inexpensive
- Involve the use of an agricultural waste product
- Very good sound insulation and acoustics
- Good indoor climate (fully breathable wall structure), non-allergenic
- Absorb radiation such as e-smog or mobile phone radiation (caution: no reception with small windows)
- When plastered, fire resistance of up to REI 90 (90 min fire resistance) tested (see Appendix)
- Very high ductility, enabling earthquake-proof construction
- Involvement of clients in construction process often possible
- Different building styles possible, allowing for creative designs
- Very durable if built correctly
- Pleasant room atmosphere (as described by many clients)

Physical properties of currently certified bales:

Certificates	**SonnenKlee ETA-10/0032**	**BauStroh GmbH ETA-17/0247**	**S-House Ballen ÖTZ-2013/008/6**
Gross density in kg/m³	95-120	100	>100
Moisture content in % by weight	<15	<18	<14
Flow resistance in kPa s/m²	1,9-2,7		2
Thermal conductivity in W/mK	0,046	0,048	0,049
Thermal conductivity II* in W/m K			0,076
Fire behaviour according to EN 13501-1	Class B2 (REI90)	Class B2 (REI30)	Class B2
Biological resistance	Class 2		
Heat storage capacity J/kgK		2.000	
Airborne sound reduction ** Rw, R in dB		43-44	
Water vapour diffusion resistance		2	4,4
Water absorption Wp (24h) in kg/m²			5,76
	* Thermal conductivity II: parallel to main fibre orientation, (bales layed flat)		
	** Structure: bales upright, 36 cm, inc. timber posts, +1-2 cm clay plaster on both sides		

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The table above does not include the approved earthquake safety data (according to tests in the USA and Japan, see Chapter 18: Appendix), as this is not a major concern in Central Europe, and earthquake safety does not have to be proven to the building authorities. There is also no information on the load-bearing capacity of the bales. The test report for the S-House bales contains a statement that the tested large bales shrank by 8 cm at a load of 210 kN/m², without static failure. Based on these figures, they are approved for load-bearing construction according to the certificate. For more information, see Section 4.1: *Load-bearing construction* and Chapter 6: *Statics*.

The airborne sound insulation value is only meaningful in relation to a complete wall structure, and is therefore not one of the properties tested for certification, although BauStroh has added these values for a tested wall structure to its certificate. The outstanding acoustic properties are difficult to quantify. The large, amorphous surface structure, ideally in combination with clay plaster, creates a harmonious, soft sound reflection, which is why some recording studios and concert halls have been built with straw bales (example given by Gernot Minke 2009).

2.5 Quality inspection of a bale of straw

1. Optical inspection
    a. Straw bale binding
    Materials such as plastic or wire are suitable for binding the straw bales. Natural yarns such as sisal yarn are not very strong, which is why they are unsuitable.
    b. Discolourations
    The straw should have a golden yellow colour. Straw bales with visible grey-black spots indicate damp areas, and consequently mould and rot, and should not be used.
    c. Edge formation
    The edges and corners of the straw bales should have little to no rounding, as this means more labour time on the construction site. Before the plaster can be applied, a smooth and seamless surface is required, which is hard to achieve with deformed bales.
    d. Weeds
    There should be few to no weeds in the straw bale, as these can have a higher moisture or protein content. Due to this characteristic, they have a higher potential for mould growth and can also form areas with lower strength.
2. Haptic testing
    a. Moisture: The straw should not feel damp.
    b. Mouldy odour: The straw bales should not have a rotten smell
3. Load test
    a. Straw bales must have a firm structure, which is provided by good compression and good tension of the binding. Loads such as the weight of people standing on them must be possible without sinking or floating.
    b. As a general rule, straw bales should not be carried or thrown on one side, to avoid damage or deformation. In addition, the bale string must not come loose, as the load is no longer guaranteed in this case.
4. Moisture test

Before using a straw bale, it is recommended to measure the moisture content (of some samples) using a sensor in the centre of the bale in order to avoid mould and subsequent defects. A straw bale may have a maximum relative humidity of 75%. This corresponds to a mass-related moisture content of less than 15 %.

5. Density test

Straw bales must have a certain density to be used as a building material. This should be at least 95 kg/m³ for non-load-bearing constructions, and at least 110 kg/m³ for load-bearing constructions.

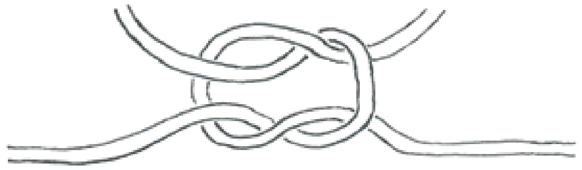
2.6 Resizing the bales

The straw bale can be installed in two different orientations:

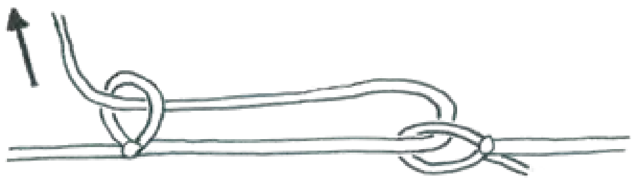
- horizontal, straws parallel to the floor
- vertical, straws perpendicular to the floor, and in exceptional cases, standing vertically (should be avoided on plastered facades)

For load-bearing construction, only the horizontal variant can be considered, since the bale is more resilient in this position. When using the straw bale as an insulating material, both variants are common.

For many types of construction using straw bales, it is necessary to adjust the bales in length or width. In width (in the horizontal position), the straw bales can be cut parallel to the cords with a chainsaw or an alligator. If necessary, the cords must be moved or an additional cord must be tied. It is not possible to cut the bale lengthwise without cutting the cords, which is why the bales must be resized an retied without loosing the tension. At the desired cutting point, new bale cords can be threaded through with bale needles, knotted and then the previous ones cut. With a little skill and physical effort, it is much quicker to open the bale (mark the cutting point beforehand) by starting with on cord and to wrap the bale parts with a new cord, compressing them with body pressure and tying them. For bales with high density this technique is not ideal and one should rather use the needle .
An effective knotting method is to tie two standard knots in opposite directions, although a second person with pointed pliers must secure the first knot.
If the bale is being adjusted by only one person, or if their own physical strength is insufficient, the pulley-loop technique is recommended. It can compensate for the lack of strength, which is particularly important for large bales. At the end, the newly created bales should have at least the same density as before, but preferably a higher one.



Standard knot, best tied with the help of a second person to fix the first partial knot.



Block knot, high tension possible

Measure bales and form joints with your hands, then untie cords

Wrap cords around the newly formed bale, press and knot (pulley block)

Finished bales

For higher density and better quality a baling needle is used. Original strings are cut after new ones are properly knotted.

Baling needle in double design

Needle point with notch for piercing the cord through the bales

Completely threaded cords - for both new bales, therefore double the cord

Pierce at a measured point. Turn the bale and tie it again

Longitudinal cuts with chainsaw or alligator.

3. History of straw bale construction

Building with straw bales started towards the end of the 19th century. In the 1890s, the first fully functioning baling machines were developed in the USA, triggered by the refusal of the railway companies to transport loose straw and hay. In Nebraska and the surrounding states, hardly any natural building materials were available to the settlers at that time, but there was a strong need for housing for newcomers. Other regions had mostly wood, clay or natural stone, which were easy to work with. When the first compressed bales of straw were found in the fields, the idea of using them as bricks was very obvious to the settlers, most of whom came from Europe, as these bales had roughly the same aspect ratios as the old solid bricks. These people therefore began to use straw bales as bricks to build walls, while the roofs, doors and windows were made of wood. At first, the buildings constructed in this way were only intended to be temporary, but when the inhabitants began to plaster their originally unrendered houses, it became clear that this construction method also worked as a permanent solution. Most of the historic straw bale houses in the USA were built between 1915 and 1930, and some of them still stand intact today.

Fawn Lake Ranch, Nebraska 1900-14

Pilgrim Holiness Church, Arthur, Nebraska 1928

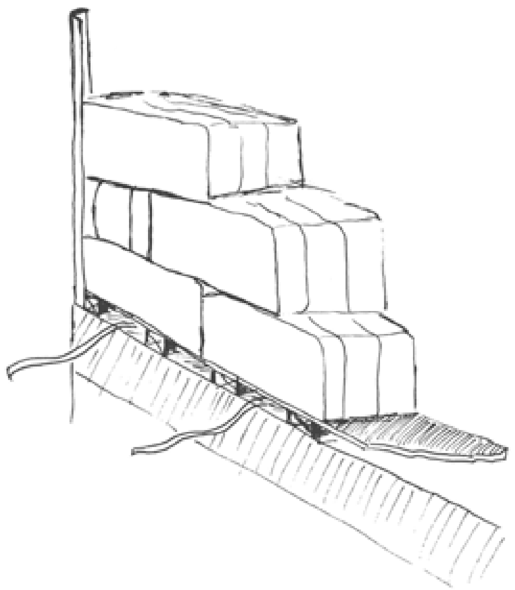
With the emergence of the chemical industry, which increasingly began to monopolise the construction sector, straw bale construction fell into oblivion, in the same way as the use of other natural building materials and construction methods. However, at the beginning of the 1980s, pioneers such as David Eisenberg, Matts Myhrman and the Steens (a couple) rediscovered this construction method, and it experienced a strong boom in the USA. Old techniques were taken up again and developed further, and their uptake and spread were greatly favoured by the American tradition of the „owner builder“. Many Americans have been building their own homes for generations, and still have more leeway in terms of building law than in Europe. The USA is one of the few countries that has its own building regulations for load-bearing straw bale constructions.

Until the straw bale culture reached its peak in Europe, only a small proportion of the straw was used, in the form of chopped straw, oil binder, algae destroyer, pellets, etc., and the rest was burnt or used for energy production. Due to the different ideas of the populations in Europe and the USA, straw was not widely recognised as a building material in Europe. In European culture, naturally cheap building constructions were associated with people from poorer backgrounds, to which people did not want to belong. The first straw bale buildings were built in connection with historical events, such as the nuclear disaster in Chernobyl, which created a need for quick and cheap accommodation. Great Britain is considered to be the first European country to value straw as a building material and, in addition to houses, has also produced a lot of furniture and interior fittings from this raw material. Straw bale construction was also accepted earlier in Holland, France and Denmark than in the rest of Europe. In 1990, the European Straw Bale Network (ESBN) was founded, and many other networks were then formed in individual countries, such as the „Fachverband Strohballenbau Deutschland“ (FASBA) and the „Austrian Strawbale Network“ (ASBN) (Gruber, Gruber and Santler, 2014).

Germany, Austria and Switzerland now have a lively straw bale building scene, which is becoming increasingly organised and professionalised. In most countries, there are now dealers who supply certified straw bales, which has also simplified the situation in terms of building law. In contrast to many other countries, straw bales are predominantly used in house construction with timber frame constructions in Austria and Germany. Small bales, either standing or lying, are predominantly used in these countries. For load-bearing construction, jumbo bales are used in the majority of cases, with classic small bales being used less frequently.

Burrit Mansion, Alabama 1938

France, 1920, still in use



Landhaus Heeze, Niederlande, 1944

4. Possibilities for use: An overview

Straw has been used in construction for many thousands of years:

- as an additive for clay plaster or rammed earth
- in the form of straw clay, as a structural element and to improve thermal insulation
- for roofing: the straw from specially bred rye (e.g. in Hungary) can withstand up to 50 years of weathering or alternatively as reed straw (reed), or rice straw in Asia.

Straw in bale form has been used in construction since the invention of the baler around 120 years ago. Straw bales can be used in house construction for external walls (insulation, plaster base, structural element), for roof and ceiling structures, or in the floor slab, as long as sufficient protection against moisture and condensation is guaranteed.

Bale installation

Depending on the building component and bale size, straw bales can be installed in different orientations according to the intended use and the necessary requirements.

As the insulating effect is significantly better when heat passes through at right angles to the main direction of the stalk, bales are installed upright in most structures. If the situation requires it, such as in single-post systems, the bale is used horizontally so that it can be pressed easily between the wooden beams, and the formation of gaps is minimised. Apart from this, a horizontal orientation is especially favoured for load-bearing construction, as the individual stalks press into each other and the connections become firmer as the load increases.

Bales that are stacked on edge shrink less under load, but are at risk of total failure from a certain load due to the buckling effect. This applies primarily to small bales, although it is also unusual for large bales to be bricked upright in self-supporting wall structures.

Directions for installation :

--lying flat

--lying upright

--standing upright

Choice of wall and ceiling structures

In projects that do not involve any personal contribution from the owners, building components that require little labour and possibly allow for prefabrication are sensible choices. Of course, costs also play a major role in this decision.

A load-bearing structure is usually the most cost-effective solution. A decision on this construction method is a fundamental one to which the design and draft must be subordinate, since the bale format, the number and size of the wall openings, and the roof loads have a strong influence on the design. The render surfaces are usually more organic in this construction method than with other structures, as it is more difficult to level out an uneven surface when rendering. In practice, there are also hybrid variants in which timber posts on screw bases take on some of the loads.

Straw bales can be installed as roof insulation in many uncomplicated variants, depending on the shape of the roof and the location of the insulation (e.g. attic), among other things. The choice of floor plate is also a fundamental decision, which may include traditional concrete slabs or timber structures.

Floorplate:

Bales are installed lengthwise between the 8/36 laminated beams and the strings are cut to close any joints

Finished floor slab with at least 30 cm ventilation and gravel bed, the bonding of the slab joints is also clearly visible

Intermediate size corresponds to the bale width, here 50cm

Large base plate protruding into the valley before filling

Bale insertion into roof structure:


2.1.
Bales are lifted onto the roof with a crane


2.2.
Cold roof structure mounted floating on the straw bales, with Boards directly on the bales, then foil + battens


2.3.
If possible, a layer of clay should be applied to an open roof space for windproofness and a moisture buffer


2.4.
Bales can be brought in from the outside or distributed between the rafters and separated


2.5.
Saddle roof with insulated roof space, inserted from the outside


2.6.
Installed from the inside, following with boards and foil

Wall structures:


3.1.
Load-bearing with small bales, lying flat


3.2.
Single post system, lying bales


3.3.
Hybrid system, large bales on edge, partially load-bearing


3.4.
Timber frame with installation level and straw facade in front. Bales doweled to timber wall.


3.5.
Old brick building, straw facade in front, bales mounted on edge


3.6.
New brick building with a straw façade doweled on bricks

4.1 Load-bearing construction

In this construction method, straw bale walls take on a large proportion of the loads applied to the outer walls of the building by the roof truss, the ceiling, and environmental factors such as snow or wind.

A load-bearing structure is the original straw bale building technique, and is also known as the Nebraska style, due to its origin in the US state of Nebraska. The straw bales are usually laid flat like bricks, and then plastered directly on both sides. Both classic small bales (36/50/100) and the so-called jumbo bales (70/120/240) are used these days; however, depending on the baler and the region, there are also other sizes that can be used. For bales that are to carry at least part of the static load, it is important to ensure sufficient density in addition to checking for moisture content and weeds. Small bales should have a minimum density of 110 kg/m^3, and preferably 120 kg/m^3 or above, and should be made of straw with fibres that are as long as possible.

Jumbo bales usually have a density of 150 kg/m^3, and often exceed 200 kg/m^3. The straw bales built into the wall steadily increase in strength during pre-compression with tension belts/straps and after the roof loads are applied, as the stalks on the touching surfaces of the bales are pressed into each other. The straw bales shrink in height due to their own weight and later due to the roof loads; in other words, they settle. By using tensioning systems, this settlement can be accelerated and, to a certain extent, can be controlled. Tensioning straps are also an important factor when it comes to calculating wind suction loads. They should therefore remain in the wall, and should be covered with plaster.

In the case of large bales, it is now possible to calculate the degree of settlement before plastering (which is often possible after just two weeks). As precondition for precise calculations, the bales must be installed in a force-fit manner, where they will meet uniform resistance from other bales or a window frame as they expand horizontally under load. The quality of small bales is subject to greater fluctuations, and correct installation has a greater impact on the extent of the settlement, which makes an exact calculation much more difficult. As a rule of thumb, we can assume a value of approximately 5% under normal conditions (small bales + light roof). More details can be found in Chapter 6: *Statics*.

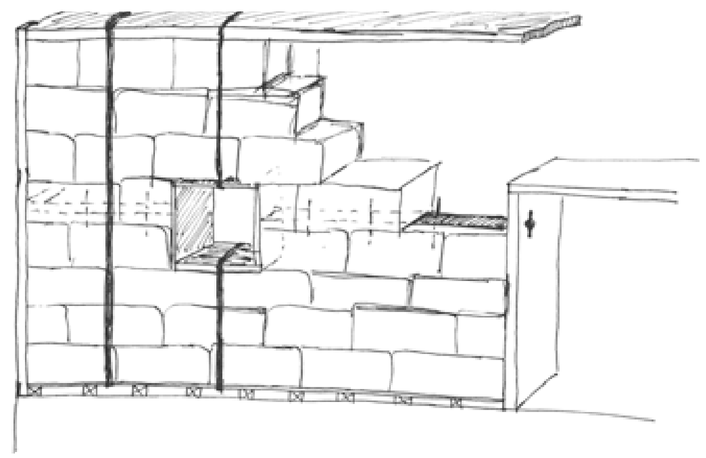
Until the small bales have been compacted, additional stabilisation of wobbly walls can be useful. For this reason, willow or bamboo sticks are often driven through several layers of straw bales; alternatively, bamboo sticks can be used on both sides of the wall as a kind of rail, and can be connected with strings between the layers of bales.

In load tests with small bales, the insertion of a board tension system instead, at half the height of the wall, has proven to be a significant improvement. In this case, hard plywood boards or OSB strips (10–15 mm thick) lie in the centre of the bale between the strings, and are connected to the lower and upper bales with wooden nails (every 50 cm) and screwed to window and door frames in slotted holes (settlement!) (Figs. 2.2 + 2.4). This results in a tension system that prevents the wall from bulging even under high loads (before plastering), and better integrates the window boxes into the wall construction.

As with all statically loaded building materials, there is a maximum wall height. The ratio between the wall thickness and wall height should be < 1:6. For a wall made of small bales with a width of 50 cm, this results in a maximum height of 3 m, which corresponds to eight bales in an uncompacted theoretical state of 288 cm and approximately 275 cm in a compacted state. This is the shell height on the straw side, to which the height of the plinth support and the wall bench/ring beam must be added. These two elements provide the only ways of varying the room height. The minimum version of the plinth structure has a height of 7 cm (e.g. 5 x 8 square timber lying + 18–20 mm OSB). A height of over 20 cm can also be achieved with correspondingly high square timbers.

Another factor to consider is the maximum unstiffened (without partition walls, corner, etc.) length of a straw wall with small bales, which is 6 m. When using jumbo bales, no signs of instability have been observed with longer wall sections (the author has built walls of up to 40 m in total length).
Both of the abovementioned maximum figures for a straw bale wall can be found in the American building regulations for load-bearing straw construction, and have proven to be realistic in practice. For more details, see Chapter 18: Appendix.
When walling, you should always start at corners, door or window openings so that the shorter sections are in the centre of the construction, as this ensures greater stability of the wall. The dimensions and positions of the windows should be based on the bale sizes, in order to minimise the work on site and to keep sources of structural damage to a minimum. Air spaces are planned above the frame elements of the windows and doors, which are stuffed after pretensioning, as these elements cannot be compressed. Filling the final gaps and joints that are less than 15 cm in size minimises thermal bridges (Minke and Krick, 2014).

The wooden boxes for windows and doors can be made from 40–60 mm thick solid wood, such as glulam or KLH. This ensures a good contact surface with the horizontally installed bales, and sufficient stability. The so-called ring beam, also known as the roof bearing assembly (RBA), may be made of solid wood or a construction of square timber, which is laid along the wall on three-layer boards or wide shuttering boards. The cavity should be filled with loose straw. The entire structure must be watertight in relation to the roof construction, so that no water can seep into the wall crown during the construction phase, and in the event of a leaking roof causing a rotting process in the core of the wall that goes unnoticed over time.



In addition to the function of holding the tension belts and connecting the wall to the foundation, the plinth support for the wall also has the task of protecting the first layer of bales from moisture. During the construction phase, it is not uncommon for water to collect on the base plate, but the bales remain dry as a result and this also remains the case later, e.g. in the event of a burst water pipe (Fig. 1.1 + 1.2). Rain hitting the side of a straw wall does not usually pose a problem, as it does not penetrate deeply and dries out again in a relatively short time, but the wall should still be protected against persistent driving rain!

The partition walls of straw bale houses are often designed as simple timber frame constructions: 6x10 square timber + rough boarding (24 mm) on both sides + 20–25 mm clay plaster on stucco. For a structurally effective, stiffening connection between the outer straw walls and the partition wall, the outer upright adjacent to the outer wall must be connected to the straw bale wall. This is possible through the use of straps that are connected to the outside with a vertical bamboo stick after each layer of bales, for example. As a result, the wall is connected to the partition wall under both compression and tension. This also prevents plaster cracks in this area (Figure 2.5). Cracking rarely occurs in load-bearing construction, as the straw bales absorb movements in the building structure well. In plastered solid brick or timber houses, structural stress accumulates, leading to plaster cracks in building corners or window reveals.

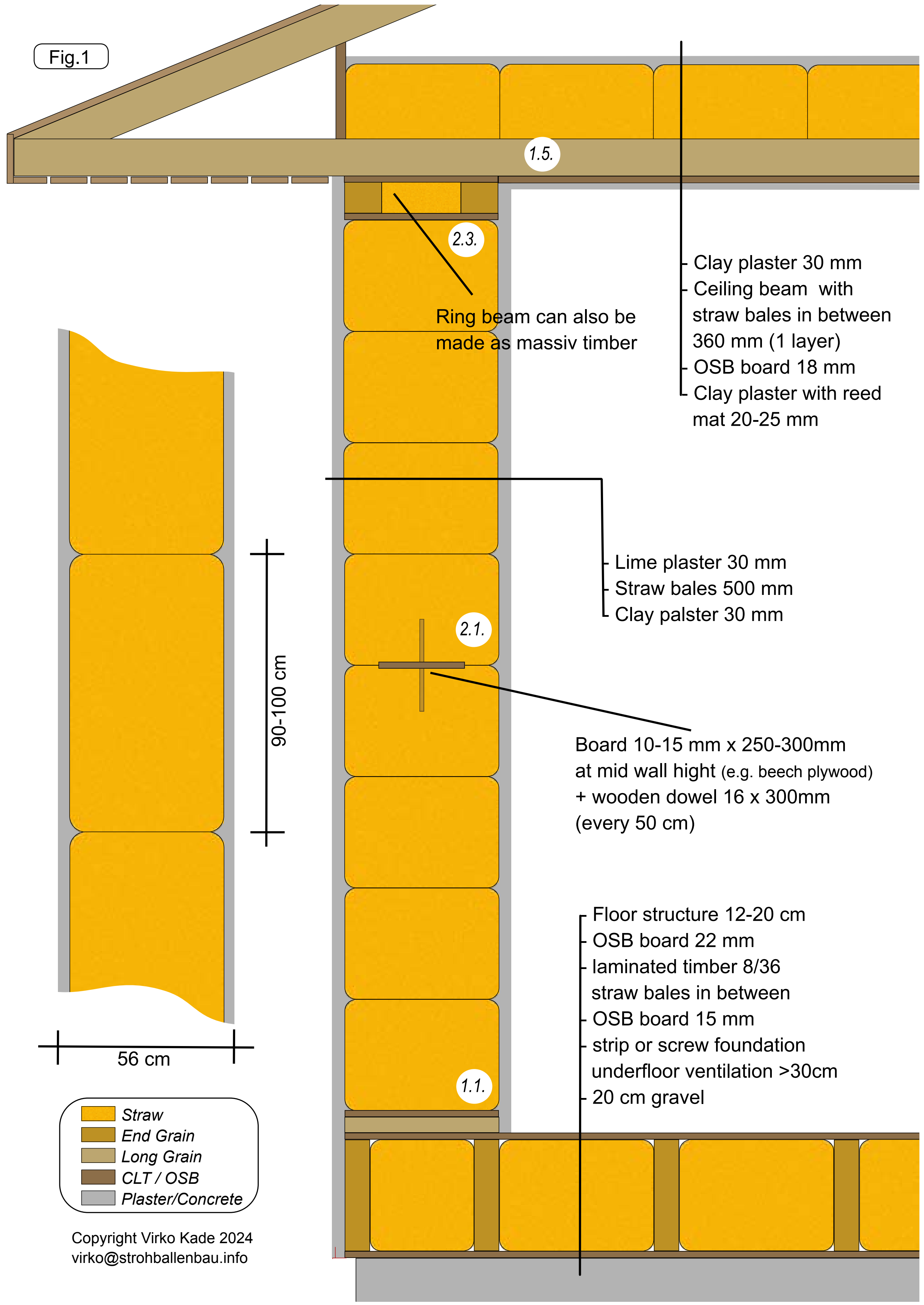
A load-bearing straw bale wall does not have its own installation level. For this reason, the majority of the installations should be installed in the partition walls. If this is not possible, power and water lines are installed in the plaster level, as this does not pose a problem with a thickness of 4–6 cm.

It is essential to ensure airtight transitions with cables and tubes! In a wet area or in the kitchen unit, we recommend an installation level in front, which can also be tiled directly. The straw bale level must first be sealed with clay plaster, including mesh. The fine plaster can then be omitted. The interior plaster forms the airtight layer in this construction, which is why it must extend to the unfinished floor and be carefully treated at transitions between components.

Advantages:
- Most favourable straw bale construction method
- Monolithic structure
- Short construction time
- Low demand for industrially manufactured building materials
- Good energy and ecological balance
- Favours organic designs
- Lower potential for thermal bridges
- High level of personal contribution possible

Disadvantages:
- Very weather-dependent during straw work
- Limited possibilities in terms of design and possible roof loads
- Currently no guarantee of eligibility for authorisation in Austria and Germany (only so-called authorisation in individual cases)
- Increased space requirements, especially for large bales
- Attachment of wall panelling only possible with increased effort
- Connections to timber construction (roof, partition walls, etc.) somewhat more complex, as plastered straw walls have an organic surface

Sample cut, variant base plate in timber with straw filling



Structure of the walls

Base ready for the first bales

The first bales are positioned

After 4 out of a maximum of 8 layers, assembly of the tension system

Wall with ring beam ready for the rafters

Rafters here as a nail truss with low weight and quick assembly

Finished plaster

Further details

OSB intermediate layer after 4 bales, fixed with wooden nails
Better: (hard)-plywood, 20-25cm x 10-12mm

OSB tension system mounted on the window frame

Free space above the windows is only filled towards the end of the settling prozess

Long hole (slot) to follow settling and still be under tension

Timber posts for partition walls are „sewn“ with straw bale wall

Bales can also lie upright under the window

4.2 Timber frame construction / ladder system

These wall constructions combine the minimalist design of the load-bearing version with the advantages of a timber frame construction.

In this construction method, the straw bale itself is not the primary load-bearing system. Another construction takes on the loads and stability of the wall, while the straw bales are used as thermal insulation and/or infill (Minke and Krick, 2014).

The roof is already finished when the straw bale walls are started, and the possibilities for statics and pre-assembly are greater. The timber used can consist of round timber posts at intervals of 2–3 m or square timbers in the grid dimension of the bale length. The posts may be positioned in the straw level (inside, outside, centre) or may be free-standing, independent of the straw wall. If only one post is used, the bales are usually installed horizontally and pre-tensioned with straps. (Figs. 2.1–2.6) When using double posts (ladder system), the bales can also be installed on edge. This allows for wall thicknesses of 42–44 cm, including plaster (Figs. 1.1–1.6). The installed straw bales and the solid plaster layers ensure sufficient rigidity in the system. Nevertheless, the timber construction should be regarded as a separate, independent structural system.

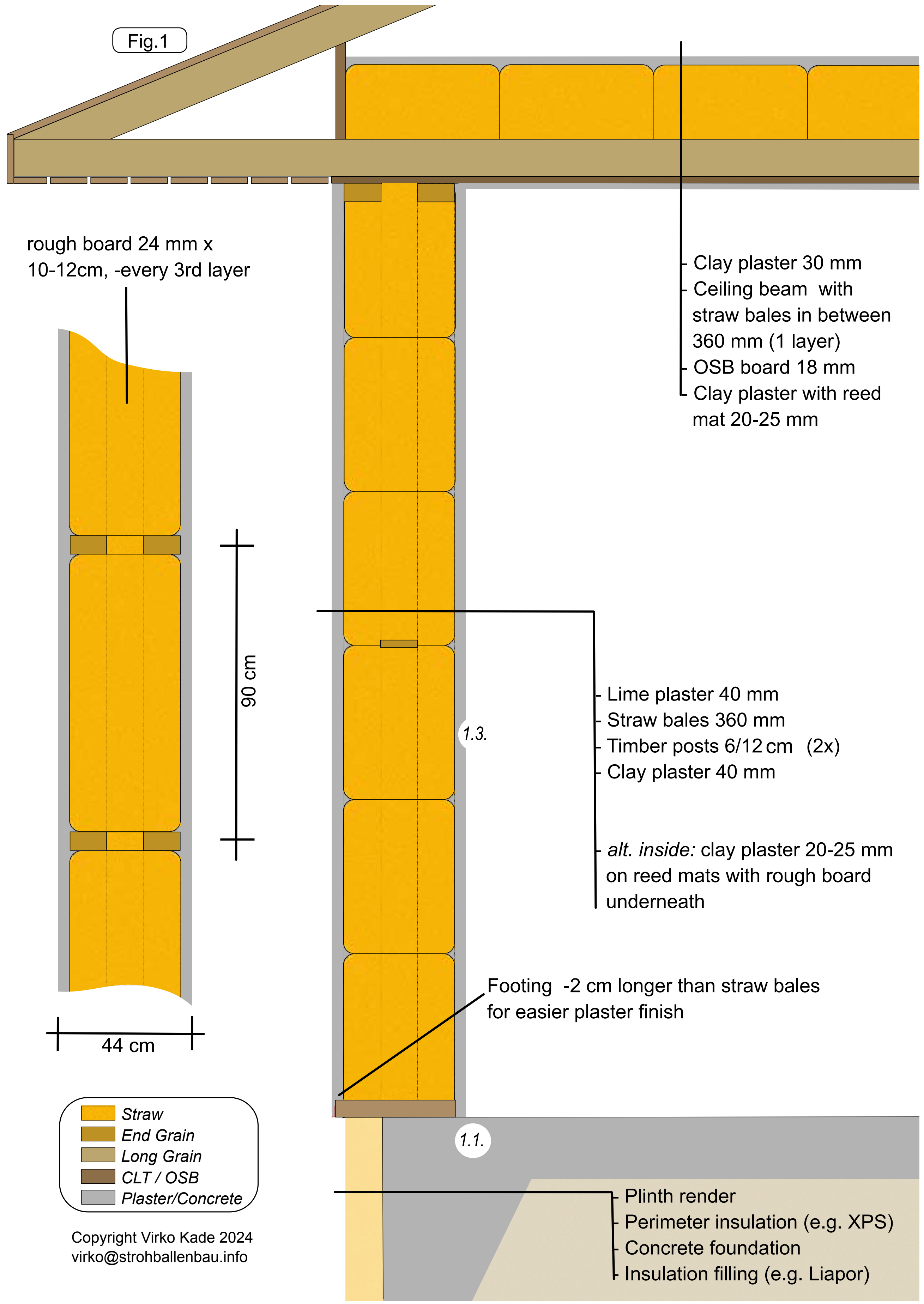
Panicle strips, which are stretched diagonally over the load-bearing posts and fastened, provide the necessary rigidity along the outer walls (Figure 1.4). From the point of view of building physics, they should be located on the inside, below the plaster level. In the case of a multi-storey construction or increased structural requirements, flat formwork (diagonal formwork/ OSB) can be mounted on the internal posts. It is possible to dispense with the tensioning straps in the ladder system if boards are used that pass through every third layer between the double posts, the straw bales are clamped down into the rungs of the ladders with suitable screws and are also fixed in the wall shoring.

