STRAW BALE BUILDING GUIDELINES

English language version, 2020

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Acknowledgements

FASBA's Straw Bale Building Guidelines have now, five years after the publication of the original guidelines, been made available in a first revised version. Association members and recognised experts have been involved in the revision process.

Fachagentur Nachwachsende Rohstoffe e. V. (FNR) has made it possible to produce the Straw Bale Building Guidelines thanks to its sponsorship.

The revision of the Straw Bale Building Guidelines has been achieved within the framework of the EU-funded UP STRAW project with Benediktinerabtei Plankstetten as the German partner.

We wish to thank each and every one of these organisations for their support.

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Interreg North-West Europe
UP STRAW
European Regional Development Fund

- **Fachagentur Nachwachsende Rohstoffe e. V. (Ed.): Straw insulated buildings, Chapter 2: Building with straw is particularly sustainable. 2017**
- **ETA-17/0247 Baustroh (Building Straw), European Technical Assessment thermal insulation made from straw bales.**
- **Leaflet Instructions on processing Building Straw**
- **P-3048/817/08-MPA BS. General Building Inspectorate Test Certificate. Load-bearing, enclosing wall construction of fire-resistance class F 30 or F 90. English translation. Braunschweig: iBMB TU Braunschweig. 8.12.2014.**
- **Meyerhoff, C.: Expert opinion GA-2018-28, English translation, 2018.**

FOREWORD

These Straw Bale Building Guidelines summarise the experience and knowledge of players in the field of straw bale building in Germany. It has been compiled by experts and members of the *Fachverband Strohballenbau Deutschland e. V.* (FASBA) for those who are currently involved in constructing straw-insulated buildings and those who will be involved in this field in the future.

Their aim is to provide these individuals with a clear and comprehensive set of guidelines and thus set a quality standard for building with straw. It currently does not have the status of accepted technical rules.

The Straw Bale Building Guidelines relate, to the greatest possible extent, to constructions in which straw bales are used as infill, non-structural thermal insulation material. Numerous practical tried-and-tested straw-insulated constructions are listed here as proven and ready for approval.

Any other applications are also mentioned briefly.

The Straw Bale Building Guidelines were published in 2014 and the first revision took place in 2019. The conversion of the General Building Inspectorate Approval (*Allgemeine bauaufsichtliche Zulassung*) for construction grade straw bales (*Baustroh*) to a European Technical Assessment was updated, a short chapter on the sustainability of straw bale construction was added and more minor corrections and improvements were made to the text.

Currently (in 2019), 450 straw-insulated buildings are estimated to have been constructed in Germany. There are good reasons to build significantly more with straw in the future, above all the outstanding environmental performance of straw-insulated buildings.[1]

For FASBA:

Benedikt Kaesberg (text),

Dirk Scharmer (expertise),

Britta Imhoff (Board)

[1] See in the annex: Fachagentur Nachwachsende Rohstoffe e. V. (Ed.): Straw insulated buildings, Chapter 2: Building with straw is particularly sustainable.

FOREWORD TO THE ENGLISH LANGUAGE VERSION

Since its publication, people outside Germany have referred to these Straw Bale Building Guidelines. With its revision in 2019 and with the UP STRAW project aiming to upscale the use of straw in the building sector throughout Europe, it became important to translate these Guidelines into English.

As a national reference text, the Straw Bale Building Guidelines refer to both a particular building technique and to national building legislation. Most of the building aspects are common sense and valid everywhere. But due to different conditions (e. g. climate), moisture-proof constructions with straw insulation are not the same all over the world. That's why allowable moisture-dependent layer properties for constructions with straw as thermal insulation may be suitable in other parts of the world, but they are approved only for German climate conditions. The legal aspects refer to German building legislation, and any other countries' building legislation will be different. Specific legal terms are displayed both in German and in English, some footnotes give further information on the meaning of these terms. So, the reader can identify that there is a specific legal aspect and decide whether to adopt, adjust or disregard it for his or her purpose.

The translation aims to be as close as possible to the original text even though, its purpose is not to represent a scientific or literal translation. For instance, the term *Strohbau*, common in Germany, became Straw Bale Building for better understanding.

Hyperlinks of the original document are kept. If English language versions are available, but not online, footnotes refer to them in the annex.

These guidelines have been compiled and published by the Fachverband Strohballenbau Deutschland e. V., that is the German Straw Bale Building Association, a registered association and the only national organisation representing straw bale building in Germany. It is referred to as FASBA, and so it is in this text.

Feedback is welcome, through FASBA's webpage or facebook site.

May this