These different variants of the timber frame construction are suitable for both small and large bales. When large bales are used, it must always be taken into account that they will need to be moved with a crane within the timber construction. If wooden ledgers are placed in the wall shoring, the choice of a correct grid adapted to the bale length is a sensitive one. The exact lengths and density have a major impact on the effort required to lay the straw bales. Especially with large bales, it is advantageous to allow 5 cm of extra space. Retying (length adjustment) is time-consuming with jumbo bales, and pressing them into the wooden structure can affect the vertical position of the posts.

Advantages:
- Favourable design
- Few layers of material
- Very low wall thicknesses possible
- Low demand for industriall materials
- Statics involves only pure timber construction statics (approval, freedom of design, etc.)
- various wall-mounting options
- Prefabrication and personal contribution possible
- Weather-independent

Disadvantages:
- Grid dimension must be coordinated with bale length
- Somewhat limited options in terms of design, as the transoms have to be replaced for every larger wall opening
- Filling the joints in the area of the posts can be time-consuming, and represents a potential weak point

Sample section, ladder system, variant with concrete slab



Ladder system

Pedestal with perlite filling, ready for the first bales

Plinth detail in the corner of the building, with tension belts visible

Filling goes quickly if the bales fit

Panicle strip

Straw insulation going through both floors without interruption

After the first layer of plaster

Single post

8/16 timber posts, here on the outside so that the bales do not press outwards despite the curve

Bales are slightly curved before attaching

With one post, inside or outside, the bale is usually installed lying flat

An intermediate layer, fixed with wooden nails, is tied to the posts for a better bond

Now the reed mat is stapled onto the wooden surfaces on the front side

Inside, before plastering

Ladder system with jumbo bales

3.1. Very solid ladder system, bales lying upright, 80 cm wide

3.2. Despite the crane, there is still plenty of manual work

3.3. Socket connection with XPS and the threaded straps

3.4. Ground floor precompressed and ready after one day

3.5. In the case of large bales, only whole and half bales should be included in the planning concept (with a theoretical length+ 5cm)

3.6. Start of roof assembly

Single post with jumbo bales

4.1. 10/25 timber posts, centered, bale upright (70 cm)

4.2. Base with foam glass fill in the „condensate pocket“

4.3. Intermediate ceiling lies on the straw bales, only after setting bolted to posts and then continue to built on the upper floor

4.4. Window openings are based on the bale size

4.5. The roof was still a long time coming...

4.6. Passivehouse with an energy index of 7 KWh/m²a

4.3 Timber frame construction with installation level

This type of wall construction combines straw bale construction with the advantages of classic timber construction, such as installation options, its own airtight layer, and additional structural possibilities.

The timber construction forms a separate unit from the straw bales, and consists of 6x12 cm timber posts (these can be thicker for point loads) with a grid dimension of 62.5 cm, an OSB board of size 18–22 mm mounted on the outside and butt-jointed, a cavity for installations filled with e.g. light clay, 24 mm rough boarding on the inside, +20-25 mm clay plaster (Fig. 2.4). The straw bales are fixed upright to the outer timber level using special dowels (Fig. 1.3). The straw forms its own insulation layer, as in classic facade insulation, and the length of the bales is therefore irrelevant in relation to the timber construction. Only the straw bales bordering the window boxes need to be adjusted in length. The parapet heights and lower edges of the window boxes should ideally be 10 cm higher than the full bale height (e.g. 2 x 50 cm + 10 = 110 cm). More details on windows are given in Section 5.2: *Window details*.

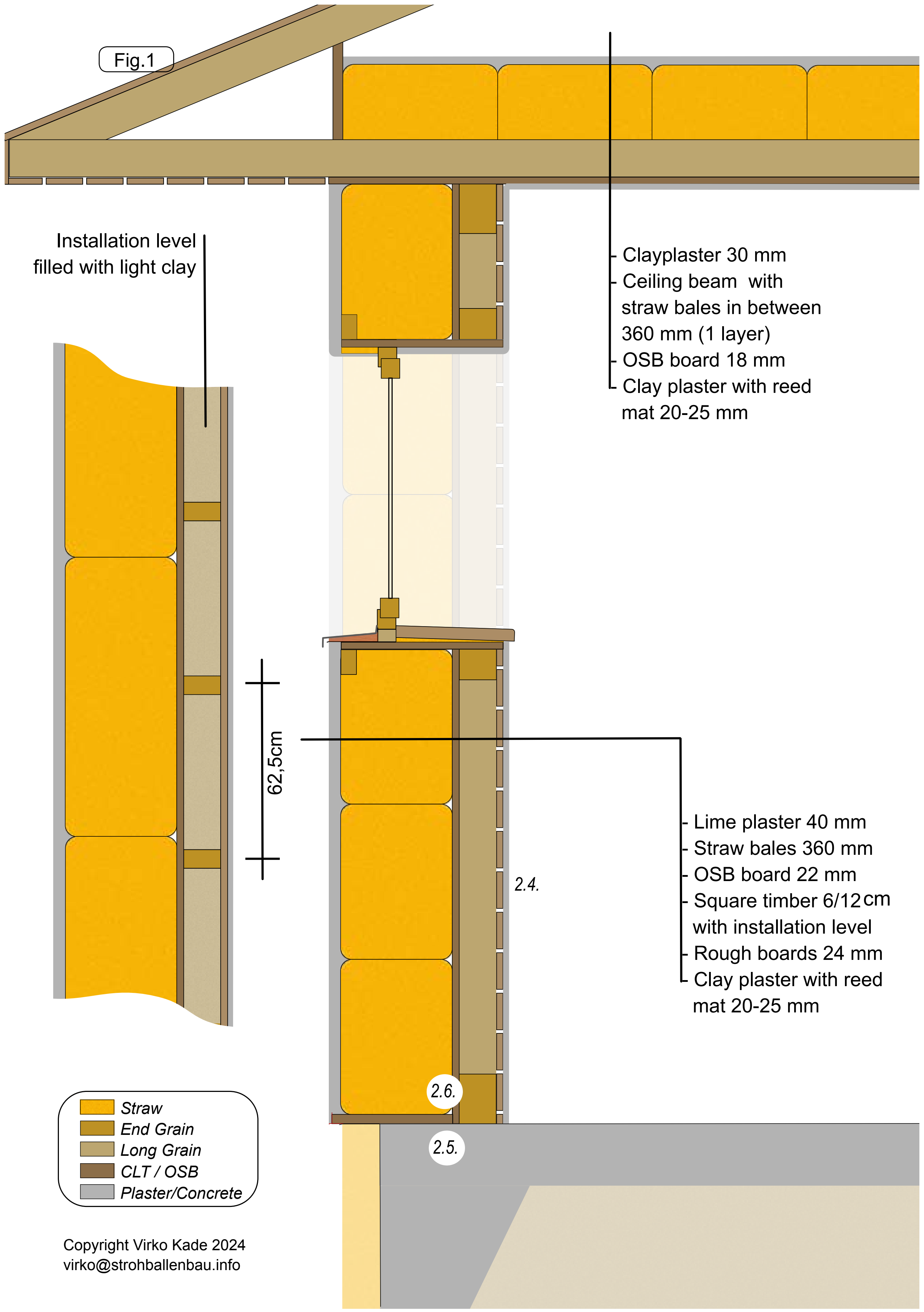
With this structure, a fast bale assembly of up to 100 m²/day is possible. The window boxes (Fig. 2.1) are the only wooden structures that project into the outer plaster level, and should be flush with the outer straw surface. In this type of timber frame construction, the wall elements can be prefabricated in the carpentry workshop and assembled on site within a very short time. After installation, the interior formwork is successively fitted and the cavity is filled with a mixture of clay (e.g. excavated material) + sawdust, for example. The 12 cm of light clay results in a „medium-heavy structure" for the energy certificate. For an imputed passive house, additional insulation such as wood wool must be used instead of clay. A similar structure is recommended for the partition walls in most straw bale houses: 6 x 10 square timber + rough boarding on both sides, and clay plaster. A cavity filled with light clay improves the indoor climate and sound insulation. OSB, which is better suited to damp rooms, can be used on one side instead of rough boarding if required.

This wall construction can be produced by many carpentry companies, even if they have no experience with straw, as the separate levels are familiar in practice. Projects based on this design can start with timber construction in late autumn or winter. The interior work can be completed over the winter, and the straw bale façade can follow in spring.

Advantages:
- Fast construction
- Prefabrication possible >> short construction time on site
- Installation level
- Positive effect on heat storage + room climate due to clay filling
- Classic airtight layer
- Statics involves pure timber construction
- Easy to implement by all professionals
- Relatively independent of the weather

Disadvantages:
- Expensive construction
- High consumption of wood-based materials
- Personal contribution is limited
- No directly plastered straw in the living area (inside)
- Relatively large wall thickness of approx. 58 cm

Sample section, timber frame construction with installation level and concrete slab



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Bale mounting

Starting with ounting the straw bales, -many windows require a lot of time resizing the bales

Straps tight, red dowel plates visible, 2 per bale, all timber construction is flush with bales, 36 cm of OSB

Mounting the bales with insulation plugs /dowels

Corner guides made of 2 boards screwed on each other at right angles, helps with bale assembly and gives nicer plaster edges

All plastered wooden surfaces are previously covered with reed mats, here the eaves in process

Fortunately, the reed straw on the roof came before working on the facade

Details

Window frame detail

Detail of window frame with connection for venetian blind motor

Light clay - loamy excavation + sawdust (e.g. 1:1 volume)

Filling in the installation level

Base sealing before installation of the bale support, here concrete slab insulated with Liapor and XPS on the front side

Bale support (e.g. 30 mm 3-layer board) mounts the strips, with which the tension belts are fixed, clearly visible

4.4 Straw bale façades on brick: Old and new buildings

This wall construction is comparable to a classical external thermal insulation composite system (ETICS). The straw bales are mounted upright on a load-bearing brick wall, as in the timber frame construction described previously, and are plastered directly. The installation is carried out using special insulation dowels, whereby a small plastic pipe (e.g. a 16 mm E-installation pipe 250–280 mm long) is pressed into the straw bales beforehand to create a drill channel in which the hole drilled in the brick wall with the dowel can later be found.

If the brickwork in an old building is poor, vertical battens are screwed to the façade at intervals of approx. 50–70 cm with baling strings before the bales are installed. The strings are laid outwards in the joint after each layer of bales, and when the façade is finished, a bamboo stick is used to tighten the strings against the bales all together against the brick wall. The bamboo sticks later disappear into the plaster (Fig. 2.5–2.6).

Base construction: (Figs. 2.1 and 2.2) In new buildings, the base of the brick wall should have been designed in such a way that a load-bearing support is created for the bales, onto which a three-layer panel (for example) is screwed. The XPS and concrete must be sealed beforehand. In old buildings, there is usually no suitable support, and this must therefore be constructed with timber. An option would be a wooden box, open at the top, whose ribs (three-layer/OSB) are screwed to the wall with longitudinal battens. At the outermost point of this box, vertical loads of up to 300 kg/m must be calculated, including plaster. Care should therefore be taken to ensure a stable design and installation. Two rough boards are placed on the ribs to support the bales and to hold the tensioning straps. The box is filled with loose straw; it is then sealed with a continuous bitumen sheet from the concrete base (behind the perimeter insulation) up to a few centimetres at the front, and finally plastered.

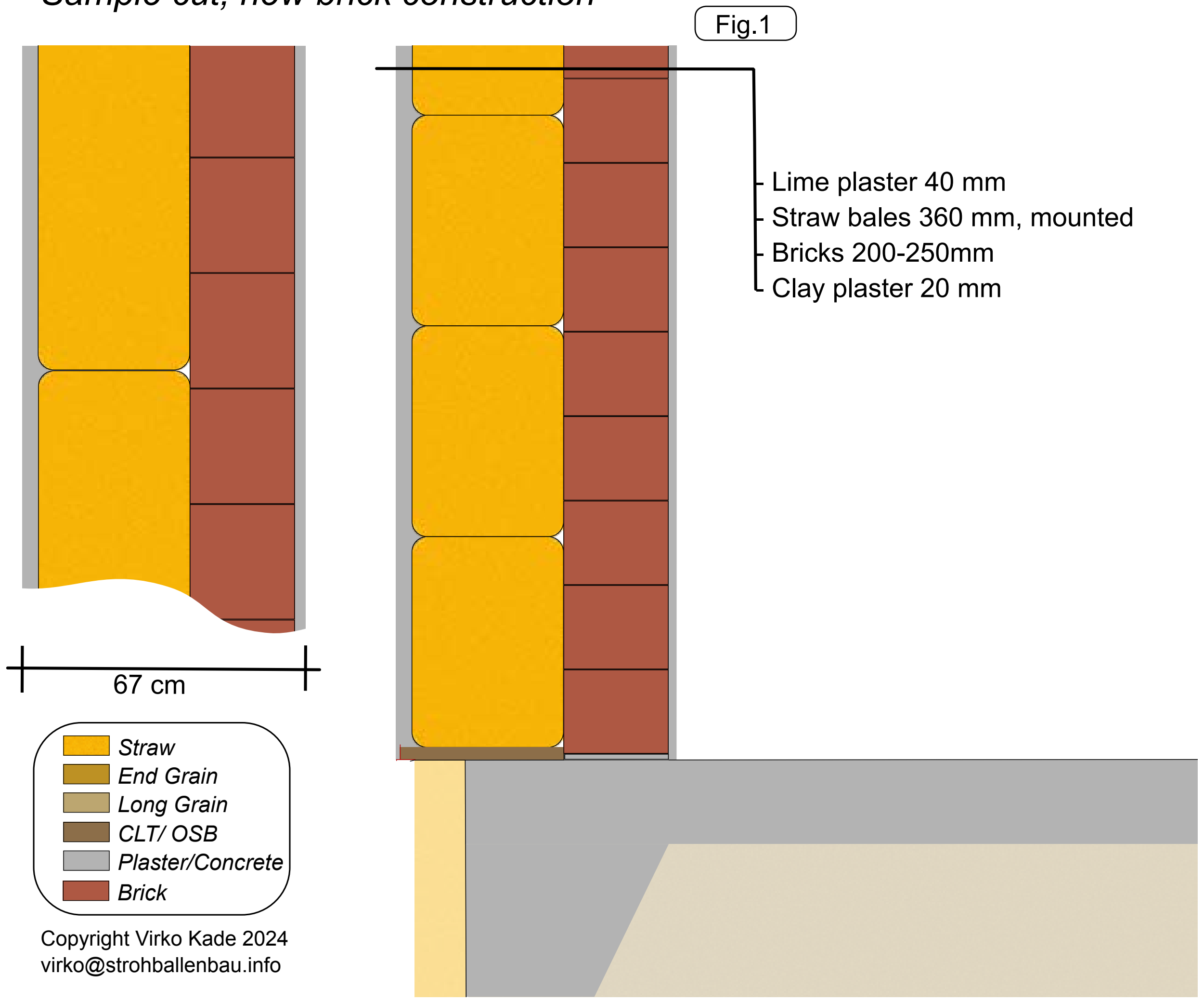
Windows: (Figs. 2.3 and 2.4) For old and new buildings, all-round wooden boxes must be installed to accommodate the windows (as for the other structures). The position of the window can be freely chosen, but should always be in the insulation level.

Conclusion: The straw bale façade only makes sense for old buildings if (i) the roof overhang is sufficient (+ 40 cm due to the straw façade) and (ii) the windows are also to be replaced. In a new building that is planned for this structure, there is hardly any extra work, and the thickness of the brick wall can be reduced to 20 cm, depending on the statics.

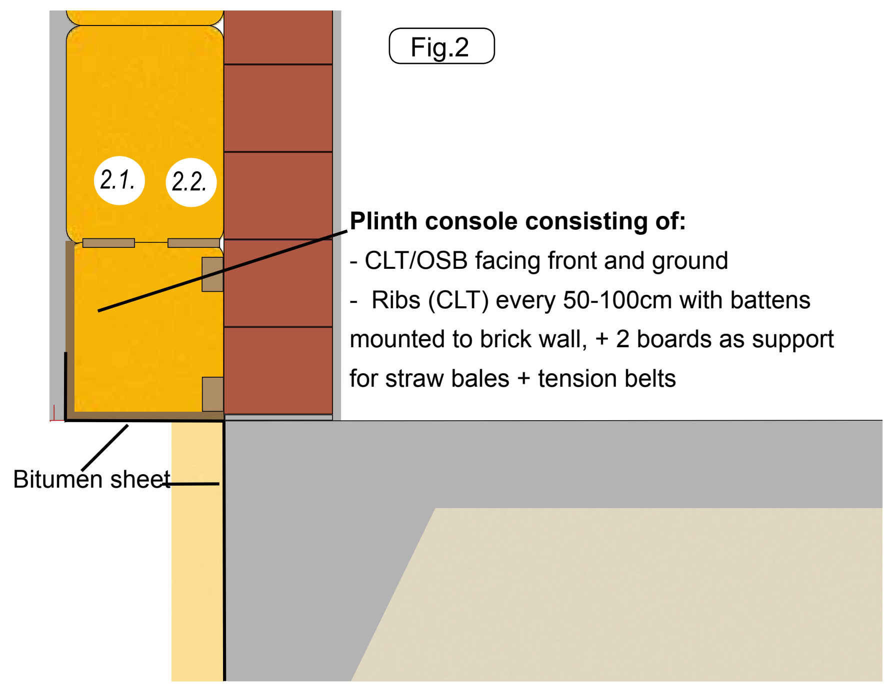
Advantages:
- Straw on brick possible, even in old buildings
- Conversion of an old brick building into a low-energy/passive house at low cost
- Also possible retrospectively

Disadvantages:
- Very thick walls
- High primary energy consumption due to brick production (for new buildings)
- Assembly somewhat more complex
- Long construction time in the shell
- Tightness to the interior more difficult, due to brick joints

Sample cut, new brick construction



Base construction new brick building



Old and new buildings

1.1.

Window and door boxes installed in the old building

1.2.

Straw bale facade grows constantly up to the sloping roof

1.3.

Ready for plastering, reed stucco clearly visible on corner bra-ckets / guides and window boxes

1.4.

New brick building planned for straw bales, base was done with a row of formwork blocks with intermediate insulation on the outside

1.5.

New brick building with conical window reveals, here pure passive house

1.6.

Brick wall with a straw facade can be so beautiful...

Further details

2.1.

Base box filled with straw, belts threaded, ready for the first bales

2.2.

Before filling with straw

2.3.

Window box here up to the inside edge of the masonry, conti-nuously and extensively glued to the masonry with a smoothline

2.4.

Window box and battens with bale string for later fixing the bam-boo sticks, no dowels here

2.5.

Bamboo stick visible, but disappears almost completely in the bale

2.6.

Here again the string going outwards

4.4 CUT technique

The cells under tension (CUT) system, which was invented by French straw bale builder Jean Marie Haquette, is a possible addition or modification to the construction methods discussed previously.

The straw bales can take on a stiffening function in combination with horizontal battens and possibly the plaster surfaces. The wooden posts are connected after each layer of bales with a small batten (e.g. 2.5 x 3.5 or brick battens) and pressed into the straw bale so that it is kept under tension. In this way, they prevent the posts from buckling, which means they can be much thinner.

This technology can be used for single or double post structures, and has a static function that does not require additional measures such as panicle strips or full formwork. The structure can also be used with 5 x 8 square timber or smaller dimensions, as an assembly aid for closed timber transom constructions (as in Section 4.3) or for brick façades. The posts, in combination with the battens, fix the straw bales in place (Figs. 1.2 and 2).

Advantages:
- Low wood consumption
- Good fixation of the bales possible
- Better than dowels for old brickwork with poor quality
- Can be used in combination with a wooden façade for mounting the counter battens
- Can also be used with pitched roofs or vaults with direct plastering

Disadvantages:
- Straw bales form part of the statics (at least, in the way it was invented)
- Air spaces can form more easily in the closed shell facades, as insufficient pressure is built up against them
- With existing constructions (wood/brick), this often involves considerable additional work, and is therefore not always economically viable

Batten with single post variant and formwork on the outside

Also possible in sloping ceilings and vaults

Pattern cut, single post

Fig.1

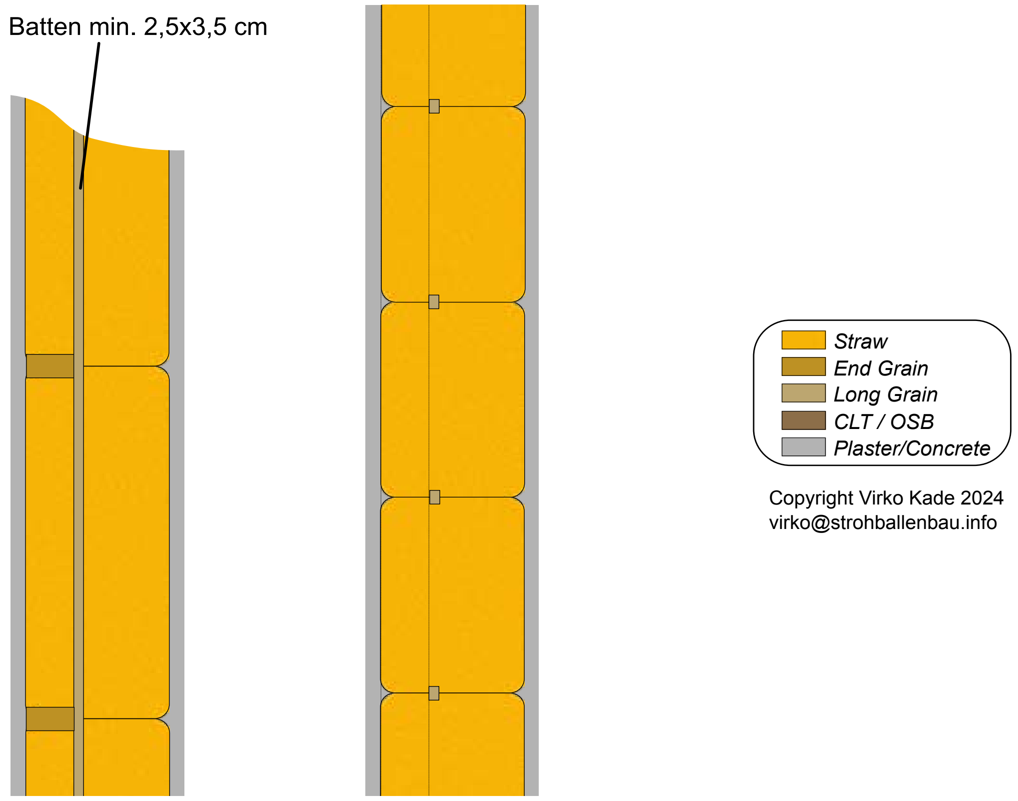
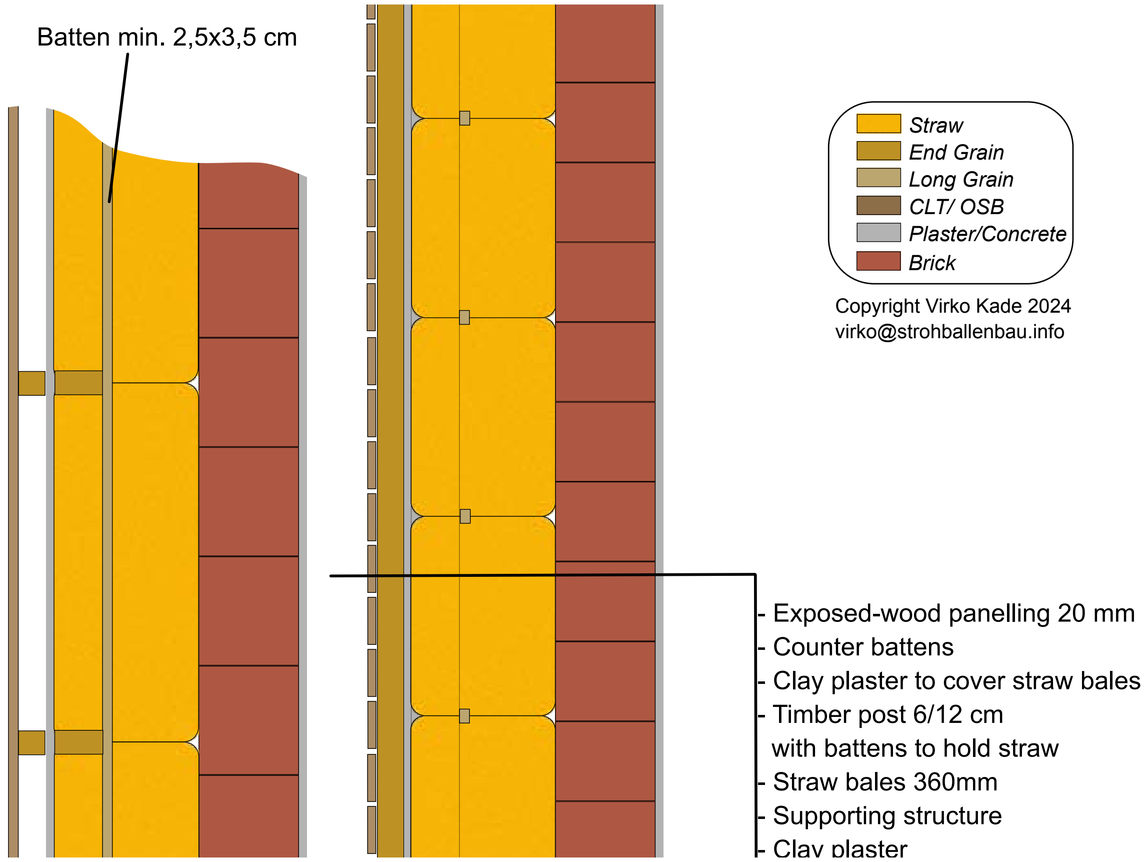


Fig.2 *counter battens with wood façades*

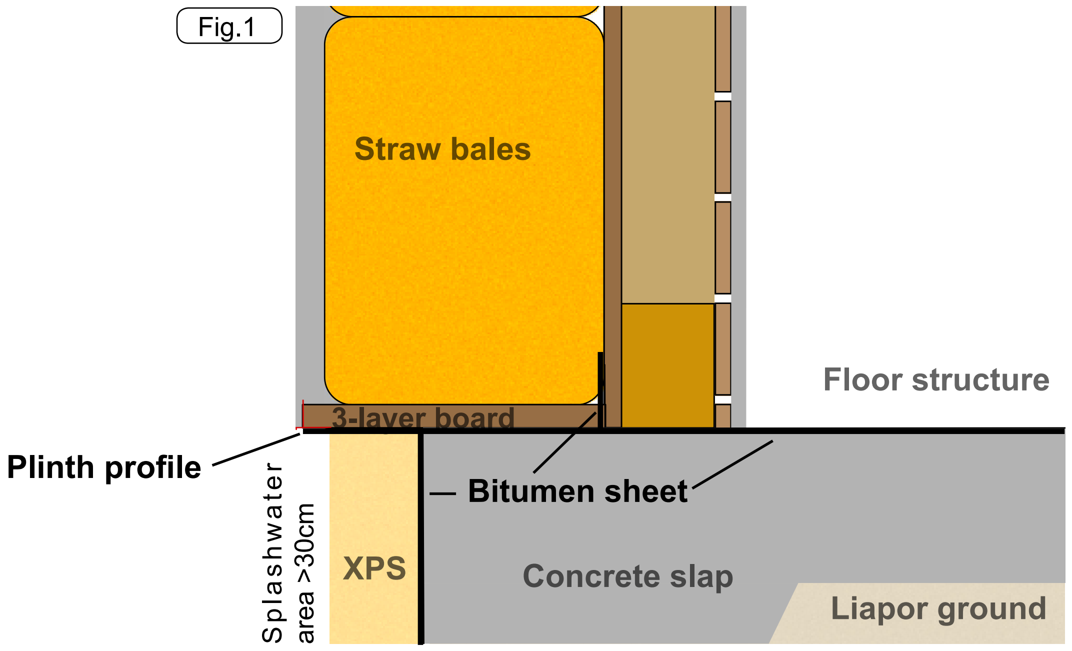


5. Details

5.1 Socket details

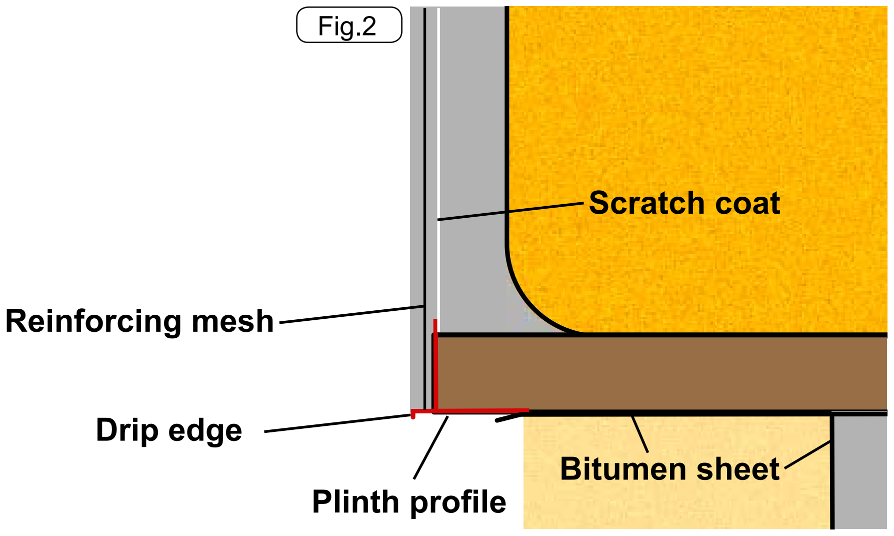
The plinth area is one of the most critical areas in all buildings, as all rainwater from the façade arrives here and must be channelled away without being able to penetrate the structure; moisture can also enter the structure from below, due to splashing water and rising damp. In addition, the design should be free of thermal bridges to minimise the risk of condensation forming. A lack of detailed planning or inaccurate realisation can lead to structural damage even in traditional brick construction, but this can occur earlier and more often, with greater impact, in timber and straw bale construction due to the properties of these materials. Planning and execution should therefore be particularly careful in this area.

Fig.1



Socket detail enlarged:

Fig.2



Plinth details

Example of socket profile with drip edge and mesh. The lower plastic surface should overlap several centimeters with the bitumen membrane and be glued

Socket profile with drip edge. Variant in metal. If there is a high proportion of splashing water, the lower edge must be well connected/glued with bitumen. Clearly visible: rough plaster, mesh plaster, fine plaster.

Socket profile already plastered, here in plastic, cut and bent round

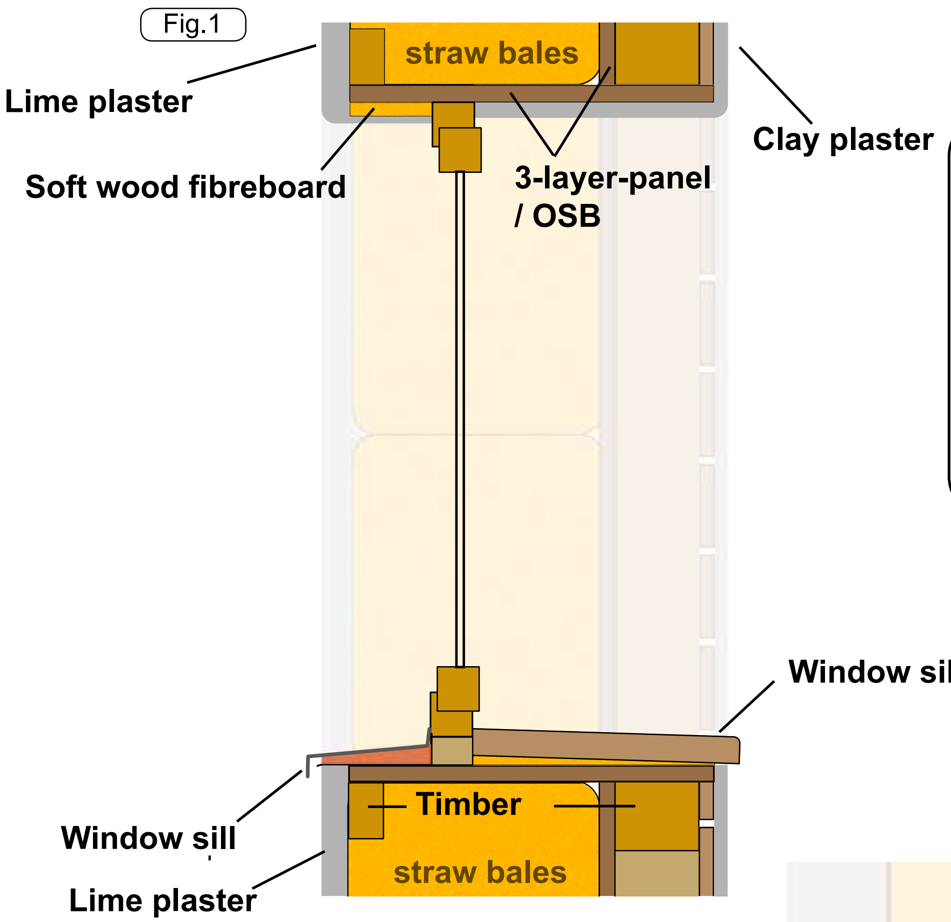
Base glued with bitumen before 3-layer board is mounted

5.2 Window details

A wooden structure is required to install the windows in a straw bale wall, and fulfils the following functions:

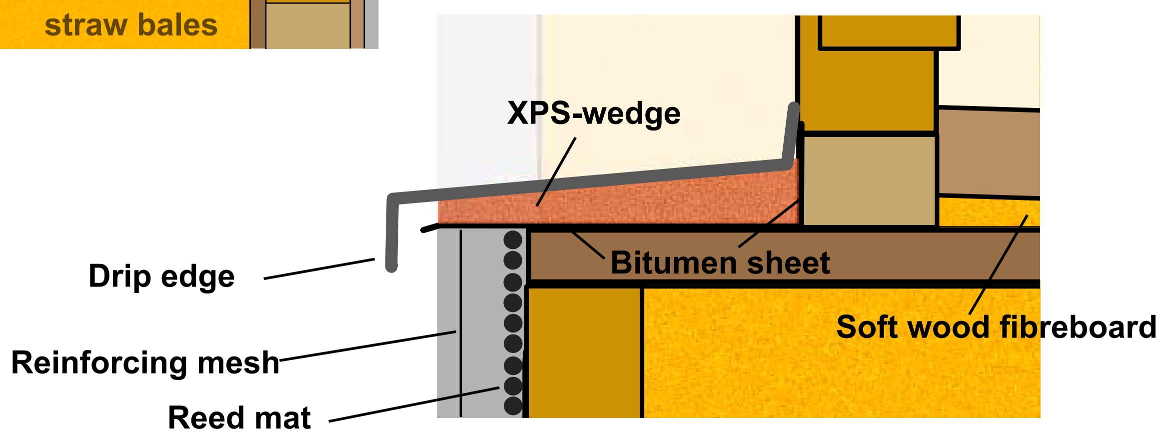
- Serves as a mounting surface for the actual window frame and the window sill
- Takes loads from the bales and plaster above the window
- Absorbs the pressure (through compaction) of the bales from both sides
- Ensures visually clear transitions from the façade to the window

For very organic transitions (large curves), this wooden construction may also be shallower than the straw bale wall. In most cases, however, it makes sense to build this blind frame/ wooden box flush in depth with the raw straw surface. In this way, the rough plaster from the straw surface can go over the front of the wooden box.



Note:
with differing wall structure only minor adaptations are made with window detail. e.g. for load bearing structure no square timber but stronger 3-layer-panel / OSB, at least 40 mm

Detail enlarged: Fig.2

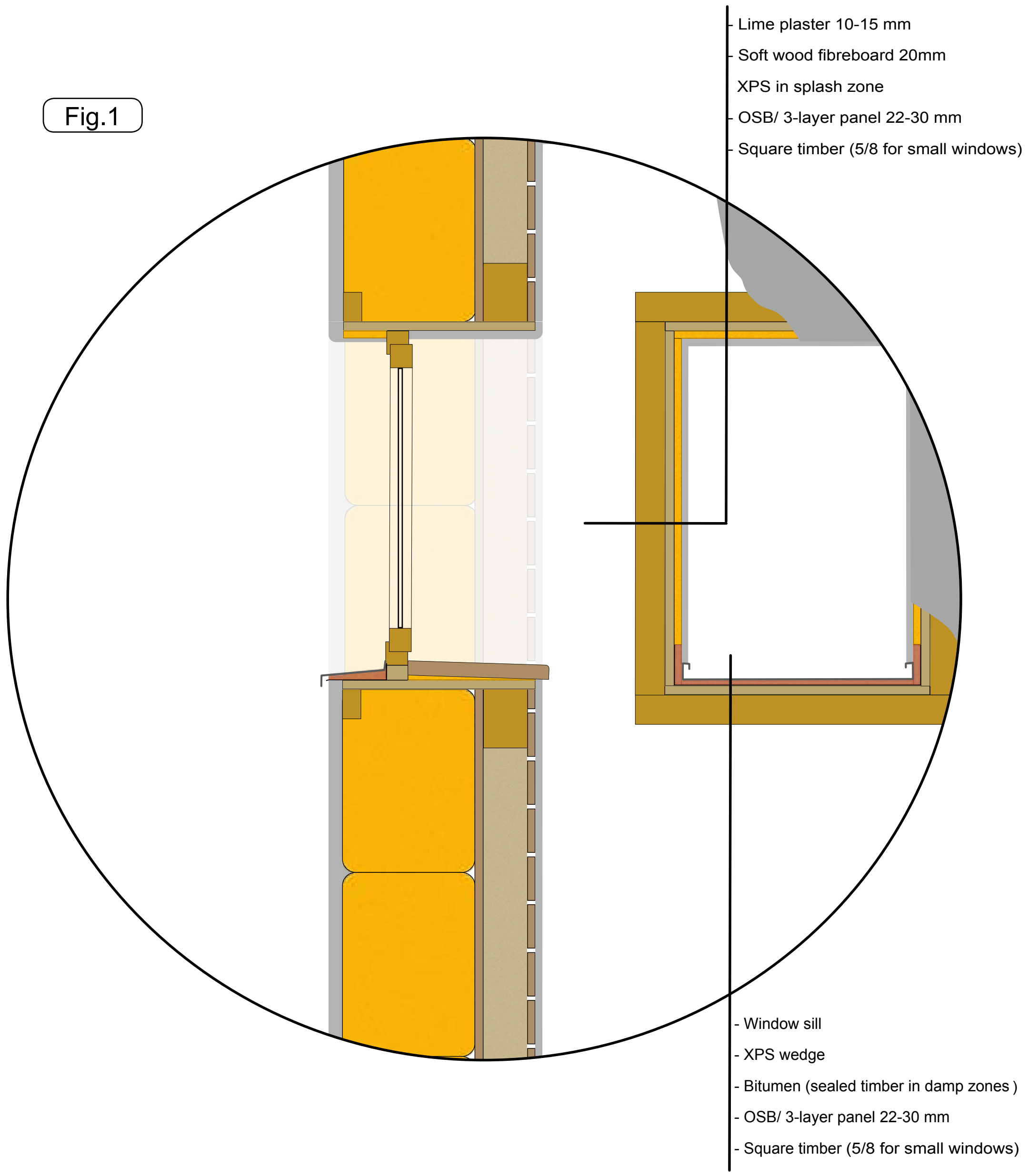


Windows with and without external blinds, window sill and plaster finished

Window frame with rough plaster only on the front side, reed mats can still be seen clearly on the box for the venetian blind

Window frame for variant without window sill, before scratch render

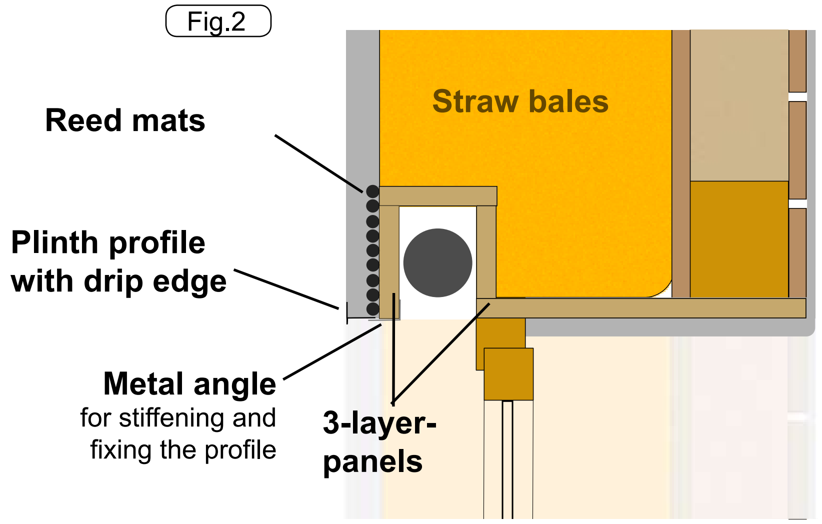
Fig.1



Heat losses can be reduced by over-insulating the window frames. With regard to moisture, the plastering of the joint is particularly prone to faults, as water can easily enter. This can be prevented by using cover strips and sealing tapes behind them or permanently elastic maintenance joints. To avoid structural damage, it is also very important to create an airtight layer. Adhesive connection tapes are used for this, which are inserted between the window frame and the plaster layer.
The corners of the windows can be finished in two different ways. Square edges can be constructed using a plaster rail. Straw bale construction also lends itself to the creation of round corners. This allows more light into the interior, which balances out the thick walls. (Minke and Krick, 2014)

Variant with venetian blinds

Fig.2



Note:
Roller blind or venetian blind are inserted into finished and plastered compartment. Mounting independent of plaster and timber structure. Outer timber structure are flush with straw bale surface.

Before installation, all joints in the area of the window boxes must be sealed with special adhesive tape.

Detail of window frame with venetian blind installed, before installation of the socket profile (drip edge), after scratch render

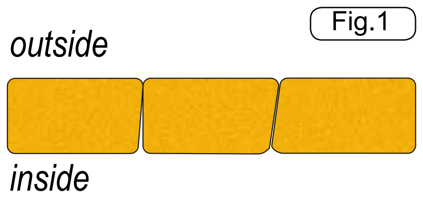
Window boxes on load-bearing building with jumbo bales The open space under the window is filled with small bales or separated big bales

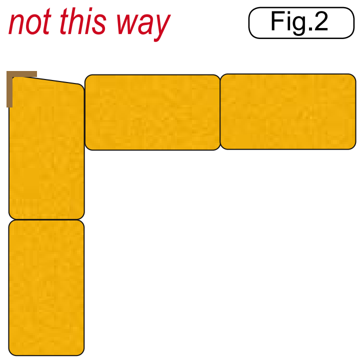
The window box here is conically designed, but with a straight window box it can also be achieved with wedges made of soft wood fiberboards

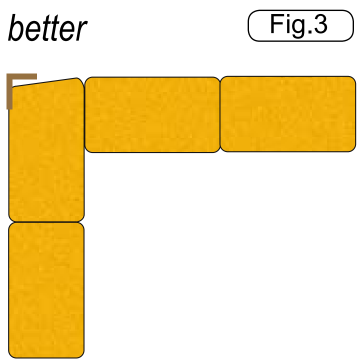
5.3 Installing the bales: Details

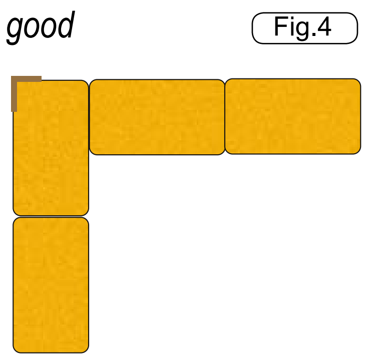
There are basic rules that apply to the assembly of the bales, which should be observed regardless of the structure. Straw bales are more like natural stones than industrial products in terms of their external shape. They rarely have a straight edge, and therefore sometimes have to be rotated around all three axes until they form the smallest possible joints with the neighbouring bales (Fig. 1). With straw facades (bales installed on edge), the closed side should always face outwards if joints cannot be avoided, so that loose, stuffed straw cannot fall out (Fig. 1). In all kinds of structures, bales are only installed with light pressure (frictional contact). They should never be pressed with full force (except perhaps into a full wooden structure), as the bales may bulge or other bales may be pushed out. For the corners of a building, it is advisable to use a corner bracket made of boards, which can later be plastered, although in the case of an organic (non-perpendicular) edge, this can be removed again before plastering. The bales in the area of the building corner must not protrude under any circumstances, but should be placed further inwards, as they may expand due to the pressure of the other bales and compaction with the tension belts and are then very difficult to bring back into the wall alignment. Especially in load-bearing construction, this expansion increases with each additional layer, which is why the bales are placed a few centimetres inwards from the second or third layer onwards.

For all wall constructions (except the load-bearing variant), bales must be connected to the actual supporting structure to keep them in position, to avoid cavities and subsidence, or because they form part of the statics. In the case of a mounted straw facade (on timber or brick), it is possible to attach the bales with strings or straps. In addition, special insulation dowels can be used, or additional battens connected to the brick or timber surface underneath can be placed in or outside the plane of the straw bale.









Corner guide: choose orientation of the bales very carefully here

Halfway up the wall, the corner guide is connected to wall underneath so the bales don't push it out

Insulation anchor FA WKRET-MET, 285 mm long, in combination with special 90 mm screw perfect for bale thickness, + extended Torx bit. For mounting the bales on the outside wall.

2 dowels per bale, each at 1/4 and 3/4 in bale length, in the middle, have proven to be sufficient in practice, although not certified!

Straw bale screw from TreePlast (Vienna University of Technology) for mounting wooden construction on straw bale wall. Length: 36 cm

Installation variant with strips and string (for old brick buildings often better than with dowels due to poor brick quality)

Box for flue gas passage. Inside insulated with rock wool, cover (flush with straw facade) inside and outside made of bromate panels (fire protection panel)

Drained gravel bed underneath wooden floor plate

Installations combined in a concrete shaft and led into the floor slab, later all cavities filled with perlite

Opening for the passage of all house connections through the straw bale level

Arrived in the technical room

Entire floor in the technical room with pond liner, including elevation the walls, in the event of a pipe break, drainage into the concrete shaft and further into the gravel bed is possible

Right side: plastered bales of straw as a seat in front of wall heating

Tool for stuffing loose straw into gaps

Water connections pre-assembled so that the cavities can be filled with light clay

Electrical sockets mounted in rough clay plaster with rapid cement, cables preferably damp-proof cables instead of pull-in wires (tightness)

„Truth window“ built into the clay layer inside

Sample wall section cut: the continuous course of the insulating material is just as visible as the penetration depth of the plaster

6. Statics

6.1 Load capacity

In Europe, most straw bale houses are built without the bales playing a static load-bearing role in the building. They serve as insulation, and usually also as a plaster base. The entire structural system is covered by a timber construction, or occasionally by a brick wall.

If a more minimalist timber construction is desired, the bales can contribute to bracing, in combination with the plaster. The clay plaster on the inside and the lime plaster on the outside play a decisive role in practice. The plaster penetrates several centimetres deep into the straw bales and forms a new, fibre-reinforced composite material, for which there are currently no usable calculations for the load-bearing capacity. Studies and real load-bearing capacity tests are currently being carried out at the RFCP in France. The previous calculation approaches assume a load-bearing layer + plaster. Even without this new composite material, the stiffening and load-bearing effect of the render can be adequately demonstrated for material thicknesses of 4–6 cm.

Based on the so-called cube compressive strength, which is 20–150 kg/cm² for lime plaster and 15–25 kg/cm² for clay plaster, this results in load-bearing capacities of 22 tons/m wall length for an external wall (with 25 kg/cm² lime) and 18 tons/m (with 20 kg/cm² clay) with a plaster thickness of 4.5 cm. A static safety factor of 10 is applied here, which leads to calculated values of 2200 kg/m and 1800 kg/m for clay. These are higher values than can normally be expected for traffic and snow loads in Austria.

$$F = \frac{100\ \text{cm} \times 4{,}5\ \text{cm} \times 25\ \text{kg/cm}^2 \times 2}{10} = 2200\ \text{kg/m}$$ lime plaster (-trass lime up to 15.000 kg/m)

Load-bearing capacity of plaster:
lime = 2200 kg/rm clay = 1800 kg/rm
(calculations for 4,5 cm plaster thickness on each side)

Regardless of the load-bearing capacity of the plaster, in a straw bale house in which a large proportion of the loads are borne by the straw bales themselves, at least the structural loads of the roof truss, insulation and roofing should be borne entirely by the unplastered straw bale walls. The American building regulations on load-bearing construction stipulate that straw bale walls without plaster must be able to bear all possible loads during use. Of course, this also applies to Austria, although safety surcharges can also be verified using plaster. The American building regulations drawn up by structural engineer Bruce King stipulate a maximum permissible load (with a large safety margin) of 400 lbs/sf (pounds/square foot), which for a small bale wall 50 cm wide equates to around 1000 kg/rm (1936 kg/m²). The author's own load tests on an unplastered small bale wall have shown a load-bearing capacity without static failure of over 1500 kg/square foot (15 kN/square foot) with a bracing technique applied at the centre of the wall. Without this, the wall began to buckle at around 800 kg/rm. In the plastered state, no structural failure occurred and only minor cracking was observed. The wall bench (RBA) was merely slid between the two plaster plates. As part of these experiments, individual bales were also tested for their load-bearing capacity using a pneumatic press. Even with a load of 3.5 tons (35 kN), none of the bales failed. After removing the loads, the compression of the bales returned to approximately 90% of the original height within a few seconds, and to 100% after a few minutes. This extreme flexibility can be found in hardly any other building material. Due to this property, load-bearing straw bale construction is one of the most earthquake-resistant construction methods (see the scientific paper in the Appendix).

The small bales used in these test setups consisted of long-stemmed wheat straw and had a density of 110–120 kg/m³.

Single bale tests up to 35 KN

Test wall unplastered

Sensor for force-deformation diagram

Test wall in plastered condition

Large bales (240 x 120 x 70 cm) with a density of > 150 kg/m³ have also tested in various laboratories. The certificate for the S-House bales from the Vienna University of Technology states that individual jumbo bales have been loaded with up to 21 tons (73 kN/m²) without failure. The Swiss straw bale building static engineer Peter Braun has also confirmed that loads of over 30 tons are possible with appropriate settlement. Measurements of a 3.5-storey building (see photo opposite) with large bales resulted in a maximum load for one bale of 4.2 tons. Braun calculated an E module of 0.3–0.5 N/mm² from the results. Test values from the HTW Chur/Switzerland also resulted in an E module of 0.42 N/mm² as a calculated value for a bale density of approximately 140 kg/m³. With these values, precise calculations for the settlement of large bales are possible. With a load of 4 tons on a large bale with a width of 120 cm and a height of 80 cm, the calculation is as follows:

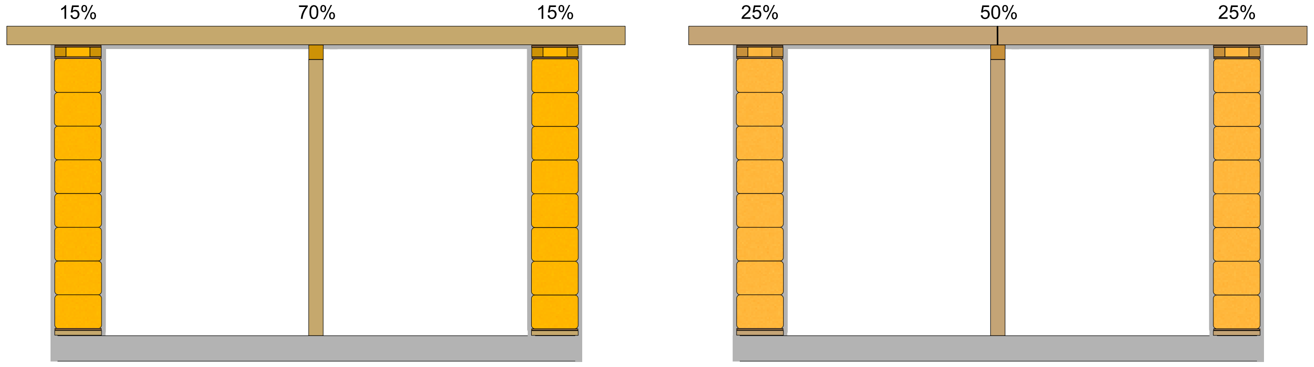
$$\text{Compressive stress: } P = \frac{F}{A} = \frac{40 \times 10^3}{1200 \times 1000} = 0{,}035 \text{ N/mm}^2$$

$$\text{Deformation: } = \frac{P}{E} = \frac{0{,}035}{0{,}4} = 0{,}1 = 10\% \text{ (rounded)}$$

E module of straw bales:
E = 0,4 N/mm²
(density >140 kg/m³)

This means that the bale with a height of 80 cm would be compressed by 10%. This very high load will rarely occur in practice, but nevertheless demonstrates the possibilities. It must also be considered that this load only occurred on the lowest straw bale layer on the ground floor, and that the calculated settlement of 10% does not relate to all storeys or the entire height of the building. An equation with the average value/floor (dead weight of the bales, etc.) + the respective added loads due to the intermediate ceiling + roof truss results in more realistic values. With four jumbo bales, their own weight already results in a theoretical settlement of 1.5–2 cm, and often more in practice, as the bales first have to interlock with each other. With ground-level construction and a light roof structure, the actual settlement of small bales is around 5% of the total straw wall height, and 3% for large bales. The settlement depends not only on the roof loads, but also on the load-bearing wall length/surface. For so-called HD bales with a density of approximately 220 kg/m³, the expected settlement is somewhat lower.

If you are working with small bales and the expected loads exceed 1000 kg/rm or the safety factor is to be increased, it is advisable to plan a load-bearing intermediate wall. During the settling process, work is carried out with retractable props, in whose place the corresponding timber posts are later installed. The props make it possible to follow the settlement. If point loads are expected at the sides of large window areas, metal supports are also used, which are later replaced by timber ledgers. In the case of continuous ceiling beams or trusses, a load-bearing partition wall can take up to 70% of the total load.

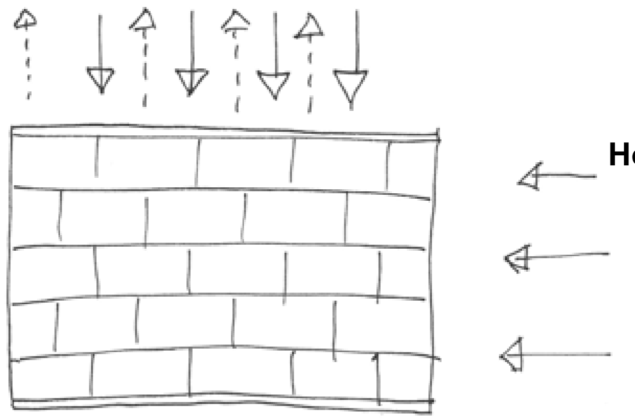


Test object for straw bale construction statics: House Fliri/Switzerland. holiday apartments. 3.5 floors. Only the corners, each consisting of 1.5 large bales, are load-bearing. Large window openings in all 4 directions.

6.2 Static forces

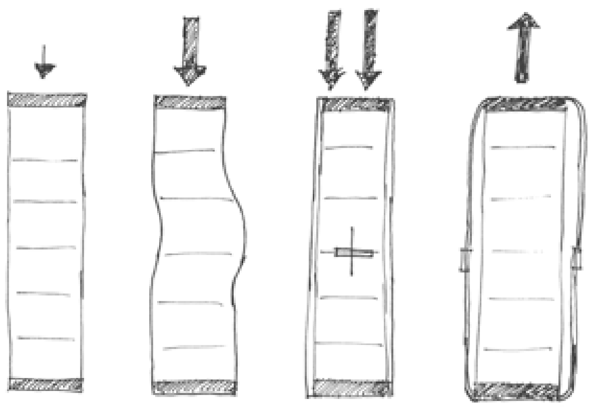
Various forces act on the load-bearing outer wall of a building, which the entire wall structure and the connections to other components such as the roof or foundations must withstand.
A distinction is made between two directions of force:

Vertical forces: roof loads + snow + wind suction



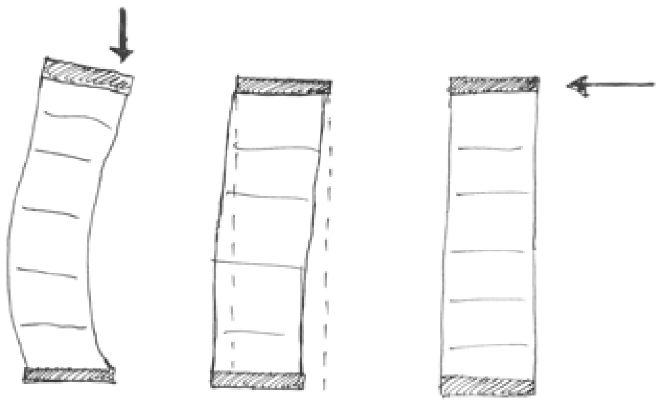
Horizontal forces: shear forces + wind

2.1 2.2 2.3 2.4



Vertical loads:
With heavier loads, the wall begins to bulge in the centre (2.2). The use of a bracing tension system (OSB) in the centre can prevent this. The plaster absorbs the remaining loads (2.3). Suction loads (wind) can only be adequately secured using straps (2.4)

3.1 3.2 3.3



Attention:
Loads on the wall crown should always be applied evenly (3.1), and only vertically, with no shear forces from roof trusses or similar (3.3), with the wall crown exactly above the plinth construction (3.2)

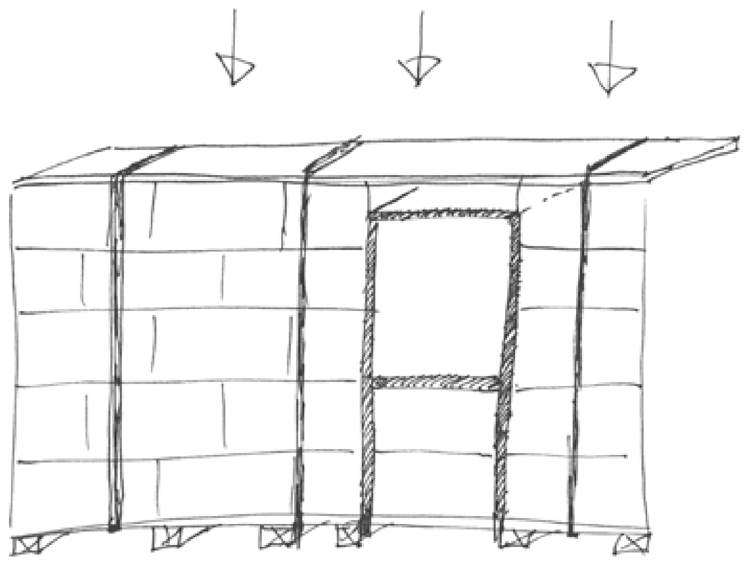
As far as roof and snow loads are concerned, the vertical forces can be absorbed well via the load-bearing capacity of straw bales and plaster layers.

Verification becomes more difficult with the forces that can arise due to wind suction. A static engineer often only accepts circumferential tension belts for these forces. These enclose the base construction mounted on the floor slab and the wall bench/RBA, to which the roof truss is then fixed. They provide a structurally effective connection between the foundation and the roof truss. If the tensioning straps are located at the plaster level, they provide additional strength, and integrate the plaster into the structural system. In addition, the plaster surfaces should overlap both the wall bench and the plinth construction (with reed stucco) over the entire surface in order to achieve a better structural connection. The tension belts are usually made of cross-woven synthetic fibres between 22 and 35 mm wide, and have a load-bearing capacity of 700–2500 kg. As the belts encircle the structure, twice the load-bearing capacity can be assumed in this case. The straps are attached to the wall with a centre-to-centre distance of 1–1.2 m.

Clamping device in use, also useful for facades to close joints and prevent settlement

During settlement, the belts should be retensioned repeatedly to achieve sufficient pre-tensioning. This allows settlement to be anticipated and controlled to a certain extent. The load application (roof loads) on the wall bench should only be vertical, and should be distributed in the centre or across the entire width.

Shear forces and one-sided load applications should be avoided. Ideally, the roof load should be evenly distributed over the entire length of the wall. To prevent uneven load distribution along the length of the wall, the smaller cavities above rigid timber structures such as window frames should only be stuffed with loose straw when the settlement over 24 hours is only a few millimetres.



7. Plasters

7.1 General
Straw bales can withstand the weather for quite a long time, as long as they do not become damp at the core. The straw stalks lie on the surface according to the water flow of the rain, so that moisture can only penetrate a few centimetres and dries out again relatively quickly. This applies primarily to bales that are installed lying flat, but even with upright installation, only a small amount of moisture penetrates. Nevertheless, the durability is limited, and the insulating effect is significantly worse without additional sealing. The fire resistance is also increased by the plaster: depending on the tests carried out, values for the fire resistance from 30 min (unplastered) to 90 or even 120 min have been found in the plastered state. This effect occurs from a layer thickness of 8 mm.
Before applying the plaster layers, care should be taken to remove or shorten loose and protruding straw in order to reduce the amount of work required later. The even surface allows the plaster to bond better with the straw bales and material consumption can be kept to a minimum (European Strawbale Gathering, 2002). The plaster layers reach a total thickness of 3–6 cm. The rule is that the thicker the plaster, the greater the heat storage and humidity equalisation effect of the wall (Minke and Krick, 2014).
With directly plastered straw bales, the capillary effect of the plaster is very effective for moisture transport, in contrast to wooden formwork or soft wood fibre boards underneath the plaster. Moisture peaks in the insulating material are transported out through the render on both sides, and can diffuse out over the surface. This property can be enhanced by a capillary gradient in the plaster structure, meaning that the individual layers (usually four) become increasingly fine towards the outside in terms of the grain size of the sand, resulting in smaller capillaries. In this way, moisture only spreads from the inside to the outside, and not the other way round. In addition to protecting against vermin, another function of plaster is to stabilise the walls. As already shown in the chapter on statics, plaster can transfer some of the vertical loads and contribute to bracing. Plaster even has a stabilising effect on old brick buildings.

Plaster are available as ready-mixes in plaster silos or as bagged goods. Increasingly, they are also mixed on site, and can be applied by machine or by hand. The main components of most plaster mixes are sand and a binding agent such as cement, lime or clay. For many industrial plasters, flowing agents, stabilisers, retarders, herbicides (against algae) or anti-freeze agents are also added to the ready-mix forms.

For a straw bale house, there are actually only two different plasters that can be considered:
1) Genuine clay plaster, which is typically used as interior plaster but can also occasionally be used as exterior plaster, depending on the climate and construction solutions (overhanging roof, etc.)
2) Pure lime plaster, without additives, for exterior use, although this can sometimes also be used indoors, e.g. on surfaces that are to be tiled, such as in the bathroom

Plasters with a high cement content and/or chemical additives usually prevent moisture transport out of the straw, and can cause condensation. For these reasons, in addition to their ecological and health aspects, such plasters should not be used in straw bale construction.

7.2 Clay plaster
Clay plaster is used as wall and ceiling plaster indoors, and to a limited extent outdoors. The use of clay plaster is one of the oldest building techniques known to mankind, as the raw materials are widespread, readily available and easy to work with. In Central Europe, the use of clay plaster was first documented in the Hungarian Körös culture (6200 to 5600 BC). In other regions (Africa, Asia), much older uses of clay as a building material have been discovered (see G. Minke - Lehmbauhandbuch).

In traditional timber-frame constructions in Europe, the individual compartments filled with wickerwork were plastered with clay, as this was the only way that the mostly weathered half-timbered beams could survive 500 years of exposure to the elements. Clay plaster removes moisture from the beams and preserves them. The cement plasters used for renovations in the 1970s and 1980s often led to massive damage to the supporting structure within a very short time. Apart from the renovation of old buildings by specialists, clay earth has become the focus of attention as a natural building material with favourable properties for building owners, architects and interior designers since the end of the 20th century, and its use is currently undergoing a boom.

Clay plaster consists of clay, sand and silt (fine sand). It hardens only through the evaporation of the mixing water, and there is no chemical reaction and no classic setting. Adhesion to the substrate is achieved by mechanical setting, and the fine platelet-shaped clay components act as a bond. The crystallised water that remains between the clay platelets even after the clay has completely dried out causes them to stick together, due to the surface tension of the water. Clay is one of the driest building materials (with an equilibrium moisture content of < 5%), and can also be moulded again with a sufficient supply of water, even after thousands of years. This is the reason why clay earth is only partially suitable for outdoor use in rainy climates. Sufficient roof overhang and hydrophobisation with special coatings are necessary in our latitudes, due to the risk that moisture will penetrate behind the coating if cracks form, which can lead to frost damage.

To improve properties such as workability, (cracking) strength, adhesion, abrasion, moisture resistance and surface texture, or to colour the finishing plaster, various materials are added to the clay plaster depending on the area of application. These include pigments, rock flour such as marble powder, fibres such as cellulose, chopped straw or hay, cow or horse manure, animal hair, or protein-containing substances such as whey, curd or animal blood.

Occasionally, lime or cement is also added to the clay. Depending on the proportions, only the colour may remain of the characteristic properties of the clay at the end of this process.

In some dry areas of the subtropics, clay plaster is traditionally applied to the entire outer skin of the house, including the roof. In order to increase resistance to the infrequent but often heavy rainfall, various organic (fibrous) substances and cow dung are added to the clay as a natural water repellent. The secret of a good clay plaster, apart from good-quality clay, is the sand. A uniform grading curve is ideal: this means that all grain sizes are present in equal proportions, which minimises the structural voids in the plaster. The sand is stable by itself. The strength is increased, and shrinkage during drying process is minimised. This makes it possible to apply several centimetres of render in one coat without cracking, which significantly improves the water retention capacity during application, an essential aspect for machine plastering. At a delivery pressure of 20 bar, the water would be pressed out too easily, leading to blockages in the delivery hose. The sand should be unwashed quartz sand that still contains the fines.

Clay plaster construction with reed mats on wooden surface, e.g. for partition walls or construction with an installation level

Clay plaster adheres to all substrates that suitable for other plasters, and forms a particularly good bond with the straw or reed stucco (wired reed straw) that is used as a plaster base in timber construction. If clay is plastered directly onto straw bales indoors, the structure usually consists of four layers. The first layer should be mixed rather „fat“ (with a higher clay content) and pressed as deeply as possible into the straw, either by the pressure of the machine and reworking with small smoothing trowels, or by hand. This first layer is referred to as pre-spraying or first coarse plaster. After this layer, straws are still visible on the surface and any unevenness caused by the straw bales has not yet been levelled out.

A clay plaster structure can be used with reed stucco on wooden formwork, e.g. for intermediate walls or structures with an installation level. After this layer has dried, the actual rough or base plaster is applied. At this stage, the straw disappears from the surface and major unevenness is levelled out. Again, it is only after complete drying that a layer can be applied in which a plaster reinforcement mesh is levelled, the so-called mesh plaster layer (approximately 10 mm). The mesh should be in the outer third, as otherwise the surface tension cannot be absorbed well. In the case of straw bale houses plastered by builders themselves, chopped straw is often used alone, instead of the mesh. However, contractors avoid this method due to the gun performance.

The final render layer is the fine or finishing render (3–5 mm). Its surface can be rubbed, brushed or smoothed, and should be painted with pure clay paint (clay plaster) after the plastering work. The total plaster build-up with straw is around 4–6 cm (material consumption), but the penetration depth is often significantly greater.

As clay does not set chemically, drying times vary greatly, and depend on humidity, temperature and ventilation. Under unfavourable conditions, drying times of several weeks may be required for coarse plaster layers, whereas with absorbent substrates such as brick, a few days are often sufficient. The mesh and fine plaster layer dries out after just a few days, as the dry coarse plaster can already absorb a lot of water.

Clay plaster has a wide range of positive properties:

- Dries out other components and preserves them
- Very dry building material (equilibrium moisture < 5%) and therefore well suited as a moisture buffer
- Good capillary effect, conducts moisture well
- Organic, compostable
- Reusable
- Unlimited shelf life
- Good heat storage capacity (1.0 kJ/kg K)
- Thermal conductivity of 0.47–0.93 W/(m K)
- Compressive strength higher than gypsum plaster (2–2.7 N/mm2, Class SII)
- Bending tensile strength of approx. 1 N/mm2
- Water vapour diffusion resistance μ = 5/10
- Density 1700–1900 kg/m^3
- Non-combustible (even with natural fibre admixture, if bulk density > 1700 kg/m^3)
- Very low primary energy requirements during production
- Can ideally even be extracted and processed at the building site
- Anti-allergenic (ideal for allergy sufferers)
- Fungicidal (kills fungal spores)
- Good modelling properties, due to high plasticity and long workability
- Significantly lower tendency to crack when the substrate moves, meaning that it is particularly suitable for wall heating and base ovens
- Neither irritant nor toxic during processing
- Is even used in the health and body care sector (healing clay, cosmetics)
- Neutralises odours (long-chain molecules that are perceived as unpleasant are broken down with the help of light = photocatalytic effect)
- Good acoustics and sound insulation
- Filters out e-smog even in thin layers (including mobile phones that are not in use)
- Contributes to ionisation of the room air
- Keeps the room air at a relatively constant humidity level (approximately 45–55%)
- Cools the room temperature by an average of 2°C in summer.

7.3 Lime plaster

Due to their properties, lime plasters are very popular in the ecological building sector and in the renovation of old buildings. Their attractive, white, easy-to-model surfaces were widely used in ancient Greece and Rome for building houses, palaces and temples, and there is evidence of even earlier use in ancient Egypt. However, the first use of this building material does not date back quite as far as clay plaster, nor does it have a similarly widespread use across all cultures on this planet, as its production requires a certain amount of effort and plenty of fuel.

Lime plaster consists of silicate-rich, ground limestone that is fired in a kiln and later extinguished with water. The CO_2 released during firing is reabsorbed and incorporated during subsequent setting. When extinguished with water, the chemical reaction generates heat (i.e. an exothermic reaction). Before this process takes place, the mixture is called quicklime, and afterwards, it is referred to as slaked lime. Setting only works with sufficient air, which is why this material is also called air lime. To prevent unused material from hardening, it is sufficient to cover the lime with water. During hardening, CO_2 is extracted from the ambient air and processed in chemical processes ($Ca(OH)_2 + CO_2 = CaCO_3$ or calcium hydroxide + carbon dioxide = limestone) so that limestone is finally formed. This hardening process can take up to five years, during which the strength continues to increase. Especially at the beginning of the process, slow drying without direct sunlight and temperatures that are not too high should be ensured, so that the mixing water does not evaporate too early and the plaster can reach its full strength.

Lime plaster structure with drip edge, here base plate in wood plastered on the front, the plastered straw bale wall already begins in the upper area

In addition to sand (at ratios of 1:2 to 1:5), various other materials can be added to this pure, natural lime. In the past, natural fibres, animal hair, limestone, or quartz sand were often used. Marble grains, marble flours and mineral lightweight aggregates can also be used.

Another frequently used form of lime is called trass lime. When trass lime plaster is sold in shops, it is usually a mixture of air lime and ground trass. Some products even contain mainly trass, with only a small amount of slaked lime. Trass was also used in the ancient Roman Empire, mainly due to its high strength. When added to normal air lime, it increases its compressive strength by a factor of seven, and at the same time reduces the possibility of lime efflorescence, which tends to arise in air lime. Trass lime binds both with air and chemically with water.

The term trass is not a precisely defined one, but usually refers to a tuff rock that is very similar in mineral composition to a material from one of the best-known mining areas, known as Reihnian trass.

Trass lime is made up of the following main components:
49–59% silica, 3–12% water, 10–19% alumina, 4–12% iron oxide, 1–8% lime, 1–7% magnesia, 3–10% alkalis (cf. Kiepenheuer).

Trass is significantly stiffer, more brittle and more absorbent than air lime, and absorbs and draws moisture from the surrounding materials correspondingly well. Hence, when using trass lime mortar, the final layer (fine/finishing render) must be hydrophobic. This can be achieved by applying an appropriate coating or a special fine plaster mixture, for example. Some manufacturers also add a small amount (< 5%) of cement or white cement to trass lime. The critical amount of cement admixture that can lead to structural problems in straw bale construction, depending on the wall structure, also depends on many other factors, such as local climate, heating system, etc. In the USA and Canada, many houses are protected on the outside with cement based plasters, and even during long snowy winters, no critical values have been achieved in measurements. From the point of view of building physics, the exterior render should be as vapour permeable as possible, which is why a cement-free render is generally recommended.

The structure of plaster and its application in straw bale construction are very similar to those of clay plaster. In the same way, this plaster is applied in at least four layers and a mesh is used. The drying times are usually shorter, but should be made as long as possible so as not to weaken the strength. We recommend suspending the façade with fleece, tarpaulin or similar.

Lime plaster can be applied by hand, but is usually done by machine, as the quality is usually better this way. For a straw façade, a plaster weight of 60–75 kg/m^2 (dry) is expected. This means that the total plaster weight for walls plastered on both sides (lime + clay) is 120–150 kg/m^2.

The first layer of lime plaster is sprayed onto the straw bale wall

Properties of lime plasters:

- Very high water absorption capacity from room air and building components
- Very open to diffusion
- High flexibility in the cured state, and hence less susceptible to cracking in the event of thermal or static movements of the substrate
- Good modelling properties, due to high plasticity and long workability
- Particularly suitable for renovating old buildings
- Very alkaline (pH value <12)
- Antibacterial, fungicidal
- Best processing temperature: 5–20°C
- Heat storage capacity 960 J/kgK
- Thermal conductivity is 0.7 W/(m K)
- Density 1600 kg/m^3 (up to 2500 kg/m3 for trass lime)
- Compressive strength > 2 N/mm2 for Class SII (and can reach 15 N/mm^2 for trass lime)
- Water vapour diffusion resistance μ 10/25
- Non-flammable
- Organic, compostable
- Absorbs gases such as carbon dioxide and sulphur dioxide and breaks them down
- Can be mined and produced regionally

Lime plaster finished, here on directly applied on a straw bale façade, wall structure with installation level

1.1.

The first layer is sprayed on and then pushed in further with a small smoothing trowel

1.2.

2x scratch coat of plaster, straw is no longer visible, on the left plastering machine for lime and clay plaster

1.3.

„Truth window“ plastered into a straw facade

1.4.

Lime plaster painted with colored milk of lime „fresco“.

1.5.

Clay plaster on large bales inside, surface painted with white clay

1.6.

Clay plaster on big bales inside, natural surface

8. On the construction site

Straw bale work normally begins with unloading the bales. The large quantities of material (120 m³ and more) are often unloaded by hand or, if large bales are used, by crane. Challenges arise in terms of unloading, and above all storing, the bales, as they take up a lot of storage and working space. For small bales, many helpers should be available, and an area should already be prepared on which the bales can be stacked. The storage area should be as close as possible to the building shell, and should be dry at the ground. A plastic sheet on the floor is not sufficient, as condensation can form and rainwater can easily collect on the floor inside the plastic. Pallets or stacks/boards with under-ventilation, and without foil on the ground, are more suitable. The stacked pile of bales should be tapered towards the top (with a pyramid or saddle shape) so that in the event of rain, the entire pile can be covered with ready-made tarpaulins in such a way that no water collects on the tarpaulin. Storing the bales under a tarpaulin for longer harbours a certain risk, as the bales can become damp. The construction process should therefore be organised in such a way that when the bales are delivered (preferably in the morning), many of them can be installed on the same day. With straw façades, the ground floor can often be completed by the evening if everything is well organised.

Good organisation also includes ensuring that the roof, including guttering, is ready for non-load-bearing construction and that all the woodwork and other preparations adjacent to the straw bales have been completed. The construction site should be well cleared and without other trades, as the straw work requires a lot of space and helpers. Having some empty BigBags on site helps with collecting the loose straw. For load-bearing construction, the roof truss should ideally be prefabricated, so that it can be assembled immediately after the walls have been pre-compressed. Depending on the building and site situation, it sometimes also happens that the (small) bales can be temporarily stored inside the building itself and then fed through the windows from the inside. In order to have enough space for straw work and plastering, a distance of 20–30 cm from the straw façade is recommended for scaffolding. A façade net on the outside, over the scaffolding, protects against excessive sun and, to a certain extent, rain, provided the roof overhang is large enough.

Having a crane or forklift on site to lift small bales to the upper floor or to insulate the roof is highly recommended. A crane must always be on site to move large bales. Sufficient space must be available for the crane‘s working area and for the bales, so that the large bales can be installed from above with the crane. A bale can weigh up to 400 kg, and the straw offers a great deal of frictional resistance. These bales can only be moved by a crane and and muscle power can only be used for fine adjustment. Both the timber construction and any scaffolding must allow for this working space.

Before the straw work begins, there is a need to check which penetrations of the straw bale wall are planned (e.g. electrical cables for outdoor lighting, power sockets, external blinds, doorbell, oven connection, ventilation, etc.). Electrical cables are laid in the joints when the straw bales are installed. Flue pipes and ventilation pipes should have their own appropriately designed wooden box, to prevent pressure from the straw on the pipes. In the case of straw facades, these boxes should already be permanently connected to the supporting structure, and should be sealed accordingly. The exact design of the flue gas duct must be discussed in advance with the individual responsible for fire protection. A ready-made F-90 flue pipe box for insertion or an enclosure with bromate boards (fire protection boards) are solutions that are usually accepted. However, due to the high insulation thickness, some certified standard solutions are not available.

Space is prepared, the bales can be unloaded

With big bales, the grapple must work well

Loose straw in the BigBag is used to plug the joints

Covering the top of the wall is sufficient in light rain

Checklist:

- Has timber construction been carried out in accordance with the straw construction specifications?
- Is there sufficient storage space for straw bale delivery?
- Are the stored straw bales protected from rain and rising damp?
- Do not use damp (>15% moisture) or mouldy bales
- Can the straw bale walls be quickly and adequately protected from rain?
- Do scaffolds leave enough space for straw and crane work?
- Is the distance between scaffold and finished straw wall 20–30 cm (max)
- What happens to loose straw? (Several BigBags may be needed, and the straw can be used later as garden mulch)

9. Prefabrication

Straw bale construction is very well suited to an owner-builder's personal efforts, and in the past mainly involved single-family homes; however, large buildings are now also being constructed with straw bales, and many owners have neither the time nor the energy to help build their homes.
For several years now, increasing numbers of companies have been producing prefabricated modules or entire walls in the factory as timber frame constructions with straw bales already installed. In some cases, a first layer of plaster has even been applied before the elements are brought to the construction site by truck.

This approach is particularly common for larger straw construction projects, as the construction process is much easier to calculate, and the construction time on site can be reduced to a minimum. Not every timber construction company has the infrastructure needed to prefabricate an entire house in individual elements in the hall, but there are companies that offer and transport their modules throughout Europe.

Whether the use of such modules makes sense for a private detached house can only be decided by each individual. To help you decide, here is a summary of the clear advantages of prefabrication, although some disadvantages should also be considered.

Advantages:
- Fast construction time on site
- Easier to calculate process and costs
- More independent of the weather
- Often easier to obtain authorisation (for large buildings)
- Uses an industrial production process, meaning that wider distribution of straw bale construction is possible
- Makes a more professional impression

Disadvantages:
- Usually more expensive for single-family homes
- High industrial timber content = less ecologically friendly
- Construction site must offer sufficient space for a truck and large crane
- Cannot be realised by every local carpenter

Conclusion:
The possibility of installing straw bales in prefabricated modules in the factory has opened up new opportunities that lead to greater distribution and better acceptance. Large timber construction companies can work as usual, and can easily integrate straw bales into their own processes. For these reasons, this approach is important for the future development of straw bale construction, even if private builders are perhaps more likely to opt for a self-build-friendly variant.

Delivering the prefab elemets to the site

Positioning the floor modules on the screw foundation

After a few hours of work already

After finishing

Prefab modules of Lorenz-Systems >>copyright Lorenz

Prefab modules of Ecococon >>copyright:Ecococon

10. Special features of the planning process

Each plan should take into account the wall structures, the materials used, and any special features. This is particularly important in straw bale construction, as many planners are not familiar with the building material, and a different way of thinking is required. The points that should be taken into consideration also depend on the way in which the straw bales are used. The most important factor is the bale size, which is not exact and is far removed from industrial dimensional accuracy. A small bale has a fairly standardised width of between 45 and 50 cm depending on the baler; the height can also vary depending on the baler, but most are around 36 cm. For all superstructures, the wooden structures should be flush with the straw surface. When planning the window frames for non-load-bearing construction, the parapet height + square timber thickness (ideally + 10 cm above the last whole bale) should be planned; for example, this gives 2 x 50 + 10 cm for the bottom edge of square timber. This approach simplifies pre-tensioning and stuffing below the window frame. The length of small bales is only important in wall construction if their positions are between a timber frame construction. An ideal situation is when the bales fit in with only slight pressure. The distance between rafters for bale insulation can also be a few centimetres longer than the bale length, as the bale strings can be cut to fill all cavities. With a straw-insulated floor slab, an intermediate spacing is selected that corresponds to the bale width, which is usually 50 cm. This significantly increases the load-bearing capacity and also makes the bales easier to install. The strings are also usually cut open in this case.

In the load-bearing construction method, the bales usually lie flat, i.e. with a theoretical height of 36 or 70 cm (for jumbo bales). This theoretical height can no longer be found above the third layer at the maximum, as the bales give way due to compression. How much settlement is actually measured in the end is difficult to calculate for small bales, and requires a lot of experience. It is therefore advantageous to assume more settlement in order to prevent the RBA from sitting on the window frame later and jeopardising the entire statics. Stiff components such as partition walls or additional posts are only installed at fixed heights once settlement is complete, and before this, construction supports or threaded rods are used. The 20–30 cm free space above the window frames up to the RBA should only be filled with straw after complete settlement. For smaller windows that are also bricked up, the overall height of the window frame should be a few centimetres less than the theoretical bale size, to allow for settlement.

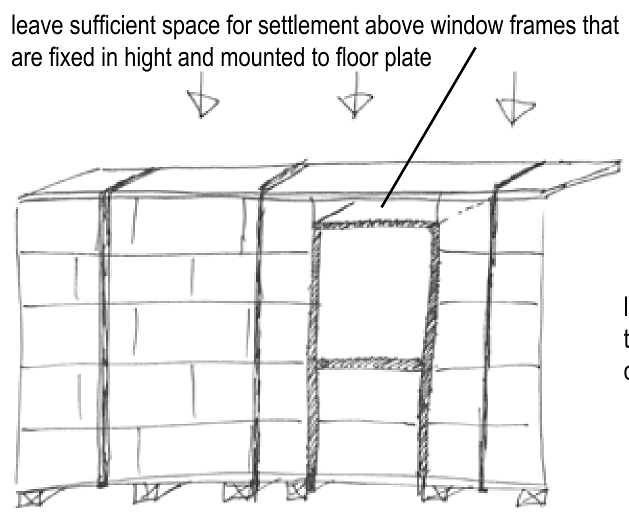
For straw bales, length has the greatest variance. It can be adjusted as required on the baler, but also depends on the swath (width and amount of straw in the lanes on the field) and the driving style. Even with good small bales, the difference in length can still be up to 10 cm. For a load-bearing building, a length of 100 cm is assumed (by the dealers who have bales of the required density and this length), although the length is less important for small bales, as many bales have to be resized despite good planning, and this can be done very quickly with small bales.

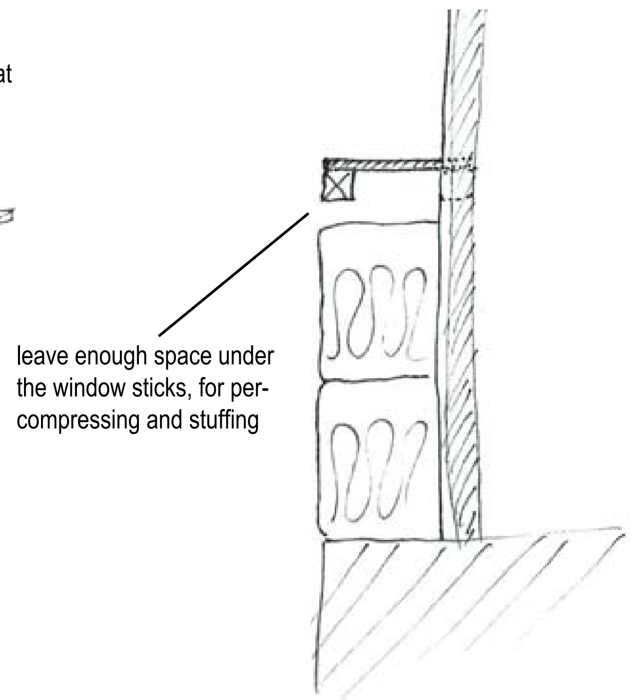
With large bales, however, there is a need to pay closer attention to the length, as rebinding on the construction site is tedious and can take 20–30 minutes per bale (assuming the availability of a crane/forklift). The theoretical length of most jumbo bales is 240 cm. This is much more precise than with small bales, but there can still be small differences in length, and gaps can occur. Hence, when planning, a length of 245 cm or even 250 cm should be used in the calculations. Stuffing a joint later is less work than having to adjust the length of the bales.

Half bales are needed in every second layer in order to build a wall. For this reason, the builder should order a corresponding number (+ reserve) of half bales from the straw bale dealer before harvesting. The desired length should be specified to the dealer as 5–10 cm shorter than the theoretically required length, as half bales are usually longer than planned in practice.

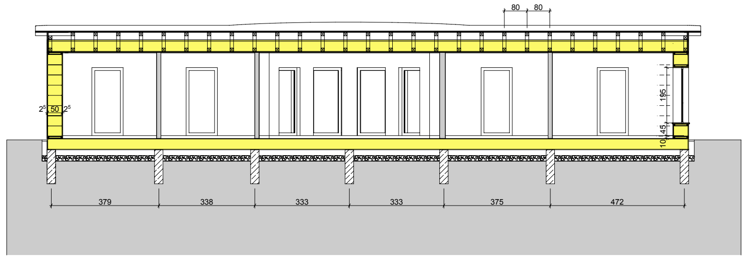
The following points should be observed in regard to the statics:

- No point loads on the RBA (wall crown or ring anchor)
- Avoid thrust forces on the RBA
- Do not place any loads on a butt-ended wall; always plan for wooden posts here
- Do not use different bales for one building, i.e. use the same batch for preference
- When heavy snow loads are expected, plan partition walls that can support these loads
- Have as few windows as possible, which are as small as possible, in the load-bearing walls (usually two)
- The wall length without bracing can be up to a maximum of 6 m (for small bales with a width of 50 cm)
- Keep roof loads as low as possible with small bales



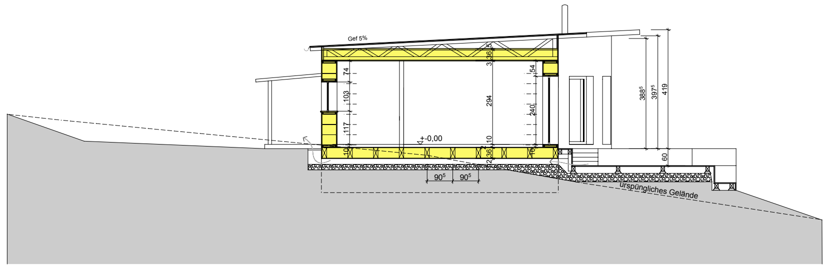


11. Project Gallery



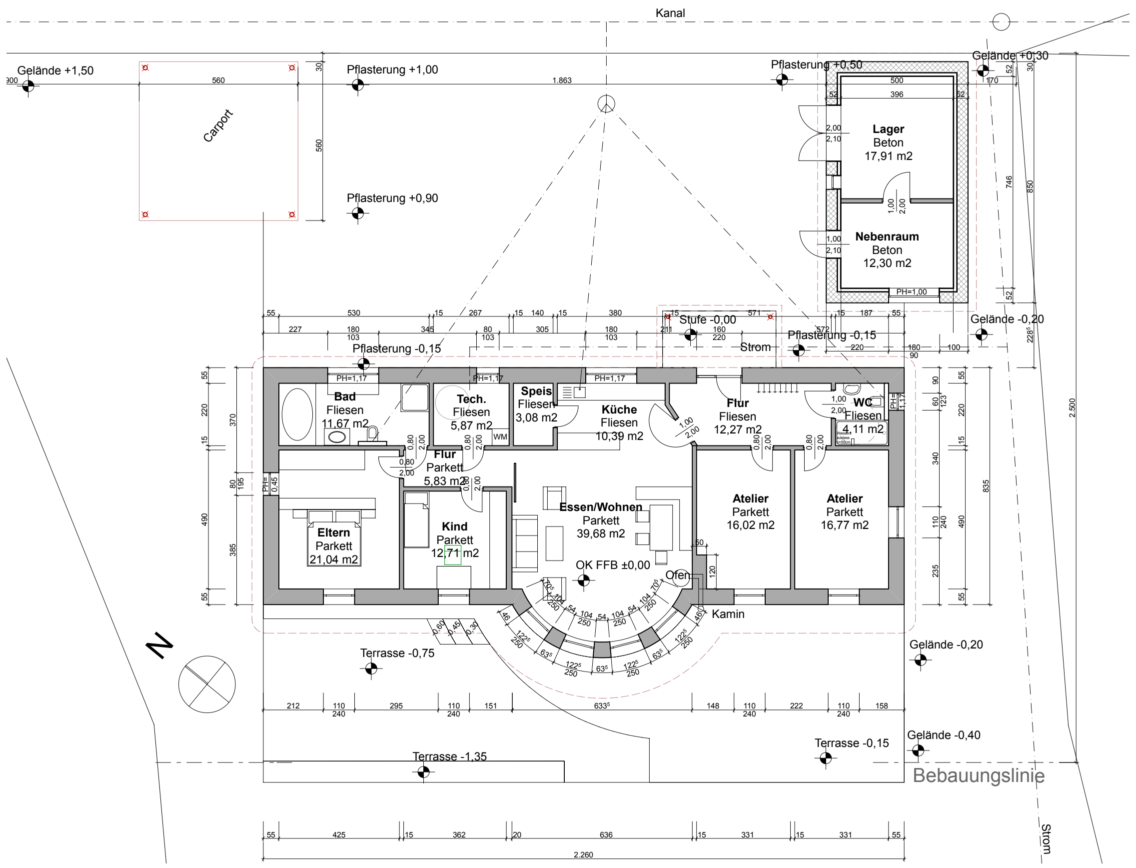
Schnitt A-A

Project near Graz: probably largest load-bearing building with small bales in Europe
Total space: 240 m²
Built: 2012
Design: Arch. Joerg Spoettl
Straw bale work: Virko Kade



Schnitt B-B

Schnitt A-A



Filling the base plate with straw bales

Everything ready for the first bales

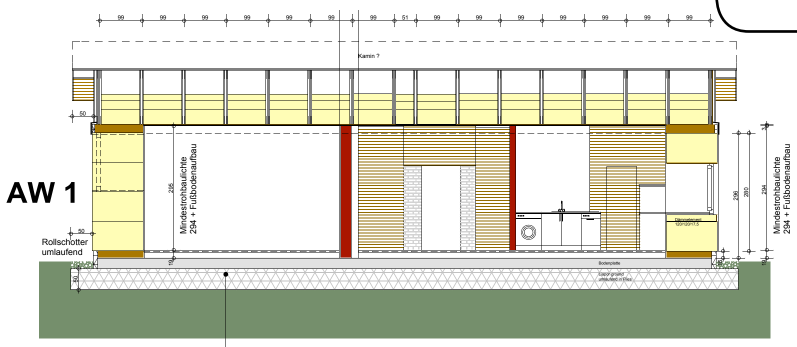
After 2.5 days of straw construction, the outer walls are in place and the roof truss can be installed

Prefabricated nail trusses are assembled

The roof skin is rain tight, the roof truss is insulated, the settlement is complete, only a few plaster preparations are left

Exterior plaster finished

Project in Fürstenfeld:
load-bearing with BigBales
Total space: 110 m²
Built: 2017
Design: Arch. Juliane Gölles
Straw bale work: Virko Kade with participants of an international straw bale workshop

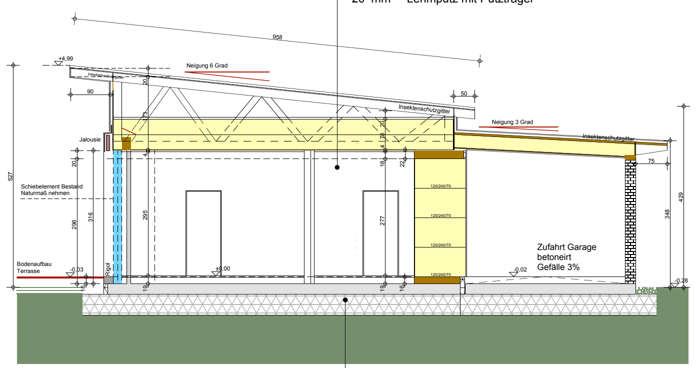


FB 1

40	mm	Bodenziegel
50	mm	Mörtelbett
60	mm	Estrich
40	mm	Schüttung
250	mm	Bodenplatte Stahlbeton
500	mm	Liapor ground umlaufend in Flies

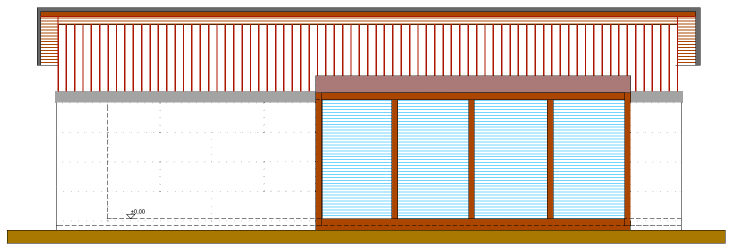
D1

		Blecheindeckung Doppelfalz nach Vorgaben des Produzenten
20	mm	Rauhschalung
720-1720	mm	Pfostenbinder dazwischen Hinterlüftung
50	mm	Lehm als Brandschutz
720	mm	Stroh 2-lagig Ballen mi90/50/36
19	mm	OSB-Platte Stöße verklebt
20	mm	Lehmputz mit Putzträger



FB 2

15	mm	Fliesen geklebt
70	mm	Heizstrich
100	mm	Schüttung
250	mm	Bodenplatte Stahlbeton
500	mm	Liapor ground umlaufend in Flies



Floor slab in concrete insulated with Liapor Ground. Straw bales are moved with a crane

On the 3rd day the roof truss is mounted

Completely assembled, ready for the formwork onto ceiling

2 layers of small bales are brought in from above, strings cut later

After 5 days of workshop, the insulated shell is complete

Only the design of the outdoor area is missing

Load-bearing with big bales NUA: 90 m² Built: 2010

Timber frame+ straw facade NUA: 220 m² Built: 2006

BigBales with ladder system, partially load-bearing, plastered on bothe sides NUA: 170 m² Built: 2012

Ladder system, straw plastered on both sides NUA: 180 m²
Built: 2014

Ladder system, straw plastered on both sides NUA: 180 m²
Built: 2014

Old brick building with straw bale facade NUA: 150 m²
Built: 2010

Timber frame+ straw facade NUA: 180 m² Built: 2015

Old brick building with straw bale facade NUA: 190 m²
Built: 2013

Timber frame+ straw bale facade NUA: 180 m² Built: 2009

Timber frame+ straw bale facade NUA: 130 m² Built: 2017

Old brick building with straw bale facade NUA: 300 m²
Built: 2012

Timber frame+ straw bale facade NUA: 150 m² Built: 2010

Hotel in South Tyrol - straw construction and planning Architect W. Schmidt

Sunny side

From above

Access side

Belgium

„Strohpolis“ block of flats in Germany

International projects by various builders

Load-bearing with small bales -Werner Schmidt/Switzerland

Rear view

Center for sustainable building in northern Germany

7-story straw bale house in the Vosges/ France

Farm in Germany

Load-bearing with BigBales, Switzerland, Arch. Werner Schmidt

12. Experimental

In order to advance the development of straw bale construction, and to test the current limits and to expand them, there are always pioneers who take risks, try out new things, carry out intensive research, or just want to make a statement.

The following is a small selection of the countless projects that have been realised worldwide by creative architects, master builders and straw bale builders. These projects are becoming ever larger and more professional. The structural potential is also being increasingly utilised. Financing by public authorities, research institutions and property developers will become easier, and is expected to lead to greater acceptance in terms of both public perception and building authorities.

Concrete-free floor slab with BigBales in Germany

Finished, walls load-bearing with large bales

Straw bale vaulted house Den Ham/ Netherlands

Straw bale pavilion for Expo 2008 in Zaragoza/ Spain

Load-bearing with big bales - Arch. Werner Schmidt/Switzerland

3.5 floors, currently the tallest load-bearing building

Large attic

Apartment for rent

Load-bearing machine hall with big bales, for company Sonnen-Klee (A) -Project of the author

Machine Hall-2 finished, 40m x 20m (Hall-1: 20m x10m)

Load-bearing straw dome with grass roof without ventilation.
Planning: Gernot Minke, Zuzana Kierulvova / Slovakia

Interior impression of the architectural office

During construction, individual barrel vaults clearly visible

Structure: Clay plaster on the inside on straw bales, clay on the outside, then pond liner and grass roof. No condensation (!) - hard to believe in terms of building physics...

Load-bearing barrel vault in Wangelin/ Germany

The formwork

Vault finished with small bales - clay plaster is applied inside

Device to cut the bales conically, (high precision is necessary)

First load-bearing building approved in Austria Client + straw bale construction: Virko Kade Built: 2004

Almost finished

Static experiments with students from the Salzburg University of Applied Sciences no conically cut bales were used

A first dome attempt... again FH Salzburg

13. Costs

It only makes a limited amount of sense to give a reliable, absolute value for construction costs, as the actual costs depend on local conditions, regionally very different costs and the wishes and priorities of the builders. In addition, the price of single-family homes has been rising at an annual rate of around 3–4% for several years (according to Statistics Austria), following a long period of stagnation (not to mention the cost explosion between 2021 and 2023).

An important point when estimating the actual costs are the ancillary building costs, as these are rarely included in an offer. Connection fees for sewerage, electricity and water, for example, can vary greatly from place to place, from 6,000 to 15,000 euros. Planning costs, official fees and notary fees, which are separate from the purchase of land, are often not taken into account in private calculations and company offers. It is also difficult to make a realistic estimate of the time and energy resources available, as these are often underestimated.

Definition:
The so-called construction costs (in accordance with ÖN B1801-1 or DIN 276) include the costs incurred on the construction site, from the excavation for the foundations to painting. All planning and authority costs are excluded, as are outdoor facilities and connection fees for electricity, sewerage and water. In 2016, an average value of approximately 2000 euros/m² net usable area was assumed for these costs of conventional house construction in Austria and Germany; with a high level of personal contribution, this value could be reduced to 1500 euros/m². In the ecological or passive house sector, these costs averaged 2200–2500 euros/m² in 2021, this was more the conventional average, but this has now risen to 3500 euros/m²!

When it comes to straw bale houses, builders assume either significantly lower or significantly higher costs. When the exterior wall of a straw bale house is compared with that of a conventionally built house, the costs can differ greatly in both directions, depending on the structure. However, the exterior walls only account for 13–15% of the total construction costs. Comparing the construction costs for a straw bale house in which the roof or floor slab is insulated with straw bales in addition to the walls gives a more realistic picture. Many projects in Austria and Germany have been completed in recent years using ecological, passive house construction methods at costs comparable to those for conventionally built houses.

Statistical surveys carried out by the German Straw Bale Building Association (FASBA) showed that the straw bale houses that had been built were only 2% more expensive than the conventional national average. In general, it can be stated that straw bale houses can be priced in the same range as conventionally built houses, or are only marginally more expensive.

Below is a list of the various items that are involved in straw bale construction. Material and labour costs can vary greatly depending on the region/state, even when comparing urban and rural areas. Hence, these net costs only give a rough idea. The prices of straw building projects in Austria over the last 15 years are used as data. Personal work by the builders was not included, but is possible for almost all items.

Pos	Layer/ Structure	(net) Costs/ m²
1	*Straw bales (small) delivered and unloaded*	15 - 25,- euros
2	*Small bales mounted on the facade (incl. dowels, excl. straw)*	20,- euros
3	*Lime plaster or clay plaster on straw bales (4 - 6 cm thick), without painting*	40 - 60,- euros
4	*Coats of clay paint inside or lime paint on the outside*	10 - 15,- euros
5	*Clay plaster on reed mats (2 - 2.5 cm thick)*	28 - 30,- euros
6	*Reed mats fully mounted (including material)*	12 -15,- euros
7	*Reed mats, material costs*	2 - 3,- euros
8	*Straw bales single layer installed into base plate or roof (excl. material)*	10 - 20,- euros
9	*Timber frame construction with installation level, 6/12 posts, OSB panel 22mm, rough boarding 24 mm, everything assembled, without cavity filling (e.g clay fill, on-site)*	60 - 70,- euros
10	*Timber frame construction (double post/ ladder system), incl. head sill and window boxes*	40 - 50,- euros
11	*Bale assembly for postion 9 or CUT system*	30,- euros
12	*Load-bearing construction of small bales (without plaster and timber construction, incl. bale)*	40 - 50,- euros
13	*Load-bearing construction with jumbo bales (without plaster and timber construction, bales and crane)*	50 - 60,- euros
	Complete superstructures	
14	*Load-bearing (pos. 12) + plastered and painted on both sides*	155,- euros
15	*Load-bearing (pos. 13) + plastered on both sides*	165,- euros
16	*Timber frame incl. straw + plastered on both sides (pos. 2,3,4,5,8)*	175,- euros
17	*Ladder system + plastered on both sides (pos 2,3,9,10)*	165,- euros
18	*Base plate (8/36 laminated beam, 15 mm OSB below, 22 mm above, fully assembled and filled with straw bales) on strip foundations (e.g.)*	110 - 120,- euros
	Comparison of conventional constructions	
19	*Bricks 50 cm + interior and exterior plaster*	125 - 140,- euros
20	*Bricks 25 cm + 16 cm EPS + interior and exterior plaster*	140 - 160,- euros
21	*Timber frame wall including insulation 25-30 cm, exposed wood + sheetrock*	190 - 240,- euros

The calculation is based on a cost for man-hours of 45.00 euro (net)   Status: 2022 Compiled by: Virko Kade

14. Building law

Getting a straw bale house approved in Austria or Germany is no longer a problem under building law, as long as the statics are taken over by another construction. Most certificates relate to suitability as an insulating material with the corresponding approval. Insulation properties, fire resistance and, in some cases, sound insulation are stated in the certificates or data sheets, and are sufficient to obtain a building permit. Most insurance companies have already accepted straw bales as a building material. For the approval of a building project, it is sufficient (depending on the building authority/region) to enclose the corresponding values according to the certificate, without actually testing the bales (in Austria, many conventional building materials that do not have a CE mark are used in practice in the private construction sector, in addition to sawn timber or plasters mixed on site, for which there is no CE mark).

If the building authority requires actual testing/certification of the straw bales used for the submission, there are two options: (i) to buy and install bales that have already been certified, or (ii) to buy bales from a straw bale dealer (or obtain them from your own field) and have the bales tested and certified on site. The relevant contacts can be found at the end of the brochure under Sources.
The Austrian certificates for building with straw bales do not involve precisely specified wall structures with straw bales as part of the approval. For straw bale buildings in Germany, there is a component catalogue compiled by FASBA with recommended, building-physics-tested superstructures. If a load-bearing building is submitted, the most commonly used option in Austria and Germany is the so-called „approval in individual cases“. The building authority responsible for this can issue a building permit without requiring structural analyses or a convincing demonstration of the load-bearing capacity of the building. In Austria, it is often sufficient for a carpenter to assume responsibility for the statics vis-à-vis the authorities, even without an opinion from a structural expert. As there is currently no general building approval for load-bearing construction in Austria and Germany (at least for small bales), approval is often a matter of negotiation. A few years ago, the certificate of the „Group for Adapted Technologies“ (GrAT) of the Vienna University of Technology was supplemented to reflect the load-bearing construction method with large bales. However, it does not specify any limiting values or static calculations, and merely states that a series of tests with jumbo bales with a maximum load of 21 tons was carried out without failure and that the bales can therefore be installed with static load. If jumbo bales are used, this certificate can therefore be included with the submission, which makes it easier to obtain permission.

In many other countries, the approval procedure and the associated distribution of liability is much simpler, which in practice leads to a greater and faster spread of the various straw bale construction methods. In the UK and Switzerland, load-bearing straw houses are now predominantly built, while in the USA, Canada and Australia, timber frame constructions are the exception rather than the rule. In France, there is a strong straw bale building lobby supported by the government, which has led to over 3,000 straw bale houses being built in recent years.

Note:
For construction projects where nothing else has been agreed between clients, planners and contractors, the current version of the German Straw Building Guidelines should be deemed to have been agreed (which can be downloaded from www.fasba.de). I also recommend using this set of rules as a basis for tender texts!

On the following pages, you will find the most important tests and data sheets for straw bale construction that are relevant to Austria, Germany and most parts of the EU:

Table of contents

14.1 Data sheet: SonnenKlee

Straw Insulation Data Sheet

SonnenKlee

Valid for the processing of certified construction straw bales according to the European Technical Approval ETA-10/0032. The approval for organic blow-in straw is currently still in progress!

Areas of application

Non-load-bearing thermal and airborne sound insulation material for walls, roofs and ceilings or floors. The insulating material must be protected from moisture, direct weathering and contact with the ground.

Processing •

Installation by trained personnel • The insulating material must be protected from moisture during transport, storage and installation. • The corresponding, regionally applicable building regulations must be observed. • Construction straw is of the prescribed density, avoiding any voids or joints to be inserted into the insulation level. • Thermal bridges are to be avoided

- **All components in vapor-permeable construction are to be designed and implemented accordingly, so that no condensation can occur in the insulating material.**
- **When insulating the top floor ceilings, accessibility (e.g. through a fire protection formwork).**

Technical specifications	Organic blowing straw	Organic construction straw bales	test standard
ingredients	100% organic wheat straw without any additives		
bulk density	Blanket 95 – 110kg/m³	100 – 125kg/m³	EN1602
	Wall 100 – 125kg/m³		
thermal conductivity fractile value	ÿ1 0 ,dry,9 0 /9 0 = 0.0448 W/mK	ÿ10,dry,90/90 = 0.0448 or 0.0792 W/mK depending on the installation	EN ISO 10456
thermal conductivity face value	ÿD(23/50) = 0.047 W/mK	position ÿD(23/50) = 0.047 or 0.084 W/mK depending on the installation	EN 12664 or EN 12667
thermal conductivity rated value	ÿr = 0.050 W/mK	position ÿr = 0.050 or 0.087 W/mK depending on the installation position	ÖNORM B 6015-5
reaction to fire	Class E		EN ISO 11925-2
resistance to molds	2		CUAP, Annex C EN ISO 846
Steam diffusion resistance number	μ = 2.3		EN12086
Water absorption, short-term	6.96 kg/m² with a bulk density of 105kg/m³		EN1609
corrosion ability	no corrosion potential r = 2.7		CUAP Annex E
flow resistance	kPa s/m²		EN29053
dimensional stability temperature and exposure to moisture		Change in length ÿÿl = 0.8% Change in width ÿÿb = 0.7% Thickness change ÿÿd = 0.0%	EN1604
moisture content of raw material	< 15%		
weed trimming straw	< 0.5 weight %		
residual grain content	< 0.4 weight %		
specific heat capacity c	2000 J/kg·K		Source: FNR - Agency for regrowing raw materials

Advice and sale of natural insulating materials:

SonnenKlee GmbH

Reinhard APPELTAUER
Reinhard APPELTAU664 266

+43 7448 21932

r.appeltauer@sonnenklee.at

www.sonnenklee.at

14.2 Data sheet: S-House-Ballen

Technical Data Sheet

S—HOUSE bales

GrAT

The **S-HOUSE bale** is a Cuboid, mechanically bound insulating material made from grain straw, which has particularly good properties in the areas of heat, heat and sound insulation.

ÿ Field of application

oh walls

o ceilings (top floor) o roof structures

ÿ Benefits use

o Optimal thermal insulation due to the higher density o diffusion-open wall and roof structure

o High heat retention and excellent summer Thermal protection through the high mass and wall thickness

o Best soundproofing properties

ÿ Benefits application

o Better edge and Corner shape due to the higher density

ÿ Benefits ecology

o Low primary energy content, because for the production (mechanical pressing) little energy is required

o CO2 binding, since the product consists of renewable raw materials

o Free from harmful additives

o Domestic insulating material from Austria

ÖTZ-2010/015/6

Technical specifications	S HOUSE bales
format	variable
Length [cm]	30 - 80
Width [cm]	30 - 130
Height [cm]	35 - 120
Density [kg/m]	>100
Thermal conductivity (in pressing direction) ÿ10, dry [W/mK]	0.043
Design value (in pressing direction) ÿr [W/mk]	0.049
vapor diffusion (μ)	4.4
Fire behavior [Euroclass according to EN 13501-1: 2007]	E
Water absorption Wp [kg/ m]	5.76
Flow resistance r [kPa s/m]	2.0
Dimensional stability at 70 °C, 50 % re. LF [%]	Length: - Broad: - Thickness: +2.6

ÿ Raw Material

o Untreated grain straw

o Yarn, cord or ribbon as a mechanical binder

Adaptive Technology group
technical University of Vienna
Development and dissemination of sustainable technologies

Wiedner Hauptstr. 8-10
A-1040 Vienna
Phone: ++43 1 58801 49523
Fax.: ++43 1 58801 49533

www.grat.at
www.s-house.at
www.nawaro.com

14.3 Data sheet „Baustrohballen“

Technical data sheet "Construction straw" according to the European Technical Assessment ETA-17/0247 of DIBt

- Status: October 2017 -

Publisher: BauStroh GmbH, Artilleriestr. 6, 27283 Verden
www.baustroh.de ~~info@baustroh.de~~

Construction straw is a thermal insulation material, infill wall former and plaster base for new buildings as well as external insulation in existing buildings

Nominal thermal conductivity ÿD (23/50) (perpendicular to stem orientation)	*0.048 W/(mÿK) **
Density when installed	*100 ± 15 kg/m3 **
Reaction to fire	*Class E, normally flammable **
Water vapor diffusion resistance factor µ	*2 **
Moisture absorption in percent by mass at 23°C and 80% rel. humidity	*ÿ18% by mass **
Moisture protection Annex B of the European Technical Assessment for Building Straw ETA-17/0247 specifies	
	physical building conditions for adequate moisture protection for external walls and roofs insulated with straw. Other building physics verifications that go beyond this are not covered by the approval, even if they are possible in individual cases. See also information sheet on direct plastering of construction straw.*
Specific heat capacity c	*2,000 J/(kgÿK) ***
Specific flow resistance Rs	*181 Pas/m ***
Heat transfer coefficient u (3 cm clay, 36 cm straw/plank stand, 3 cm clay)	*0.153 W/(m2ÿK) ***
Fire resistance class (normally flammable with > 8 mm plaster)	*F 30-B***
Evaluated airborne sound reduction index Rw, R (thatched outer wall with 36 cm straw between plank stands, 1 cm each / 2 cm of clay plaster on one side)	*43 and 44 dB, respectively ***
CO_2 reduction in the atmosphere at u = 0.10 W/(m2ÿK) during production	*88 kg/m2 wall (CO_2 equivalent)*

A properly executed straw component is protected from pests, fire and moisture.

* Source: European Technical Assessment for "Construction Straw" ETA -17/0247
** Source: Straw Construction Guideline 2014 FASBA eV

The sources and documents mentioned are stored on our website at: www.baustroh.de/downloads

14.4 Fire resistance test

MPA Braunschweig
Seite 8 zum Prüfbericht Nr. 3248/3833 vom 14.08.2003 -CM-

8 Besondere Hinweise

8.1. On the basis of the test results available (see Tables 1 and 2) with a fire resistance duration of > 90 minutes and further test experience available, it is recommended that the fire resistance class ‘REI 90’ be classified in the future classification standard for the preparation of a general building inspection test certificate.
>>translated within the original document

8.2. Voraussetzung für die Gültigkeit der vorgenannten Aussagen ist, dass die in diesem Prüfbericht angegebenen Randbedingungen eingehalten werden.

8.3 Die Gegenüberstellung und der Vergleich der Prüfergebnisse mit den Anforderungen der Bauregelliste für die Erstellung eines allgemeinen bauaufsichtlichen Prüfzeugnisses als Anwendbarkeitsnachweis im deutschen bauaufsichtlichen Verfahren sind in der Tabelle 3 (Anlage 1) dargestellt.

Der Direktor
i.A.

RR Dipl.-Ing. Nause

Der Sachbearbeiter

Dipl.-Ing. Maertins

Braunschweig, den 14.08.2003

Verzeichnis der Anlagen siehe nächste Seite.

14.5 Lambda value test (without surcharge)

Gruppe angepasste Technologie
Technische Universität Wien
zHd. Herrn D.I. Wimmer
Wiedner Hauptstrasse 8 - 10
1040 Wien

MAGISTRAT DER STADT WIEN
MA 39 – VFA
MAGISTRATSABTEILUNG 39
VERSUCHS- UND FORSCHUNGSANSTALT DER STADT WIEN
gegründet 1879
AKKREDITIERTE PRÜF- UND ÜBERWACHUNGSSTELLE
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Telefax: (national 01), (international +431) 79514-99-8039 oder DW
Internet e-mail: post@m39.magwien.gv.at

MA 39 - VFA 2000-0563.02

Wien, 6. November 2000

Untersuchungsbericht

über die Messung der Wärmeleitfähigkeit von

Strohballen

Antragsteller: Gruppe angepasste Technologie
Technische Universität Wien

Antragsdatum: 6. April 2000

Prüfgut: Das Prüfgut (2 Holzrahmen, - oben und unten mit Eisengitter abgeschlossen und mit Stroh verfüllt) wurde am 6. April 2000 an die MA 39 - VFA geliefert. (um Messverfälschungen zu vermeiden wurden vor der Messung die Eisengitter entfernt).

Die Rahmen besaßen die Abmessungen
500 mm x 500 mm x 100 mm

Auf Wunsch des Antragstellers wurden die Rahmen mit Strohfüllung nach einer entsprechenden Vortrocknung geprüft.

Prüfprogramm: Messung der Wärmeleitfähigkeit mit dem Plattenapparat gemäß ÖNORM B 6015-1 (letztgültige Ausgabe)

Kurzbeurteilung: Die Strohballen weisen eine Wärmeleitfähigkeit von $\lambda_{10,tr}$ = 0,0380 W/mK auf.

Der Bericht umfasst 2 Seiten.

14.6 Extract: S-House-Ballen load capacity

2.10 Brandverhalten

Die Konditionierung des Prüfgutes erfolgte entsprechend EN 13238 bei einer Temperatur von 23 +/- 2 Grad C und bei einer relativen Luftfeuchte von 50 +/- 5 Prozent bis zur Massekonstanz.

Die Prüfung erfolgte gemäß ÖNORM EN ISO 11925-2.

In Übereinstimmung mit der ÖNORM EN 13501-1 wird das oben angegebene Bauprodukt bezüglich seines Brandverhaltens mit **„E“** klassifiziert.

2.11 Load Capacity

The material to be tested was analysed by the state testing institute ‘Baulabor’ - Graz at the higher technical college ‘Ortweinschule’. The test report was sent to the client on 20 April 2012.
The test to determine the load-bearing capacity (compressive stress with force deformation measurement) for straw bales was carried out with 8 different test specimens measuring 240cm x 80cm x 70cm. The test was carried out in the testing centre‘s hall at 19-21 C and 40-41% relative humidity.
The pressure application was carried out with a hydraulic test frame M5 at a centric load application of 3.0 KN/s. The tests were finished at a load of approx. 210 KN and a compression of approx. 80 mm.

The results of the compression load must be taken into account when using the ‘S-House bales’ for load-bearing straw bale construction (see section 1.2)

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3 Produktbestimmungen / Prüfbestimmungen
(Herstellung, Kennzeichnung und Überwachung)

3.1 Herstellung
Die Herstellung erfolgt mit einer geeigneten Presse durch ein Verdichten (Pressen) in Längseinrichtung und wird bei Erreichen der gewünschten Länge mit dem Bindemittel (Garn, Schnur, Band) abgebunden.

Die Herstellung muss nach den Zusammensetzungen und dem Herstellungsverfahren erfolgen, die im Qualitätshandbuch beschrieben sind.

3.2 Prüfbestimmungen
Die unter Punkt 2 Anforderungen sowie Eigenschaften ermittelten Werte sind mit den Prüfbestimmungen der OIB-Richtlinie „Brennbare Dämmstoffe für den Wärme- und/oder Schallschutz“; Ausgabe Februar 2000 sowie ergänzenden Nachweisen, nachgewiesen worden.

15. Building physics

15.1 General introduction

Building physics is concerned with the physical properties of individual building materials and multi-layer structures. Of particular interest here are the investigation of insulation properties, the heat storage capacity, the way in which moisture is absorbed and transferred, general moisture tolerance, and sound insulation and acoustics. Historically, building physics became more important at the beginning of the 1970s, and was used as a companion to both traditional and modern construction techniques. Traditional construction involves the use of natural and locally available building materials or refining them on site with little effort before they are used in a building. Traditional construction methods develop based on the experience and precise observations of many generations, and is usually optimally adapted to local needs and conditions. After the Second World War, in the 1950s and 60s, the focus turned to industrially manufactured building materials such as concrete. Triggered by the oil crisis at the beginning of the 1970s, houses began to be insulated with EPS (polystyrene, only a few centimetres thick) on the façade. However, this first phase of modern construction often led to structural damage, due to condensation and mould formation. These negative effects were exacerbated by the switch from radiant to convection heat in heating systems, which meant that building components themselves were hardly heated at all, in contrast to the use of tiled and wood-burning stoves. Since then, attempts have been made in the domain of building physics to describe practical experience with new construction methods using measurement technology and mathematics, in order to avoid future structural damage. This relates to both negative and positive experiences. From the point of view of building physics 20 years ago, a directly plastered straw bale wall could not function without structural damage; however, thousands of buildings worldwide have proved the opposite. In the meantime, simulations have improved considerably, and can evaluate superstructures more realistically.

Straw bale construction fulfils the definition of traditional building methods, with a history stretching back over 100 years; however, it also fulfils the requirements of modern construction in terms of living comfort, insulation effect and demand. The potential of this building material seems inexhaustible, and new applications are constantly being developed, especially in the area of modular construction. Large-volume projects, as in residential construction, only receive the necessary legal and investment security for complex approval procedures through building physics. This enables greater dissemination and acceptance.

15.2 Insulation effect as a function of density and humidity

The thermal conductivity depends on several factors. The direction of the heat flow, the position and density of the stalks in the straw bale and the temperature have the greatest influence. In terms of the insulating capacity of a material, the lower the thermal conductivity value, the better (Eggenberger, 2016). A very loosely compressed straw bale has poorer thermal insulation than a well-compressed one. However, above a bale density of approximately 115 kg/m³, the insulating effect decreases slowly again, as there are too few air pockets. The change in the density of the bale also affects the proportionate components of the heat transport. The lower the number of stalks and the density, the more convection and radiation predominate in the straw bale. In contrast, a densely compressed bale has a higher proportion of heat conduction. For building straw bales, it is advantageous to create an even proportion between the heat transport types (Krick, 2008).

For these reasons, a minimum density of 90 kg/m³ is specified for sufficient insulating effect. A thermally ideal density range of 90–115 kg/m³ has already been determined in many research projects. Below is a more recent result from Benjamin Krick's doctoral thesis from 2008. Although barley cannot be compared to wheat for directly plastered and load-bearing structures (as it is not suitable for this use), the curve described above can be clearly seen in the graph. The dependence of the thermal conductivity on the temperature is also clearly visible.

However a minimum density of 100 kg/m³ is specified in various certificates due to fire protection tests and other requirements, and higher values are required for load-bearing construction.

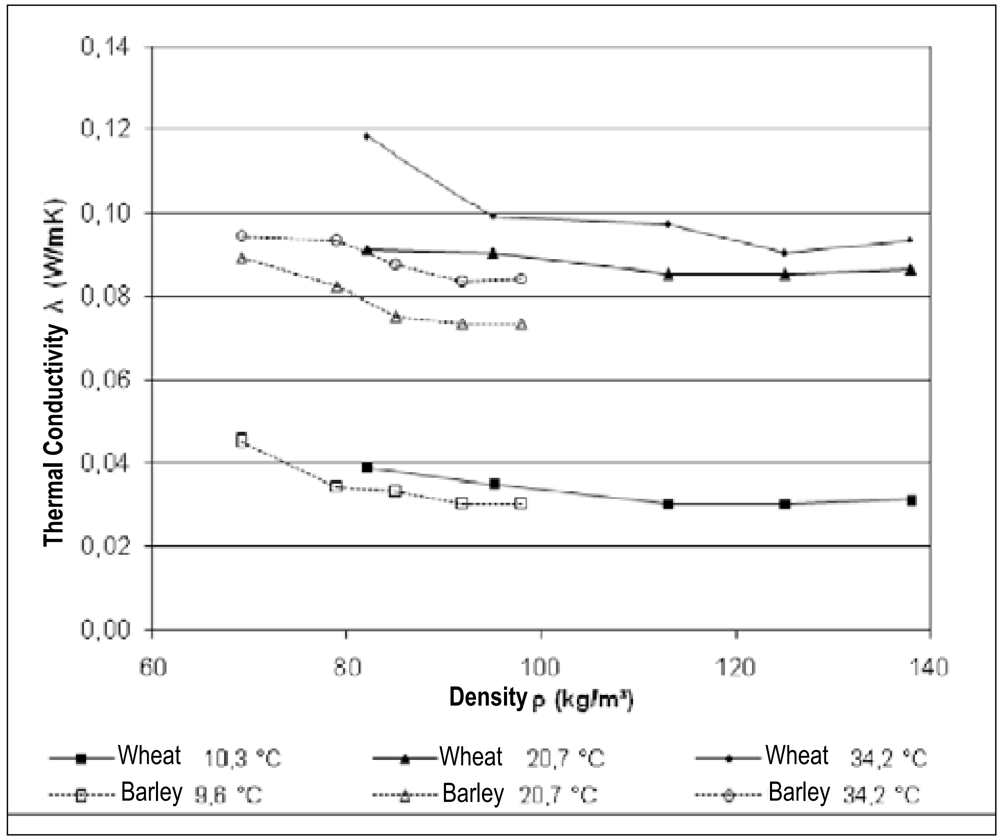


Fig.1

Benjamin Krick, 2008

All natural insulating materials were previously subject to an EU regulation that added 20% to the actual measured lambda values. The first values for straw bales (73–83 kg/m^3) determined in Austria in 2000 in the MA 39 test laboratory in Vienna were 0.038 W/mK (according to ISO 8301) and 0.0337 W/mK (according to ÖNORM B 6015) and thus were the same as for EPS insulation. The resulting calculated values with the 20% surcharge were then 0.0456 and 0.0404 W/mK. For most current straw bale certificates, the calculated value is between 0.045 and 0.05 W/mK.

For natural insulation materials, the optimum moisture content for insulation purposes is between 8–14 M%, which generally corresponds to the so-called equilibrium moisture of the material (from: „Wandsysteme aus nachwachsenden Rohstoffen“, 2001, Wimmer et al.).

The flat-rate surcharge for natural insulation materials has now been dropped due to the evidence provided. However, building materials such as straw are still structurally penalised!

At 100–130 kg/m^3, straw bales have a significantly higher density than many other insulating materials. In comparison, we have values for EPS of 15–30 kg/m^3, rock wool 15–80 kg/m^3, and XPS 25–40 kg/m^3. Straw bales also have a heat storage capacity that can affect the temperature profile of the building if the bales are in direct contact with the heated room and there is no other (insulating) layer in between. Tests carried out for this purpose resulted in a calculated value of 2000 J/kgK.

A straw bale wall plastered on both sides is almost a solid construction in terms of weight, but can have a total weight of 200 kg/m^2 (for small bales). At least the 4–6 cm of interior plaster and the straw bale itself can be activated for heat storage.

15.3 Sound insulation and acoustics

In addition to high masses, the use of materials with low rigidity is also important. Straw bales provide good sound insulation not only due to their structure, but also due to their mass. The layers of the construction must be acoustically decoupled from each other. Hence, direct mechanical connections between the two outer panels should be avoided in straw bale buildings, so as not to impair sound insulation.

Another way to improve sound insulation is to use plaster or panel layers of different thicknesses. The thicker layer should be on the sound source side of the structure. In terms of sound insulation, clay plaster is more suitable than cement or lime plaster, as it contains a proportion of straw and has a lower modulus of elasticity and reflective surfaces.

As in other areas, the openings and connection details are also problematic areas in terms of sound insulation and need to be carefully considered. An air opening of just one square millimetre has a major impact on the sound insulation of the entire construction (King, 2006). Sound insulation must be analysed separately for each construction using calculations and simulations, and should be confirmed for the existing building using sound tests, as every small change has an impact on sound insulation (Eggenberger, 2016).

The best values are achieved when both sides of a straw bale wall are plastered directly. Previous tests relate to airborne sound transmission. The table below presented by Teslik, Fabian and Hruba in 2017 shows the differences between a wall plastered on one side and on both sides. The idea that a higher sound reduction index could be effective here due to the higher density was decisive for the separate measurement while still damp. However, this was not confirmed. The final result for the dry wall plastered on both sides was Rw = 54 dB, a higher value than for the tested structure of the „Baustroh” certificate with Rw = 43–44 dB.

The reasons for the poorer values according to the certificate are firstly the wall structure with a timber stud construction, and secondly the slightly lower plaster thickness. A value of 54 dB with Rw ≥ 46 dB corresponds to sound insulation level I, which according to DIN 4109 is specified as Rw ≥ 53 dB; according to ÖNORM B 8115-5, this falls into sound insulation class A.

As a straw bale wall plastered directly on both sides buffers stresses and movements in the building structure very well and is earthquake-proof, such a wall structure should also absorb structure-borne sound well in addition to airborne sound. However, no measurements are available to verify this.

Fig.2

Chapter	Layer	Thickness	Density of material	Basic weight of material	Laboratory weighted sound reduction index	Improvement to the sound insulation
		[mm]	[kg/m^3]	[kg/m^2]	R_w [dB]	ΔR_w [dB]
6.4.1	Straw bales	350	90	31,5	28	-
6.4.2	Clay plaster (wet)	25	2000	50	35	7
	Straw bales	350	90	31,5		
6.4.3	Clay plaster (dry)	25	1650	43	41	13
	Straw bales	350	90	31,5		
6.4.4	Clay plaster (dry)	25	1650	43	54	26
	Straw bales	350	90	31,5		
	Clay plaster (dry)	25	1650	43		

„Determination of the airborne sound insulation of a straw bale partition wall“, 2017, Teslík, Fabian und Hrubá

A straw bale wall plastered with clay ensures good acoustics indoors. For concert halls and recording studios, the sound should be evenly harmonised at as many positions in the room as possible. Both the clay and the straw promote this particular type of sound reflection, which is why straw bales have previously been chosen as the building material for some such specialised rooms.

Concert room planned by Arch. Gernot Minke, Germany

Inside with a special rib structure made of clay

15.4 Primary energy demand and global warming potential

When constructing buildings, it is not only the direct ecological aspects and the possible impacts of the materials on the occupants that are relevant; the impacts of the production and delivery of building materials on the environment are equally important. Some materials have already incurred a very high energy consumption during production, which cannot be offset by savings during their useful life.

This is included in the primary energy content PE. In the case of PE, the pressing of the bale, the bale twine, loading and transport processes and the machinery with its proportionate production costs are taken into account for straw. If the cultivation of straw were included, i.e. if it were not a waste product, the value would increase sevenfold, reaching similar values to cellulose.
As a natural and organic building product, straw can be composted or burnt without any problems (Scharmer and Kaesberg, 2017).

Straw uses photosynthesis to grow, in which CO_2 is absorbed from the air. In the process, carbon and oxygen are separated from each other. While the oxygen is released back into the environment and has a positive effect on living organisms, the plant continues to utilise the carbon by storing it in its structure. When the straw has finished growing, the plant begins to rot and releases CO_2 back into the environment. The amount of CO_2 is the same as that absorbed for growth. The same process occurs when the straw is burnt, except that the process is faster (Minke and Krick, 2014).

Various building scenarios are defined in more detail in the table in Fig. 3. Different materials are used for the individual building components. Straw is one of the variants that are compared with other structures in terms of primary energy demand (production and maintenance) and global warming potential.

Fig.3

COMPONENT VARIATIONS, SIMPLIFIED ILLUSTRATION

Components	Wood straw[1]	Wood cellulose[2]	Wood-Miwo[3]	MW-Miwo-KS[4]
Foundation	Reinforced concrete strip foundations with 60 mm perimeter insulation			
Sole (U = 0.21 W/[m^{2*} K])	Concrete on gravel, cellulose-insulated wooden floor	Reinforced concrete floor, cellulose-insulated wooden floor	Reinforced concrete floor, EPS insulation, screed, tiles	Reinforced concrete floor, EPS insulation, screed, tiles
Exterior walls (U = 0.15 W/[m^{2*} K])	Timber frame, straw insulation, clay plaster with emulsion paint on the inside, lime plaster on the outside, hydrophobic façade coating	Plank frame, blown-in cellulose, OSB, gypsum fibreboard with emulsion paint, wood fibre insulation board with thin plaster, hydrophobic façade coating	Plank frame, mineral fibre insulation, OSB, gypsum fibreboard with emulsion paint, wood fibre insulation board with thin plaster, hydrophobic façade coating	2-shell masonry, interior sand-lime brick, mineral fibre insulation, facing bricks
Interior walls	Timber studs, cellulose insulation, timber formwork, clay plaster, emulsion paint	Wooden studs, cellulose insulation, gypsum fibre boards, emulsion paint	Metal studs, mineral fibre insulation, gypsum fibre boards, emulsion paint	11.5 cm sand-lime brick, gypsum plaster, emulsion paint
Storey ceiling	Open wooden beam ceiling, tongue-and-groove planking, ballast, wood fibre soundboard, wooden floor	Open wooden beam ceiling, 3-layer slab, ballast, wood fibre soundboard, wooden floor	Open wooden beam ceiling, OSB board, ballast, mineral fibre sound insulation board, wooden floor	Reinforced concrete floor/ceiling, mineral fibre sound insulation board, screed, tile
Roof (U = 0.15 W/[m^{2*} K])	Rafter roof, roof tiles, underlay board wood fibre, straw insulation, timber boarding, clay plaster, emulsion paint	Rafter roof, roof tiles, underlay board wood fibre, cellulose insulation, vapour barrier, counter battens, gypsum fibre, emulsion paint	Rafter roof, roof tiles, underlay board wood fibre, mineral fibre insulation, vapour barrier, counter battens, gypsum fibre, dispersion paint	Rafter roof, roof tiles, underlay board wood fibre, mineral fibre insulation, vapour barrier, counter battens, gypsum fibre, dispersion paint
Windows (U_w = 0.91 W/[m^{2*} K])	Wooden windows Triple glazed	Wooden windows Triple glazed	Wooden windows Triple glazed	PVC windows Triple glazed
Building technology	Pellet boiler, solar thermal system, ventilation system with heat recovery, standard radiators, copper heating water pipes			

[1] *Timber-straw: Straw-insulated, plastered building in timber construction.*
[2] *Wood-cellulose: Cellulose-insulated, plastered building in timber construction.*
[3] *Holz-Miwo: Mineral fibre insulated, plastered building in timber construction.*
[4] *MW-Miwo-KS: Masonry construction with mineral fibre insulation, facing bricks and inner shell made of sand-lime brick.*

„Straw-insulated buildings“, Specialist Agency for Renewable Resources

Fig.4

Environmental impact and use of resources

Production (A1-3), maintenance, repair (B2-3)

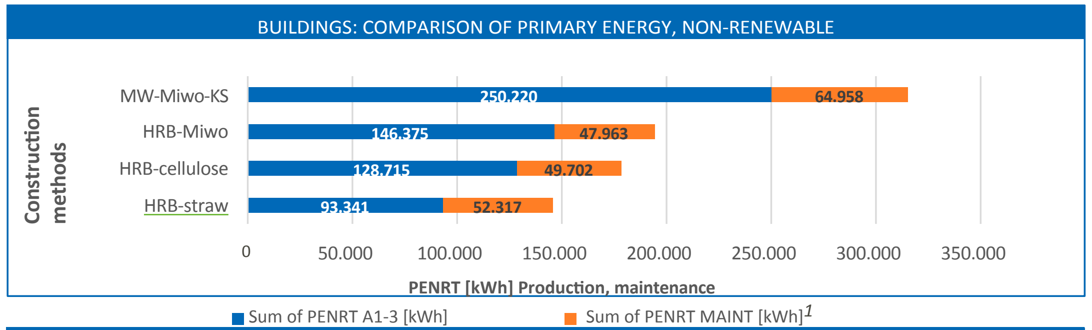
Non-renewable primary energy

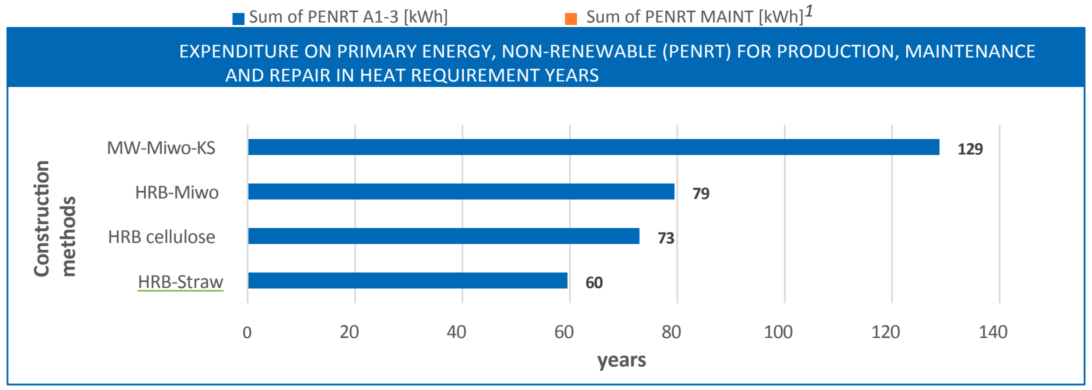
Primary energy**,** non-renewable**,** total (PENRT)

The straw-insulated building requires only around half of the non-renewable primary energy (PENRT [kWh]) for its construction compared to conventional solid construction. The expenditure of non-renewable primary energy for the construction, maintenance and repair of the four building types (145,658-315,178 kWh) corresponds to a heat supply (annual PENRT of 2,447 kWh) of 60 years (straw construction) to 129 years (solid construction). This means that a straw-insulated building can be used for the construction, maintenance and repair costs alone.

of solid construction and supplied with heat for 69 years (for selected building technology, see table on page 9). The exterior wall is particularly relevant for the variations in construction methods. A comparison of different external walls clearly shows the advantages of ecologically optimised construction methods. The difference in the amount of non-renewable primary energy required for the exterior walls for modules A1-3 and B2-3 alone (93,014 kWh) corresponds to the heat requirement of the balanced building for 38 years.

A further comparison of the external wall, which is particularly relevant for the variations in construction methods, shows impressively that the difference in the greenhouse potential for modules A1-3 and B2-3 (43,387 kg CO_2 equivalent) corresponds to 361,500 km of driving with an economical 5-litre mid-range car.





[1] *Life cycle phases analysed: Production phase modules A1-3 and utilisation phase modules B2 and B3 (maintenance and repair), abbreviated MAINT for maintenance*

„Straw-insulated buildings“, Specialist Agency for Renewable Resources

Fig.5

Global warming potential

Global warming potential (GWP [kg CO_2 -equivalent])

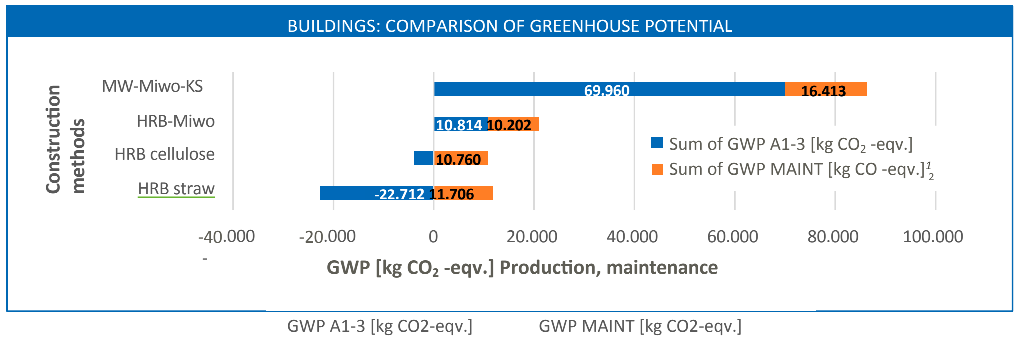
The difference between the solid construction and the ecologically optimised building in straw construction in terms of global warming potential is approx. 97 t CO_2 equivalent. An economical 5-litre mid-range car can travel 811,000 km before the same climate impact is achieved - that is roughly equivalent to circumnavigating the earth 20 times.

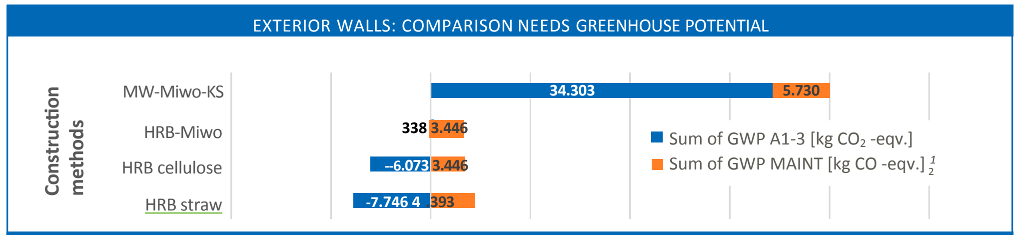
The provision of the finished insulating material "building straw" causes many times lower emissions compared to other insulating materials and requires significantly less energy to produce. It takes place quasi "incidentally" in the agricultural sector, which is running harvesting process. Due to the fact that grain is grown everywhere in Germany, transport routes can be greatly minimised.

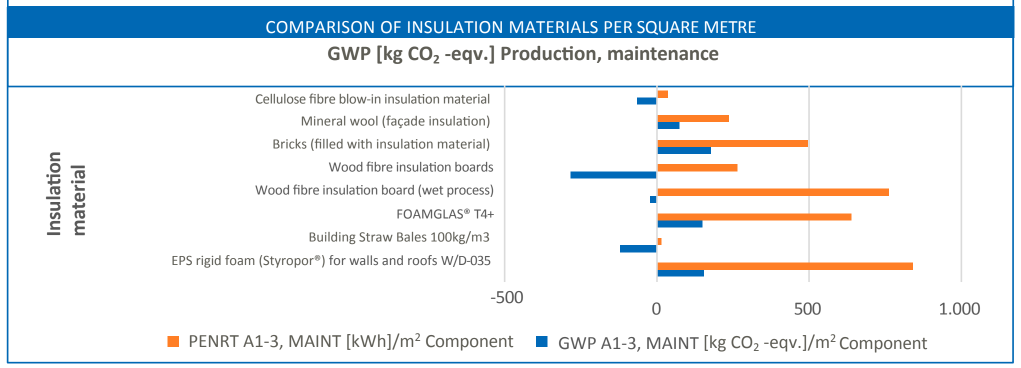
Utilisation phase

The consumption of non-renewable primary energy for the heating requirements of the building model, which is the same for all four construction methods, is as follows for the 50-year balancing period

122,368 kWh. Due to the relatively short service life of the building technology (25 years) and the high replacement costs associated with this, it accounts for a large proportion of the environmental impact and expenditure on non-renewable primary energy.







„Straw-insulated buildings“, Specialist Agency for Renewable Resources

15.5 Humidity

This issue must be treated with great care in straw bale construction, as it harbours a high potential for future damage to the building. As straw is a plant-based and renewable raw material, it also has the property of decomposing. Particular attention must be paid to the storage of the bales before the building is erected and during construction in the area of the floor and ceiling connections (Gruber and Gruber, 2008).

The moisture itself can enter the building component in a variety of ways. The main causes are driving rain, rising damp from the ground and condensation in the component layers (Minke and Krick, 2014). Before the building is erected, care must be taken to ensure that the bales are stored dry. Pallets on which the straw bales can be placed are suitable for this purpose. Additional protection is provided by arranging them in a pyramid shape and then covering them with a waterproof film to prevent water from penetrating and rain puddles from forming. The bales should not be sealed airtight so that the straw can dry out again and does not start to sweat (Gruber, Gruber and Santler, 2014).

Horizontal waterproofing made of bitumen, plastic or metal sheeting is used to prevent moisture from rising from the ground into the structure. To protect the straw bales from splashing water, a construction in which the first layer of straw bales starts above the splash zone is preferable. The height should be at least 30 cm above ground level. It is also possible to protect the straw bales with boards or water-repellent plaster. Measures in front of the wall construction, such as gravel or gravel beds, can reduce the reach of splash water. Hard surfaces in front of the building are less helpful (Minke and Krick, 2014). To prevent the rain hitting the building from penetrating the structure, the façade should be designed with a crack-free and weather-resistant render or ventilated cladding (Hein et al., 2014).

The basic rule for straw bale construction is that you should only build where you can also build with wood without any problems. In addition, the straw should not have any moisture on an annual basis, as otherwise this indicates permanent moisture in the straw bale and the material will start to decompose (Gruber and Gruber, 2008).

„Condensate pocket“ for any moisture peaks that may occur in the bottom bale of the straw bale wall, space filled with perlite between the floor sills and drainage holes to the outside, below the drip edge. Ready for the first bales.

Facade suspended during construction. Protected at the top with plastic tarpaulin and with facade mesh on side.

Perimeter insulation (XPS) neatly sealed base. Ready to receive a 3-layer panel and the first bales of straw.

15.6 Building physics for tested superstructures

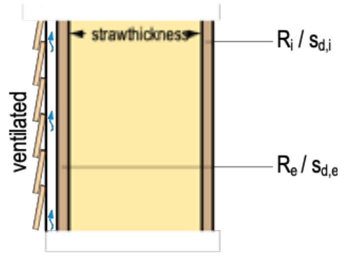
The following is a list of tested superstructures where increased condensation is unlikely and which are part of the general building material approval for straw bales in Germany. There are also many other structures that work in practice, in terms of building physics, but these are not covered by this approval process. If we leave the framework of authorised structures, condensation can form and fungal spores can develop. Whether this actually happens depends heavily on the local climate, the type of use and the exact composition of the plasters and paints.

The following four pages are taken from the FASBA Strawbale Building Guidelines 2019. For complete document see: https://fasba.de

Allowable moisture-dependent layer properties for structures with straw as thermal insulation in Germany (Annex B ETA-17/0247 Building Straw)

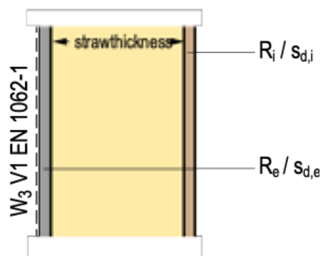
a) Exterior wall structures with back-ventilated external cladding for weather protection

Line	Straw thickness [m]	$s_{d,i}$ [m]	R_i [m²·K/W]	$s_{d,e}$ [m]	R_e [m²·K/W]
1	≤ 1.00	**≥ 0.10**	**≤ 0.35**	**≤ 0.50**	**-**
2	≤ 0.48	**≥ 0.76**	*≤ 3.14*	≤ 0.50	-
3	≤ 0.48	≥ 0.10	≤ 0.35	*≤ 1.00*	**≥ 1.00**
4	≤ 0.48	**≥ 2.00**	≤ 0.35	*≤ 1.50*	**≥ 0.70**
5	≤ 0.48	≥ 0.10	≤ 0.35	*≤ 1.50*	**≥ 1.43**
6	≤ 0.48	≥ 0.10	≤ 0.35	*≤ 2.00*	**≥ 1.90**



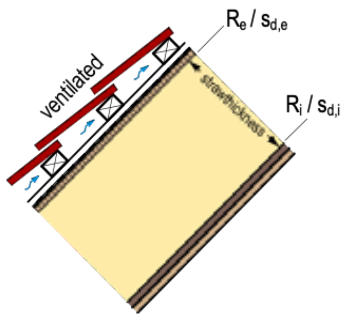
b) Plastered exterior wall structures with no weather protection
Plaster in accordance with EN 998-1 with water-repellent coating
in accordance with EN 1062-1 in W_3 and V_1

Line	Straw thickness [m]	$s_{d,i}$ [m]	R_i [m²·K/W]	$s_{d,e}$ [m]	R_e [m²·K/W]
1	≤ 0.70	**≥ 0.10**	**≤ 0.35**	**≤ 0.50**	**-**
2	≤ 0.48	**≥ 0.76**	*≤ 3.14*	≤ 0.50	-
3	≤ 0.48	**≥ 3.00**	≤ 0.35	*≤ 1.50*	**≥ 0.30**



c) Roof structures with ventilated roofing

Line	Straw thickness [m]	$s_{d,i}$ [m]	R_i [m²·K/W]	$s_{d,e}$ [m]	R_e [m²·K/W]
1	≤ 0.48	**≥ 2.00**	**≤ 0.35**	**≤ 0.50**	**≥ 0.14**
2	**≤ 0.36**	**≥ $s_{d,e}$**	≤ 0.35	*≤ 3.00*	≥ 0.14



Note:
Line 1 characterises the allowable basic version.
Additional lines: possible versions with modified element characteristics (with grey background) which in turn require modified layer characteristics (values shown in bold).

Symbols, indices:

- $s_{d,e}$ diffusion-equivalent air layer thickness for the external layers / cladding
- $s_{d,i}$ diffusion-equivalent air layer thickness for the internal layers / cladding
- R_i thermal resistance for the internal layers / cladding
- R_e thermal resistance for the external layers / cladding
- W_3 water permeability of coating classified acc. to EN 1062-1 and tested acc. to EN 1062-3: $W_{24} \leq 0.1$ kg/(m²·√h); Index 24 = test duration of 24 h
- V_1 water vapour flux density of coating classified acc. to EN 1062-1 and tested acc. to EN 1062-3: $V_1 > 150$ g/(m²·d) with $s_d < 0.14$ m

Explanation of Annex B ETA-17/0247 Building Straw

Annex B details the biohygrothermal suitability of straw-insulated constructions depending on their building material properties. The tables provided for the three construction component types contain the necessary layer properties for preventing harmful mould growth in the relevant outer area of the straw insulation. For this, growth conditions for the germination of spores must not be created by water vapour diffusion[11] from the inside into the straw insulation or from rain from the outside in connection with the given temperatures relating to the climate and construction component. From a construction perspective, this can only be achieved via a combination of suitable thermal resistances inside, outside and of the insulation itself (specified in the Annex in a simplified manner as the straw thickness), and via suitable diffusion-equivalent air layer thicknesses of the internal and external finish and the straw insulation itself (also indirectly contained in the straw thickness).

With the tables in Annex B and the information below, experts are provided with the information they need to plan construction components which are allowable from a moisture-proofing perspective and/or check the permissibility of a component construction from a moisture-proofing perspective. The following information sets out the different scenarios relating to the physical construction parameters from the tables using the example of the exterior wall structures pursuant to Table a).

Straw-insulated external wall constructions with back-ventilated weather protection are allowable from a moisture-proofing perspective in accordance with Table a) Annex B as set out below:

> ***Line 1:*** *If the straw thickness is not greater than d = 1 m and if, at the same time, the construction component layers between the straw insulation and the outdoor climate demonstrate a diffusion-equivalent air layer thickness of a maximum of* $\mathbf{s_{d,e} = 0.5\ m}$ *and the construction component layers between the straw insulation and the interior space feature a diffusion-equivalent air layer thickness of at least* $\mathbf{s_{d,i} = 0.1\ m}$ *and a thermal resistance of a maximum of* $\mathbf{R_i = 0.35\ m^2{\cdot}K/W}$*, then the construction component is allowable.*

> ***Line 2:*** *If, in contrast with this, the room-side layers feature a higher thermal resistance of up to* $R_i = 3.14\ m^2{\cdot}K/W$ *, e.g. because the straw insulation was installed in front of masonry, then the diffusion-equivalent air layer thickness inside is to be increased to at least* $\mathbf{s_{d,i} = 0.76\ m}$*. The straw thickness may be no more than d = 0.48 m for this.*

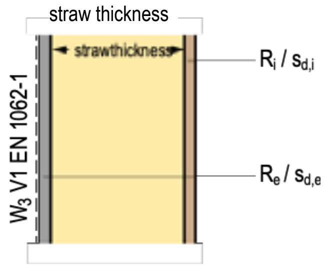
[11] Convective entry is to be excluded anyway. (See ETA-17/0247 Building Straw, Annex A, 4) on joint tightness of the inner cladding.)

Line 3: *If the outer layers on the outside, in deviation from the example construction in Line 1, demonstrate a diffusion-equivalent air layer thickness of up to* $s_{d,e}$ *= 1.0 m, then the thermal resistance of the outer layers is to be increased to at least* $\boldsymbol{R_e}$ ***= 1.0 m²·K/W****. The straw thickness may be a maximum of d = 0.48 m for this.*

All further lines and tables follow the same logic.

Exterior wall constructions with direct weather exposure and plaster must contain plaster according to DIN EN 998-1 with a water-repellent coating according to DIN EN 1062-1 in W_3 and V_1.

Review of an intended construction component



An exterior wall construction with direct weather exposure and plaster should be created and checked with regard to its permissibility according to Annex B. The exterior wall construction should have the following properties:

- Straw thickness d=0.36 m,
- 3 cm lime plaster inside with a water vapour diffusion resistance factor of μ = 10 and thermal conductivity of λ = 0.70 W/(m·K),
- 3 cm lime plaster according to DIN EN 998-1 on the outside with a water vapour diffusion resistance factor of μ = 10 and thermal conductivity of λ = 0.80 W/(m·K),
- Facade coating, identified either directly with the classifications W_3 and V_1 or $w_{24} \leq 0.1$ kg/(m²·√h) and V > 150 g/(m²·d) with $s_d < 0.14$ m.

The physical construction parameters move in accordance with Table b), Line 1, Annex B ETA-17/0247 Building Straw:

Diffusion-equivalent air layer thicknesses s_d = d· μ [m]
External: $s_{d,\,e,\,present}$ = 10·0.03 m + 0.13 m= 0.43 m ≤ $s_{d,\,e,\,allowable}$ = 0.5 m
Internal: $s_{d,\,i,\,present}$ = 10 · 0.03 m = 0.3 m ≥ $s_{d,\,i,\,allowable}$ = 0.1 m

Thermal resistance R = d / λ [m²·K/W]
External : R_e no requirement
Internal: $R_{i\ present}$ = 0.03 m / 0.8 m·K/W = 0.038 ≤ $R_{i\ allowable}$ = 0.35 m²·K/W

<u>Results: The construction is allowable according to Table b), Line 1, Annex B ETA-17/0247 Building Straw because all the layer properties are maintained in the combination as shown above, the external plaster meets the requirements and a suitable facade coating is used.</u>

4.3.1 <u>Miscellaneous</u>

The suitability of straw in external construction components which do not comply with Annex B ETA-17/0247 Building Straw, for example non-filling or pressurised constructions, other layer properties or other areas of application must be proven separately.

In particular, the following applications are deemed to be other areas of application in this regard:

- any type of pressure load on straw by a dead load or traffic load or by component reinforcement;
- layer properties which deviate from Annex B ETA-17/0247 Building Straw (The suitability from a moisture-proofing perspective must be proven here, e.g. by means of a biohygrothermal evaluation with WUFI® and WUFI-Bio.);
- <u>Attached external wall insulation:</u> When straw is to be installed without clearly defined frame as a continuous prefixed insulation layer in front of external walls (mechanical strength in the compartment);
- <u>Internal walls:</u> When straw is to be installed in internal walls (behaviour in a permanent indoor climate without guaranteed joint tightness to the indoor environment);
- <u>Non-ventilated roof areas:</u> When straw is to be installed in non-ventilated roof spaces (moisture-proofing suitability);
- <u>Top-floor ceilings:</u> When straw is to be installed above upper storey ceilings without defined compartment formation and/or pressurised (mechanical strength);
- <u>Floor panels and basement ceilings:</u> When straw is to be installed in floor panels or in ceilings against an unheated basement and/or is to be used in a pressurised manner (moisture-proofing suitability, mechanical suitability).

4.3.2 <u>Load-bearing construction</u>

The term 'load-bearing straw bale construction' is used to describe a construction method in which some or all of the load-bearing components are straw bales (in wall or vault constructions). The bales are compressed and perform tasks relating to the structural stability of the built structure.

The construction method originates from Nebraska and was first used there in approximately 1880 after the invention of the baling machine. It is now used all over the world.

In Germany, there are no generally applicable procedures and measurement concepts for ensuring the structural stability and usability of buildings with load-bearing components made from straw bales. The approval and proof of suitability must take place by means of permission on a case-by-case basis.

Calculations by the University of Applied Sciences, Salzburg

The following are building physics calculations obtained from the FH Salzburg for superstructures that are not covered or are only insufficiently covered in the previous tables, but are nevertheless often used in practice.
The simulation program WUFI-Pro 6.2 „Transient heat and moisture“ is used to determine the material moisture content in building structures over the course of a year. This approach to calculation considers the coupled heat and moisture transport in one-dimensional multi-layer building components. The mutual dependency of heat conduction and moisture flow is taken into account iteratively within the numerical process. The calculation model on which the program is based includes water transport due to water vapour diffusion and capillary conduction as well as moisture storage.

General conditions

- The following parameters were defined as initial conditions for the calculations:
- Outdoor climate: Climate dataset for Holzkirchen, Germany
- Indoor climate with normal moisture load according to EN 15026
- Typical building moisture content: Straw 10 kg/m³; lime plaster 250 kg/m³, clay plaster 294 kg/m³
- Initial temperature in the component: 20°C

Moisture sources:

- Exterior wall (small bales):
- Layer of lime plaster: depth in layer 2 cm, limitation to free water saturation 250 kg/m³, proportion of driving rain 1% boundary layer
- Layer of straw/clay plaster: limitation to free water saturation 294 kg/m³, air infiltration model IBP, flow rate through the envelope 3 m³/m²h, height of air column 5 m, no mechanical pressure from ventilation system
- Exterior wall (jumbo bales):
- Layer of lime plaster: depth in layer 2 cm, limitation to free water saturation 250 kg/m³, proportion of driving rain 1 % boundary layer
- Layer of straw/clay plaster: limitation to free water saturation 294 kg/m³, air infiltration model IBP, flow rate through the envelope 3 m³/m²h, height of air column 5 m, no mechanical pressure from ventilation system
- Floor: Limitation to free water saturation 294 kg/m³, air infiltration model IBP, flow through the envelope 3 m³/m²h, height of the air column 5 m, no mechanical pressure from ventilation system

- Start of calculation: 01.10.2019
- End of calculation: 01.10.2025

Material parameters used for straw bales can be found in table 2:

Density ρ		[kg/m³]	100,0
Porosity ψ		[m³/m³]	0,9
Specific heat capacity c_p		[J/kgK]	2.000,0
Thermal Conductivity λ		[W/mK]	0,045
Water vapor diffusion resistance factor μ		[-]	1,3
Typical building moisture content		[kg/m³]	10,0*

Table 2: material parameters for straw bale insulation (Danielowicz net al. 2008)

Table of components

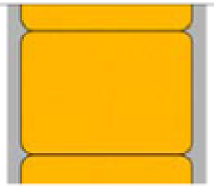
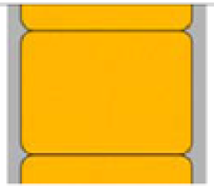
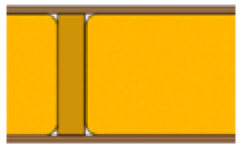
construction	component sketch	depth of layer [cm]	superstructure (outside-inside)
1 wall		4 50 4	lime plaster straw bales (small) clay plaster
2 wall		6 120 6	lime plaster straw bales (BigBales) clay plaster
3 floor		2,2 36 1,5	OSB 3 straw bales OSB3

Table 1: calculated constructions, superstructures and depth of layer (Kade 20218)

Notes on the superstructures:
In the calculations, the lime plaster was assumed to be a non-hydrophobic layer and the driving rain only 1%. As with the calculations from FASBA on the previous pages, we recommend the use of a fine plaster layer or a coat of paint that is both impermeable to driving rain and open to vapour diffusion.

Wall 1: classic, load-bearing wall with small bales, built horizontally with a width of 50 cm, plastered on both sides
Wall 2: Structure as for wall 1, but with jumbo bales, 120 cm wide, plaster thickness set slightly higher, as more realistic in practice with large bales
Floor from inside to outside: calculated here without floor structure (12–20 cm), which is added in practice; OSB board 22 mm, joints glued, glulam beams (8/36 cm) with straw bales in between (36 cm); OSB board 15 mm, joints not glued, supported on concrete strip or screw foundations, at least 30 cm under-ventilation, 20 cm drained gravel bed, soil

a. Construction 1: wall (small bales)

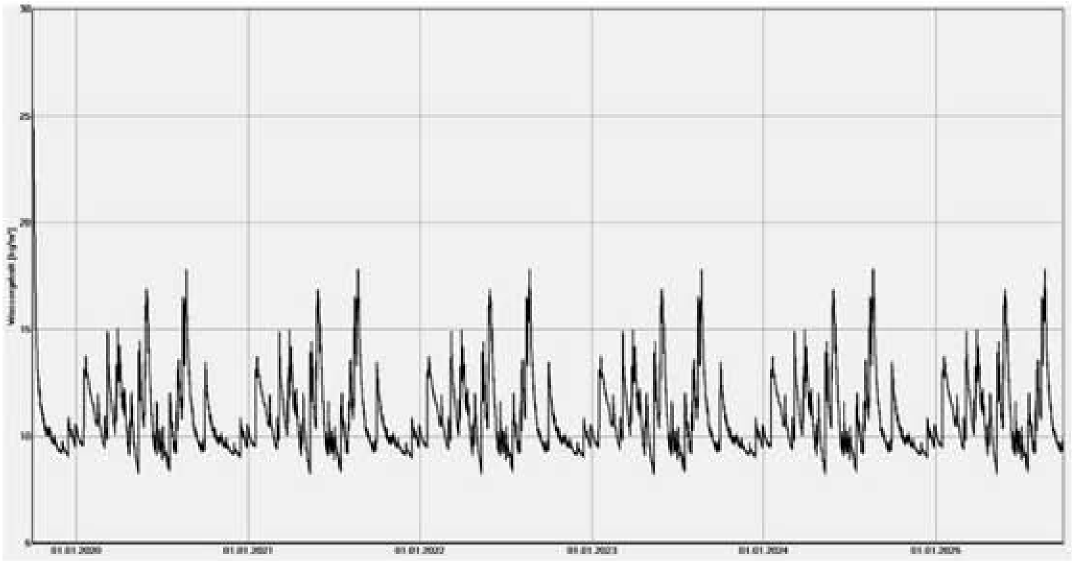


Figure 6: Total water content [kg/ m³] Construction 1

In Figure 6 it can be seen that the total water content in kg/m^3 of construction 1 shows a strong decrease within the first two months after the start of the simulation.
After this initial behavior, dynamic equilibrium begins to set in and the component is in the steady state.

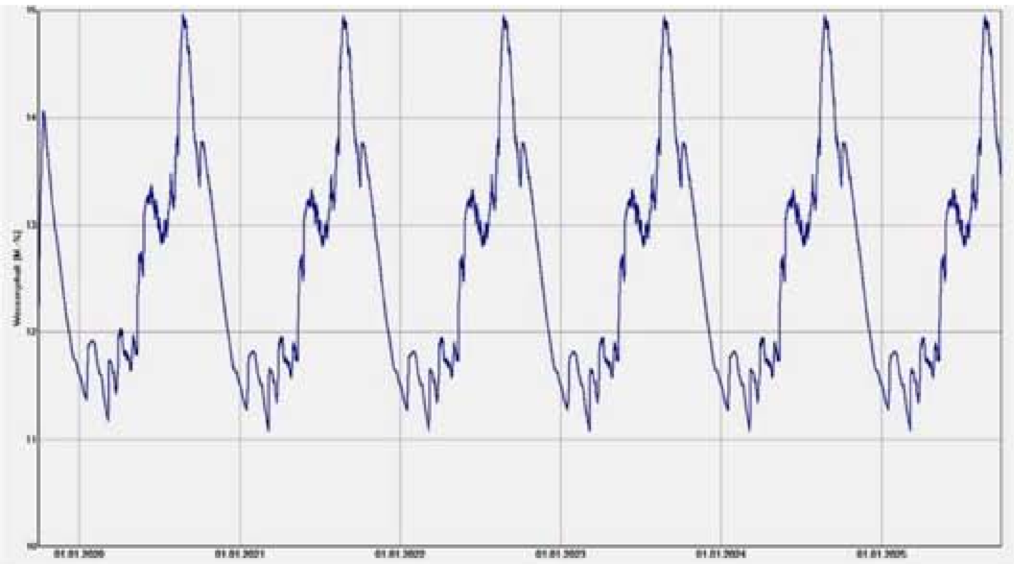


Figure 7: Water content [% by mass] straw insulation, construction 1

Figure 7 shows that the water content in M% within the straw insulation at the beginning of the Simulation increases from approx. 10% to 14%, but this to at least 11.2% over the winter dries up. This course is confirmed over the entire calculation period. The highest Water content of approx. 15% by mass is recorded in August.

b. Construction 2: Wall (jumbo bale)

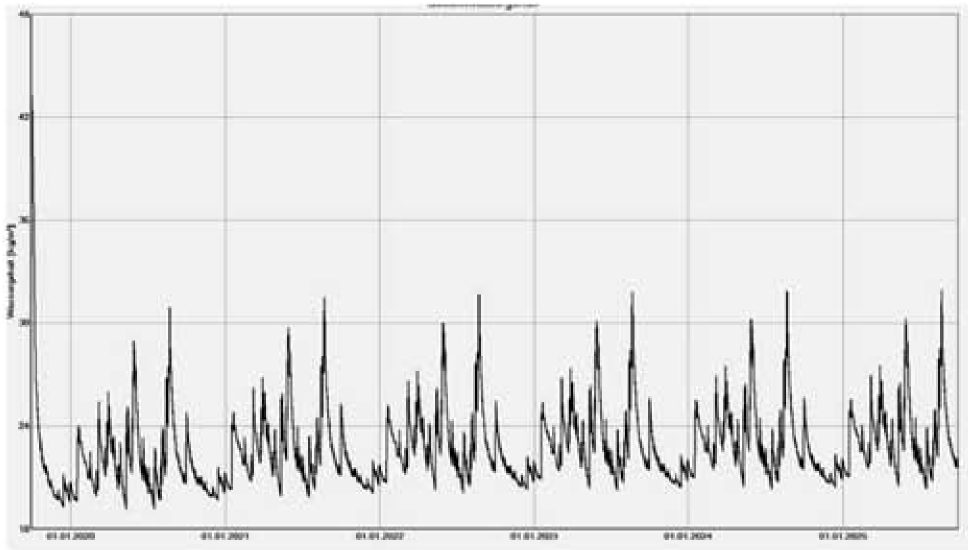
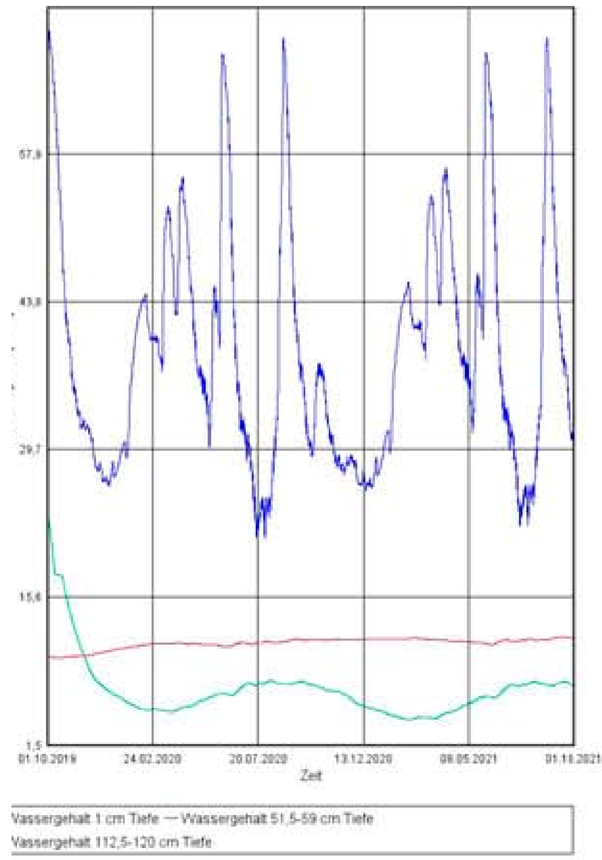


Figure 11: Total water content construction 2

In Figure 11 it can be seen that the total water content in kg/m^3 of the construction is 2 a strong decrease within the first two months after the start of the simulation listed. After this initial behavior, a dynamic equilibrium begins set and the component is in the steady state.



e 13: Water content [% by mass] at three positions in the straw bale insulation, construction 2

Fig. 13 shows the water content at three monitor positions within the jumbo bales. It can be seen that the critical moisture content between a minimum of 20 and a maximum of 60% by mass only occurs
at a depth of 1 cm. Monitor position 2 (51.5 – 59 cm depth) and monitor position 3 (112.5 – 120 cm depth) have uncritical moisture levels. Damage caused by rot is not to be expected in these two areas.

ıre 13 represents the water content at three monitor positions within the jumbo bales
ın be seen that there is only a critical moisture content at a depth of 1 cm
veen a minimum of 20 and a maximum of 60% by mass. Monitor position 2 (51.5 - 59 cm

age due to rot is not to be expected in these two areas.

c. Construction 3: floor

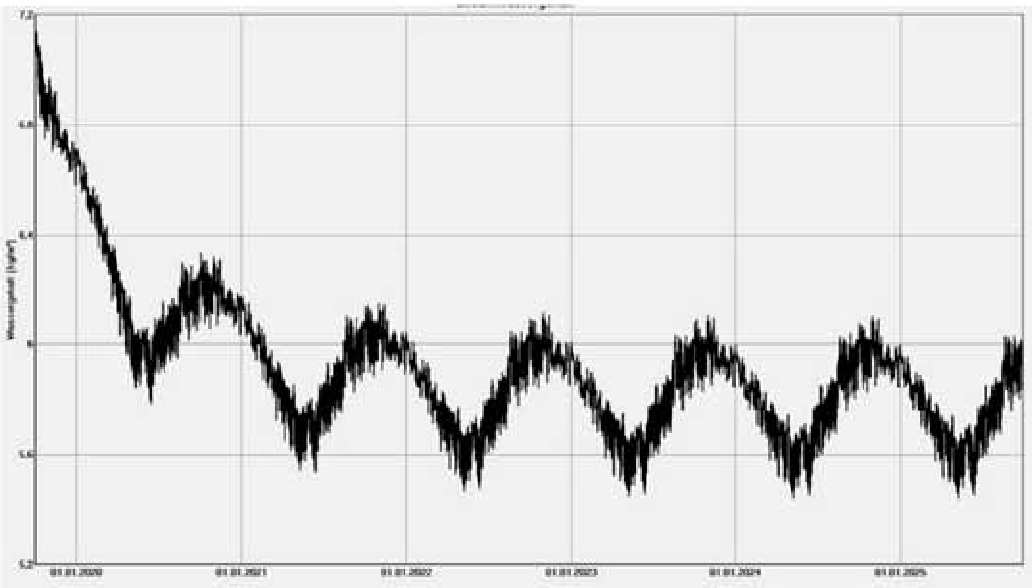


Figure 15: Total water content construction 3

Figure 15 shows that the total water content in kg/m^3 of construction 3 shows a strong decrease within the first eight months after the start of the simulation. After this initial behavior, a dynamic equilibrium begins to set in and the component is in a steady state with a total wate content of between 5 and 6.2 kg/m .

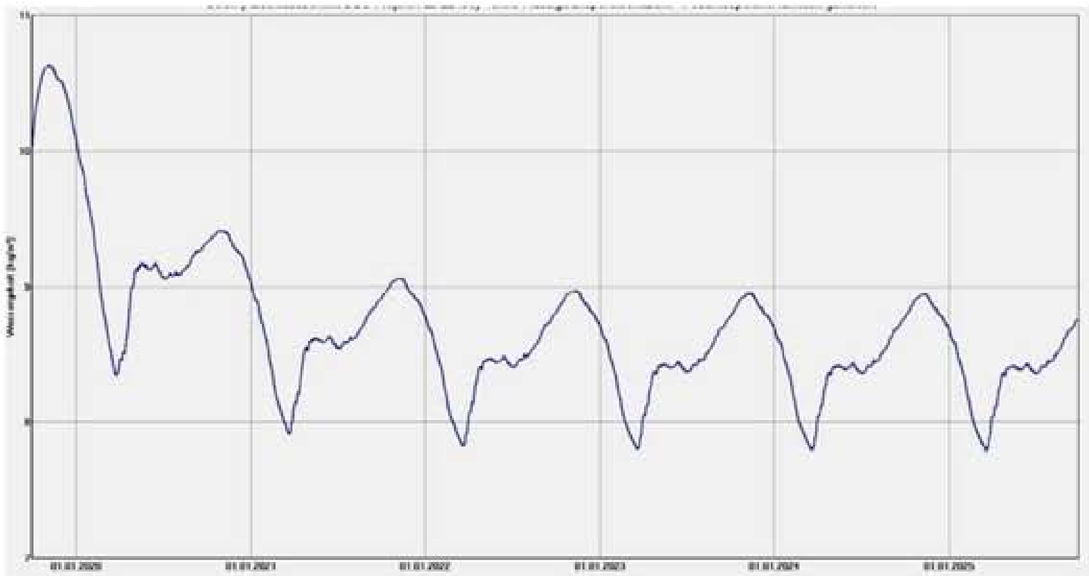


Figure 16: Water content [% by mass] straw insulation of construction 3

Figure 16 shows that the water content in M.-% within the straw insulation continuously decreases over the simulation period. The component dries out. The water content varies between 8 and 9.5% by mass.

Summary of results

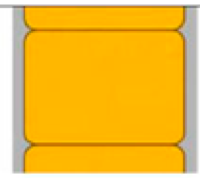
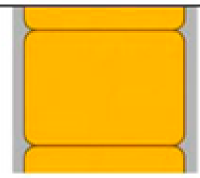
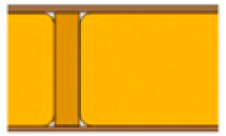
construction	component sketch	risk of frost	risk of decay
1 Wall		Low hazard	Low hazard
2 Wall		Increased risk	Increased risk
3 Floor		Low hazard	Low hazard (Straw area) Increased risk (boundary OSB outside/straw)

Table 6: Summary of simulation results, risk of frost and rot

Discussion of results:
Construction with jumbo bales has been ongoing for around 15 years, and has not yet shown any measurable or obvious structural problems in practice. According to the simulation, however, there is a possibility of accumulation of moisture at a wall depth of 5 cm.

For structure 3, there is generally no rising damp below the ventilated floor slab in practice, which is why the lower OSB board is not considered critical. However, this could also be replaced by a cement-bound board.

A situation-specific analysis is always desirable!

- Particular attention should be paid to the following aspects:
- The moisture balance and drying can be improved with vapour barriers
- All materials must be installed with the typical construction moisture content
- Good airtightness must be ensured
- Moisture transport must be ensured between the individual components in the outer area of a straw-insulated component
- The component must be completely insulated, and the cladding must be tight and without cavities
- Straw-insulated components must be professionally protected from precipitation and splash water until the cladding is completed
- In locations with less radiation in summer and more shade, the drying potential decreases further

The detailed calculation can be sent by e-mail on request and is available for download from the author‘s website.

16. Straw bale construction in the tropics

Straw has been and is being used in all regions and climatic zones for the construction of buildings. Roof coverings made from reed or cereal straw have proved just as successful as the addition of chopped straw to clay or other types of mortar. Rice straw is, or was, traditionally used as a roof covering in many parts of Asia. Depending on the local climate, however, this type of roofing may need to be replaced much sooner than reed-covered roofs in Europe, for example. The often year-round high moisture content in the air can lead to a faster decomposition process than in temperate or dry climates.

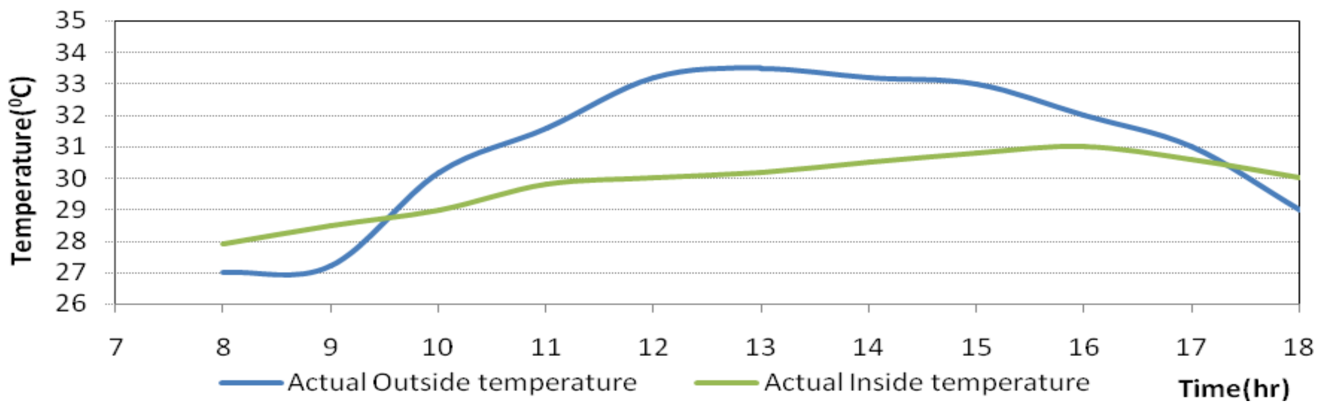
When using straw bales as a building material in the tropics, however, we have the advantage over roofing that the walls are usually plastered on both sides, and thus can provide protection against moisture peaks and heavy rainfall. However, the design and the plasters used are even more important here than in other climate zones, and can make the difference between success and failure. Long-lasting heavy rainfall, such as during the monsoon, must be kept away from the plaster, while at the same time the increased moisture content in the straw bales must be channelled back outside. Flooding is very common in some regions during the rainy season and must be taken into account in planning, for example by raising a brick plinth or elevating the building, as is traditional in some regions. This means that the house stands on stilts, so to speak. In Europe, the use of so-called screw foundations, which create a similar situation, is becoming increasingly common.

Compared to the wheat or rye straw often used elsewhere, rice straw has a higher silica content, which leads to greater strength and, above all, better resistance to moisture. Rice straw should therefore be used for construction in the tropics wherever possible. When using straw bales in the tropics, however, there are further fundamental considerations regarding their purpose. The function of straw bales as a classic insulating material plays a rather subordinate role in this case. However, there are several reasons why straw bales should be used.

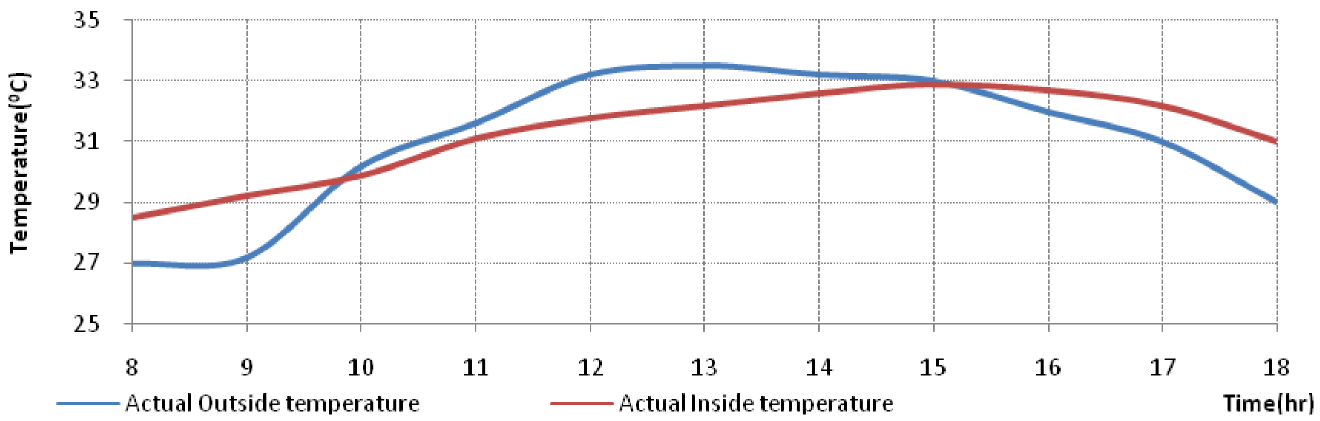
With plastered straw bale walls, we find a strong thermal inertia, which is why temperature peaks can be buffered. By using clay plaster indoors, the humidity in the room can be reduced and the temperature lowered by a further 2°C. A research project in Sri Lanka showed that the temperature curve for a straw bale house was significantly better than for a brick house. The use of straw bales therefore also results in a pleasant quality of living for people in the tropics.

Research project in Sri Lanka
J.P.S.Chamila, R. U. Halwatura
Department of Civil Engineering, University of Moratuwa
„PERFORMANCE OF STRAW BALE HOUSES IN TROPICAL CLIMATIC CONDITION“

Temperature curve straw bale building



Temperature curve brick building



In addition to the convincing ecological advantages of straw bales as a building material, there is another factor that favours the use of straw bales in rural areas of Asia. The availability of building materials and the often limited financial possibilities of the rural population make straw bales an interesting option if, for example, the rice straw can be pressed into bales directly in a local field.
This could also solve a massive environmental and health problem that is commonplace in many regions of Asia, in that the disposal of straw after harvesting very often only takes place in the form of extensive burning.

Regarding the current spread of straw bale construction in tropical regions, it can be said that houses have been built with straw bales in Australia for many years, even in tropical regions. We find a similar situation in the USA, the country of origin of straw bale construction. Here, too, straw bales are used in tropical climates.
Apart from a few research projects, however, straw bale construction has not yet arrived in the Central Asian region.

Conclusion:

Whether the use of straw bales as a building material works under tropical conditions depends not only on the abovementioned properties and details of the plaster, but also strongly on the local conditions of the building site. In very humid locations without much air movement, we are certainly more likely to reach the limits of the building physics performance of straw bale construction. This is why opinion among professional straw bale builders is rather divided: some advise against it, whereas others have had good experiences.

A Chinese study (at a tropical site) shows that only the first few centimetres might have moisture peaks, without a high risk of decay (source below). The question of whether straw bales can be used for construction in the tropics is answered in the affirmative, but not as obviously as in other climate zones. The strong dependence on local climate and design details requires a more sensitive approach. There is certainly still a need for more research in order to sound out the limits more precisely and possibly find special material compositions for extreme situations, or to be able to clearly define the conditions under which straw bale construction works well in the tropics.

Resources for straw bale building in the tropics:
How Straw Decomposes, Matthew D. Summers, Sherry L. Blunk, Bruan M. Jenkins. www.ecobuildnetwork.org/pdfs/ How_Straw_Decomposes.pdf
Straw Bale House Moisture Research, CMHC (Canadian Mortgage and Housing Corporation). www.cmhc-schl.gc.ca/ publications/en/rh-pr/tech/00-103-E.htm
Moisture Properties of Plaster and Stucco in Strawbale Buildings, Dr. John Straube. www.ecobuildnetwork.org/pdfs/ Straube_Moisture_Tests.pdf
Monitoring the Hygrothermal Properties of a Straw Bale Wall, Dr. John Straube and Chris Schumacher. www.ecobuildnetwork.org/pdfs/Monitoring_Winery.pdf
Chinese study: “Research on Prediction Model for Durability of Straw Bale Walls in Warm (Humid) Continental Climate—A Case Study in Northeast China” 2020 by Xunzhi Yin, Qi Dong, et al.

Research project on the campus of the Hanoi University of Civil Engineering - Vietnam

Raising the brick plinth

Load-bearing walls are ready for roof truss

Press event with shell construction almost ready

Installation and calibration of moisture sensors

Author and project conductor

First layers of plaster finished

17. Discussion aid

Mice and insects
In principle, mice and insects can be an issue for all insulation materials. Styrofoam facades are often hollowed out and eaten away by both creatures, and woodpeckers peck through the thin-layer plaster to get to the insects. In conventional house construction, there are often areas where the insulation is only protected by foil or adhesive tape, or in the best case by a 12 mm plasterboard. These are no obstacles to mice or insects, which is why these building materials are often inhabited or eaten away. If straw and mineral wool or polystyrene are placed openly next to each other, mice will go into the materials in which they can more easily build tunnels: the straw bale offers greater resistance, and is more likely to be refused. In the constructions described in this book, straw bales are protected with either several centimetres of lime or clay plaster or solid wood. The layers should also overlap by several centimetres to create tight transitions, which makes it very difficult to get into the straw after plastering at the latest. Due to the very low residual grain content, the only remaining reason is to build a dwelling. Straw itself serves at most as a source of food for termites, which prefer wood (although there have been several such cases in the USA).

Fire
Straw contains a very high proportion of natural silicates, which have a low melting point and therefore ensure cooling, making it difficult to reach the ignition point of the straw. In addition, a tightly compressed bale of straw contains too little air to burn. A fire resistance period of at least 30 min is therefore measured in the open state, and at least 90 min in the plastered state. We also see a significant improvement in fire resistance from plaster thicknesses of 8–10 mm (60–90 min). With a flame thrower, it takes 90–120 min to burn a hole through a plastered straw wall without igniting the bale around the flame cone.

Moisture and mould growth
If mould is present in the construction, this can lead to damage, decomposition of the material and the release of toxic substances in the building components. In addition to moisture, temperature, time and the presence of nutrients also contribute to mould growth. The optimum temperature range to promote growth is between 20°C and 30°C. (Minke and Krick, 2014)
In relation to the four substrate groups, straw as a building material is assigned to Group I. This includes the biologically utilisable substrates. (Hein et al., 2014)

Even if the breeding ground were suitable for mould, a spore would first have to land on it that could start to grow under favourable environmental conditions. With dry straw, there is no risk of mould growth. To keep the potential low, it is very important that the moisture content of the straw bale is below 20%. In addition, due to the abovementioned silicate content and the waxy protective layer over the stalks, the straw itself hardly absorbs any moisture, and only after a long period of time. Until then, the moisture is contained in the stored air, from where it is transported back to the outside by the good capillary effect of the straw bale, provided that the structure is open to diffusion. Lime and clay plasters directly on straw support this process through their absorbency and their own capillaries. Moisture peaks generally only penetrate the outer layers, and leave the bale before the rotting process can begin. It is important to use clay and pure lime plaster without cement (or only a very small amount). Straw houses over 100 years old have shown no signs of rotting so far. Since straw has a similar structure to wood, it can generally be said that situations that work for wood also work for straw. Splash water should therefore be avoided, and the results/recommendations from Chapter 15: Building Physics should be taken into account.

Wind
The fairy tale of the three little pigs and their straw house is familiar to many of us: the wind carries their straw house away with ease.
A straw bale wall plastered on both sides has a weight of up to 200 kg/m2 (for small bales) and is therefore a very solid wall structure that can withstand wind and other influences well. The stiffening effect of the plaster alone is sufficient to achieve the necessary rigidity. In constructions made of timber or brick, the roof truss is secured against wind suction in the traditional way. In load-bearing straw bale constructions, this function must be guaranteed by the tensioning straps in combination with the render.

Service life
Buildings constructed with many traditional methods on earth have a lifespan of many centuries, sometimes even thousands of years, thanks to the use of local natural materials and optimal adaptation to local conditions. With over 100 years of history, the durability of straw bale construction has been proven to be often better than that of modern construction methods. If built and maintained correctly (with the roof, gutters, window sills and plaster regularly checked for function and tightness) and if the points listed in this book are taken into account, straw bale houses can certainly last for several generations.
The local climate is a factor affecting moisture, and hence durability. Straw bale construction is suitable for arid (dry) and temperate climate zones. In tropical climates with permanently high humidity, limits may be reached where straw bale construction is no longer the ideal construction method. *(previous chapter).*

Allergies
To date, there are no known allergies directly related to straw. Reactions to ingredients in the endosperm, e.g. gluten, do not occur with straw, as the residual grain content is very low. If straw is stored for a longer period of time, a layer of dust is deposited, which can lead to coughing, especially when processed indoors. Spray agents can also cause allergic reactions if they have been used in grain cultivation. After installation and the application of a clay layer inside, these occasional reactions are no longer an issue, because the straw bales are sealed off from the room and because the clay plaster has an anti-allergenic effect.

18. Appendix

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18.1 US building code (with Austin considered as an example, others similar)

3605.3 Wall Height. Bale walls may not exceed one story in height and the bale portion may not exceed a height to width ratio of 5.6:1, unless the structure is designed by an engineer or architect licensed by the State to practice as such, and approved by the building official. For example, the maximum height for the bale portion of a 23-inch thick wall would be 10 feet - 8 inches, unless designed by an engineer or architect and approved by the building official.

Exception: In the non-load-bearing exterior end walls of structures with gable or shed roofs, an approved continuous assembly is required at the roof bearing assembly level.

3605.4 Unsupported Wall Length. The ratio of unsupported wall length to thickness, for bale walls, may not exceed 15.7:1, unless the structure is designed by an engineer or architect licensed by the State to practice as such, and approved by the building official. For example, for a 23 inch thick wall, the maximum unsupported length allowed is 30 feet, unless designed by an engineer or architect and approved by the building official.

3605.5 Allowable Loads. The allowable vertical load (live and dead load) on the top of load-bearing bale walls may not exceed 400 pounds per square foot (psf) and the resultant load shall bear at the center of the wall. Bale structures must be designed to withstand all vertical and horizontal loads as specified in the Building Code.

3605.6 Foundations. Foundations must be sized to accommodate the thickness of the bale wall and the load created by the wall and roof live and dead loads. Foundation (stem) walls that support bale walls must extend to an elevation of not less than 8 inches above adjacent ground at all points. The minimum width of the footing must be the width of the bale it supports, with the following exceptions:

1.The bales may overhang the exterior edge of the foundation by not more than 3 inches to accommodate rigid perimeter insulation.

2.Pier and Beam Foundations require a 12" wide (minimum) footing.

3605.7 Wall and Roof Bearing Assembly Anchorage.

3605.7.1 General. Vertical reinforcing bars with a minimum diameter of 1/2" must be securely embedded in the foundation and must extend above foundation a minimum of 12 inches. These vertical bars must be located along the centerline of the bale wall, spaced not more than 2 feet part. A vertical bar must also be located within 1 foot of any opening or corner, except at locations occupied by anchor bolts.

3605.7.2 Intersecting Walls. Walls of other materials intersecting bale walls must be attached to the bale wall by means of one or more of the following methods or an acceptable equivalent:

1. Wooden dowels at least 5/8" in diameter of sufficient length to provide 12 inches of penetration into the bale, driven through holes bored in the abutting stud, and spaced to provide one dowel connection per bale.

18.2 Load test of plastered wall made of small bales in Sydney

Pilot Study: Two Storey Load Bearing Straw Bale Wall University of Western Sydney. July 2000

The results of this table have been shown in the following chart (Figure 13.)

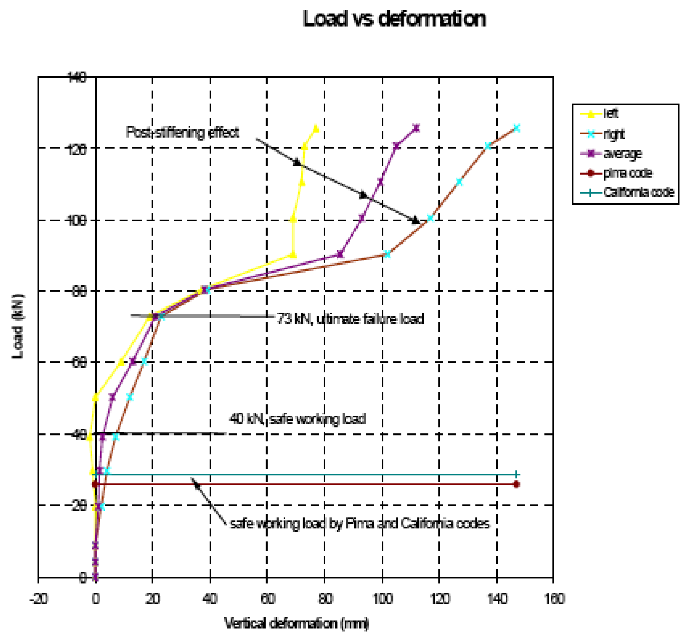

Figure 13 Load Deformation Curve (Source J. Zhang)

The wall demonstrated some interesting and fascinating structural characteristics. Apart from the obvious failure region when the load reaches about 80 kN, it also reveals that the post-failure behaviour has a distinct feature of post-stiffening effect due to the compressibility of the material.

When the wall is first loaded, the behaviour follows a typical linear path. The left side deformation reading is negative indicating it is moving upward instead of downward as one would expect. This is due to the eccentricity in the applied load and in the wall itself. This eccentricity creates a significant bending effect so that the wall is bent toward the right hand side.

For this reason the average deformation between the left and right provide a more meaningful interpretation of the result. It can be seen on the average curve at the load level of just above 40 kN, there is a significant increase in deformation, demonstrated by the change of slope in the curve. One would stipulate that due to the compression of straw bale, the interaction between the straw and the cement render becomes less significant resulting in the ‘softening’ of the wall. As the load increases the wall starts to ‘yield’. At the load level of 70 kN there is a significant increase in deformation, which marks the failure of the wall. This failure is probably due to the significant separation between the straw bale and the cement render. As the load increases further, the straw bale becomes fully compressed, therefore becoming more solid as the load starts to increase further. Although this post-failure capacity cannot be used in the design of straw bale wall, it does illustrate that the post-failure behaviour is rather stable.

18.3 Excerpt: Nine monitored strawbale houses with cement stucco in Canada

that point, but mid-bale monitors showed significant spikes one week after precipitation, with a drying trend within two weeks. One year later, exterior monitors were installed. Exterior straw showed no signs of mold or decomposition. The maximum moisture content reading was 8% (unadjusted). This structure has no significant design modifications to prevent exterior wetting. But, the site is protected by vegetation and topography. Significant winter drying can also occur due to chinooks.

HOUSE #5

SIGNIFICANT FACTORS

- West coast location, with almost double the precipitation (950mm) of the wettest Alberta location
- Warmest location, in terms of average yearly mean temperature (+9.9C)
- Interior surface of bales have not been plastered
- No vapor retarder or air barrier is in place on the interior
- North wall receives little if any precipitation, protected by 70 cm gable and vegetation
- South exposure receives significant precipitation

SUMMARY

This structure has been occupied for at least one year without any interior parging. This may allow significant exfiltration and possible moisture build-up at the exterior during the winter months. Given the high average yearly temperature, exfiltration would be somewhat moderated as compared to Alberta locations. A lack of interior parging would likely also help in terms of summer drying. Both the west and north walls registered sustained moisture content readings of 14%-17%(unadjusted) during the summer months. Readings at this level were indicative of borderline to unacceptable conditions in two Alberta structures.

Although the north wall is well protected from precipitation, high moisture content readings persisted during the summer months. This is likely a situation where high moisture content within the wall coincides with high atmospheric RH levels. The builder of this house felt that the exposure may be overprotected by vegetation (forest within 4 m of the wall) and a reduction in air circulation may be affecting drying.

It is also important to note that although the south wall experiences significant precipitation, the maximum readings reach the 14-17%(unadjusted) only during the winter. During the summer, moisture content never increased above 10% (unadjusted).

HOUSE #6

SIGNIFICANT FACTORS

- Oldest house in study (9 years)
- Site unprotected by vegetation or topography
- Minimal interior venting (radiant floor heat, no kitchen fan, no HRV)
- West and northwest exposures fully protected by verandah
- North, east and south walls protected by a standard 70 cm overhang
- South exposure subjected to significant backsplash
- Moderate precipitation, but extremely variable wind directions.
- Significant backsplash on south side.
- 'Weldbond' glue added to interior plaster batches to prevent cracking and possibly reducing permeability
- Exterior sheathed with plywood / building paper prior to parging
- Frequent periods of drying may occur in the winter when the temperature is above freezing and the atmospheric conditions are windy with low RH

SUMMARY

This is the oldest house in the study. Straw that was examined during monitor installation showed no signs of decomposition at any of the installation locations.

V. Sheathing the exterior bale surface with plywood, then using building paper and cement based stucco
VI. Building paper, used as a vapor retarder on the interior prior to parging
VII. Cement based exterior stucco, earthen plaster interior
VIII. Bales elevated well above grade to eliminate backsplash

4) Designs which produced borderline or unacceptable moisture readings included two or more of the following:
   I. Minimal or absent overhangs
   II. No capillary break between foundation parging and above grade stucco
   III. Structures subject to extreme interior wetting without drainage
   IV. Below-grade bales
   V. Inadequate backsplash protection
   VI. Northern exposures

5) Walls with southern exposures were generally much drier than other exposures and were able to handle significantly more exterior wetting.
6) Interior humidity control seemed to have little affect on exterior bale moisture content. NOTE: This is not to say that a lack of interior venting is a recommended building practice.
7) Extreme diurnal variances in RH (with spikes as high as 98%) do not seem to be indicative of straw degradation. Moisture content values correlated most closely with the minimum daily RH value. Prolonged high RH values (over 85%) generally indicate a problem.
8) It is unclear how well Radio Shack digital hygrometers function under prolonged high humidity conditions.
9) When using Timbercheck wood moisture meters to monitor moisture content, the maximum recorded in wall reading was 14%-17%(unadjusted). At this level, borderline to unacceptable conditions were observed.

It was recommended in the previously submitted (interim) report that hydrophobic coatings at the exterior stucco surface may be an appropriate means to prevent wetting. None of the houses in this study incorporated this strategy. If such products are incorporated as the primary strategy against wetting, detailing around exterior wall openings must be meticulous. Although many of these products are highly vapor permeable, they also act as a capillary break at the exterior stucco surface. Significant leaks, due to poor detailing, will dry only through vapor diffusion and not through a combination of diffusion and capillary action. Although sheet moisture barriers have been used successfully in two houses in this study, a similar caution should apply.

18.4 Earthquake test: University of Reno/ Nevada

vertical and lateral loads. The fishing net provides tensile strength and ductility. At the foundation interface it provides shear and overturning resistance, allowing the building to displace to a certain extent, then pulling it back to its original position [PAKSBAB]. During the full-scale house test spalling, cracking, and base displacement occurred, as shown in Figure 7; however, the structure remained standing and the damage was classified as reparable.

Figure 7. Damage to the house after 0.82g (200% Canoga Park)

Conclusion

Based on these data, the veranda wing walls (see Figure 8) have a significant impact on wall behavior and should be more closely examined to maximize structural performance. While the straw bales and gravel bag foundation accomplish enough damping for the structure to remain standing, amplification of the veranda wall movement due to its cantilevered design increase the damaging effects of an earthquake.

Careful consideration should be applied when redesigning the wing walls. Further stiffening would have negative effects on the beneficial damping properties of the straw bales, thereby reducing stiffness performance during an earthquake throughout the entire structure. Reduction of the veranda wing wall extension or complete removal of the wing walls from future plans could possibly enhance performance, at the expense of comfort and aesthetics.

18.5 Data sheets for clay plasters

ISO-Lehm

Clay plaster mortar - according to DIN 18947 - LPM 0/0.5 f - S II - 1.8

Key figures (required values according to DIN, see information in brackets)	
Properties	ISO LEHM fine plaster is a ready-mix - in accordance with DIN 18947 and suitable for machine application. Full declaration: Ground building clay, mixed-grain sand 0 - 0.5 mm, vegetable fibres.
Plaster application thickness	1 mm to 3 mm
Grain group	0 / 0,5
Oversize	< 1 mm
Bulk density class	1,8
Drying shrinkage	2,1 % (≤ 3 %)
Strength class	S II
Compressive strength	2.7 N/mm^2 (≥ 1.5)
Bending tensile strength	1.03 N/mm^2 (≥ 0.7)
Adhesive strength	0.26 N/mm^2 (≥ 0.1)
Water vapour diffusion resistance μ	5 / 10
Building material class	A 1
Thermal conductivity	0.91 W/mK
Abrasion	0,5 g (≤ 0,7)
Water vapour absorption class	WS III
Delivery form	25 kg bags and big bags (1.0 tonnes)
Storage	When stored in a dry place, ISO LEHM Feinputz has an unlimited shelf life.
Yield	25 kg make approx. 17 litres of plaster mortar. 3 mm plaster application = 6 m^2 1.0 tonne yields 680 litres of plaster mortar. 3 mm plaster application = 240 m^2
Water addition	Approx. 5 litres of water per 25 kg of ISO LEHM fine plaster, dry, approx. 200 litres of water per 1,000 kg. Depending on the substrate, application thickness, application type, water hardness, etc., the specified water addition must be adjusted by the applicator.

Claytec

LEHMPUTZMÖRTEL: Declaration and material characteristics DIN 18947

	Clay undercoat plaster	**Clay top coat coarse**	**Clay top coat fine**	**Clay plaster Mineral 20**	**Clay plaster Mineral16**
Full declaration	Clay, sand, straw	Clay, sand, straw	Clay, sand, perlite, flax	Clay, sand	Clay, sand
Grain group, oversize	0/4, < 8 mm	0/2, < 7 mm	0/1, < 2 mm	0/4, < 5 mm	0/2, < 5 mm
Fibres	Barley straw up to 30 mm	Barley straw up to 10 mm	Flax up to 15 mm	-	-
Application thickness	8-15 mm (if necessary 35 mm)	7-10 mm	2-3 mm	5-20 mm	5-20 mm
Drying shrinkage	2 %	2 %	4 %	2 %	2 %
Strength class	**SII**	**SII**	**SII**	**SII**	**SII**
Bending tensile strength	0.7 N/mm2	0.7 N/mm2	1.0 N/mm2	1.0 N/mm2	1.0 N/mm2
Compressive strength [1]	**1.5 N/mm2** (≥ 1.5)	**2.0 N/mm2** (≥ 1.5)	**2.0 N/mm2** (≥ 1.5)	**3.5 N/mm2** (≥ 1.5)	**2.5 N/mm2** (≥ 1.5)
Adhesive strength [1]	**0.10 N/mm2** (≥ 0.1)	**0.15 N/mm2** (≥ 0.1)	**0.25 N/mm2** (≥ 0.1)	**0.20 N/mm2** (≥ 0.1)	**0.20 N/mm2** (≥ 0.1)
Abrasion [1]	**-**	**0,6 g** (≤ 0,7)	**0,1 g** (≤ 0,7)	**0,1 g** (≤ 0,7)	**0,1 g** (≤ 0,7)
Bulk density class	1,8	1,8	1,8	2,0	2,0
Thermal conductivity	0.91 W/m-K	0.91 W/m-K	0.91 W/m-K	1.1 W/m-K	1.1 W/m-K
μ-value	5/10	5/10	5/10	5/10	5/10
Water vapour adsorp.	**WS III**	**WS III**	**WS III**	**WS III**	**WS III**
Building material class	B2 [2]	B2 [2]	A1	A1	A1

[1] Values in brackets Requirement for categorisation in the highest strength class S II
[2] Better categorisation possible subject to fire protection tests (Lehmbau Regeln DVL 2009, p. 97)

18.6 New construction statistics for Austria 2005–16

2005 bis 2016 fertiggestellte Wohnungen und neue Gebäude nach Gebäudeeigenschaften und Art der Bautätigkeit

Gebäudeeigenschaft, Art der Bautätigkeit	Österreich[1])						Österreich ohne Wien[2])[3])					
	2016[4])	2015[4])	2014[4])	2013[2])	2012[2])	2011[2])	2010	2009	2008	2007	2006	2005
Wohnungen	**56.359**	**53.191**	**47.817**	**50.933**	**47.870**	**46.208**	**36.506**	**37.501**	**49.010**	**48.467**	**42.203**	**38.390**
in neuen Gebäuden[5])	44.300	42.704	37.157	40.942	37.842	36.684	28.885	32.208	42.629	41.821	36.655	33.488
in neuen Wohngebäuden	43.902	42.083	36.772	40.491	37.387	36.186	28.486	31.808	42.001	41.329	36.222	33.133
mit 1 od. 2 Wohnungen	14.656	13.959	14.218	15.683	16.794	15.788	14.607	16.161	22.646	21.418	19.540	17.974
mit 3 od. mehr Wohnungen	29.246	28.124	22.554	24.808	20.593	20.398	13.879	15.647	19.355	19.911	16.682	15.159
in neuen Nicht-Wohngebäuden[5])	398	621	385	451	455	498	399	400	628	492	433	355
durch An-, Auf-, Umbautätigkeit[6])	12.059	10.487	10.660	9.991	10.028	9.524	10.028	5.293	6.381	6.646	5.548	4.902
komplett neu[6])	5.040	4.382	4.480	4.615	4.338	3.494	4.338	.	.	.	.	.
entstanden durch Teilung[6])	216	209	219	250	161	131	161	.	.	.	.	.
darunter Wohnungsteilung[6])	102	122	132	119	108	88	108	.	.	.	.	.
entstanden durch Zusammenlegung[6])	152	62	70	62	31	21	31	.	.	.	.	.
darunter reine Wohnungszusammenlegung[6])	53	25	26	20	18	12	18	.	.	.	.	.
Vergrößerung[6])	4.178	3.648	4.054	3.518	3.227	2.833	3.227	.	.	.	.	.
Verkleinerung[6])	1.198	1.070	990	887	798	622	798	.	.	.	.	.
sonstige Umbautätigkeit[6])	1.275	1.116	847	659	1.473	2.423	1.473	.	.	.	.	.
neue Gebäude[5])	**21.140**	**19.566**	**19.620**	**21.103**	**21.760**	**20.037**	**17.872**	**19.442**	**28.750**	**26.672**	**24.312**	**22.276**
neue Wohngebäude	16.517	15.576	15.633	17.144	18.090	17.127	15.566	17.272	23.664	22.669	20.624	18.911
mit 1 od. 2 Wohnungen	13.949	13.251	13.547	14.878	15.972	15.062	13.952	15.448	21.382	20.216	18.474	16.992
mit 3 od. mehr Wohnungen	2.568	2.325	2.086	2.266	2.118	2.065	1.614	1.824	2.282	2.453	2.150	1.919
neue Nicht-Wohngebäude[5])	4.623	3.990	3.987	3.959	3.670	2.910	2.306	2.170	5.086	4.003	3.688	3.365
Gebäude für Gemeinschaften	41	62	30	42	53	48	45	50	53	57	49	42
Gebäude für Büro-, Verwaltungszwecke	191	211	181	200	177	194	174	231	369	327	272	220
Hotel, Gasthof, Pension u.ä.	179	165	150	160	276	143	140	183	269	256	311	236
Groß- und Einzelhandelsgebäude	193	149	167	220	187	188	165	183	360	307	313	384
Gebäude d. Verkehrs- u. Nachrichtenwesens	34	30	14	39	30	53	35	40	77	46	64	52
Industrie- u. Lagergebäude	612	570	573	543	538	538	493	596	1.093	857	811	645
Geb. f. Kultur, Freizeit, Bildungs-, Gesundheitswesen	257	260	223	221	238	244	248	235	374	283	247	243
Kirchen, sonstige Sakralbauten	16	11	11	13	12	10	3	4	9	5	8	2
freistehende Privatgaragen b. Ein- u. Zweifamilienwohnhaus	1.966	1.682	1.724	1.525	1.433	1.016	664	430	1.560	1.144	1.029	1.023
landwirtschaftliche Nutzgebäude	1.134	850	914	996	726	476	339	218	922	721	584	518

Q: STATISTIK AUSTRIA, Baumaßnahmenstatistik. Erstellt am 21.11.2017. Datenabzug vom 15.09.2017. Rundungsdifferenzen wurden nicht ausgeglichen. 1) Ohne durch An-, Auf-, Umbautätigkeit fertiggestellte Wohnungen in Wien. - 2) Den Fertigstellungen wurden offene Bauvorhaben neuer Gebäude mit mindestens 1 Hauptwohnsitzangabe zugerechnet. Altersätze wurden dabei nicht berücksichtigt. - 3) Den Fertigstellungen wurden ohne Bauvorhabensmeldung neu erfasste Objekte zugerechnet. Die Zurechnung der ohne Bauvorhabensmeldung eingebrachten Objekte war wegen fehlender Angaben nicht vollständig möglich. Um weitere signifikante Verzerrungen wegen inkorrekter Meldungen der Bundeshauptstadt insbesondere für das Jahr 2008 auszuschließen, beziehen sich die hier dargestellten Inhalte auf Ergebnisse über Österreich ohne Wien. - 4) Ergebnisse, die in Bezug auf die bis zum Datenabzug registrierten Nachmeldungen aufgeschätzt sind. - 5) Ohne sonstige bzw. Pseudobauwerke. - 6) Ohne Wien.

18.7 Cereal harvest worldwide

Austria has about 2 million tons of cereal straw each year, Germany 25 million tons

Cereal production by country

for many cereal crops the grain-straw factor is 0,7 which doesn´t mean all of it is suitable for building

The table shows the countries with the largest production of cereals (barley, oats, millet, sorghum, corn, rice, rye and wheat).[1]

Rank	Country/Region	Cereal production (in million tons)	Production per capita (in kg per person)
1	People's Republic of China	658	460
2	United States	478	1,400
3	India	382	270
4	Brazil	156	710
5	Russia	149	1,000
6	Argentina	101	2,200
7	Canada	72.1	1,900
8	Indonesia	65.9	230
9	France	62.5	940
10	Ukraine	61	1,500
11	Bangladesh	59.8	350
12	Vietnam	50.3	440
13	Germany	49.1	600
14	Pakistan	48.7	210
15	Turkey	46.8	530
16	Mexico	42.4	320
17	Thailand	41.7	590
18	Poland	39.9	1,100
19	Ethiopia	34.2	270
20	Nigeria	32.1	140
21	Myanmar	31.3	560
22	Australia	29.9	1,100
23	Philippines	28.3	250
24	Spain	27.1	600
25	Egypt	26.9	240
26	Iran	24.7	280
27	Kazakhstan	22.6	1,300
28	Romania	20.2	1,100
29	Italy	19.9	330
30	Hungary	19.3	2,000
31	South Africa	18.1	290
32	United Kingdom	17.3	260
33	Tanzania	16.2	260
34	Japan	15.1	120
35	Cambodia	14.9	880
36	Serbia	12.5	1,900
37	Nepal	11.7	380
38	Mali	10.2	460
One million to ten million tons			
39	Denmark	9.93	1,700
40	Iraq	8.93	190
41	Bulgaria	8.74	1,400
42	Paraguay	8.63	1,300
43	Belarus	8.37	910
44	Czech Republic	8.21	800
45	Uzbekistan	7.98	460
46	Lithuania	7.26	2,700
47	Afghanistan	6.41	150
48	Sweden	6.32	600
49	Niger	6.14	230
50	Austria	6.02	660
51	Sri Lanka	5.99	380
52	Peru	5.89	250
53	Syria	5.67	250
54	Burkina Faso	5.53	230
55	South Korea	5.32	100
56	Algeria	5.21	120
57	Kenya	5.11	95
58	Laos	5.01	620
59	Guinea	4.99	340
60	North Korea	4.89	190
61	Ghana	4.79	140
62	Sudan	4.72	83
63	Slovakia	4.69	890
64	Madagascar	4.53	170
65	Finland	4.46	800
66	Malawi	4.39	150
67	Colombia	4.22	80
68	Croatia	4.11	1,100
69	Cameroon	3.99	130

source: based on the *Food and Agriculture Organization Corporate 2023*

Sources

Internet Resources

- www.fasba.de (German Straw Bale Construction Association)
- www.baubiologie.at (Austrian straw bale network)
- www.strawbuilding.eu (European Straw Bale Building Association)
- www.strohballenbau.info Facebook/Strohballenbau (pages of the author)

Straw bale dealer

- www.sonnenklee.at (certified organic straw, also certified externally, A)
- contact@grat.at (GrAT contact for external certification, A)
- www.pirabe.at (jumbo bales and very densely compressed small bales, A)
- www.strohmax.at (Jumbo bales)
- www.baustroh.de (certified building straw bales, D)

Literature

- Straw bale construction manual, Minke & Krick
- The straw bale construction, Minke & Mahlke
- (New) building with straw, Gruber & Gruber
- Wall systems made from renewable raw materials, Wimmer & Hohensinger et al.
- Straw-insulated buildings, brochure available for download from https://baustoffe.fnr.de
- Investigation of straw bales and constructions..., PhD thesis, Benjamin Krick
- Stroh kompakt, Adensam & Breinsberger & Staribacher & Hiller & Unfried et al.
- Clay building manual, Minke
- Straw bale building guidelines (D), download from www.fasba.de
- The Strawbale House, Steen & Steen & Bainbridge
- Build it with Bales, Myhrman & MacDonald
- Buildings Of Earth And Straw, King
- The Thermal Resistivity of Straw Bales for Construction, McCabe
- Straw Bale Building Details -CASBA

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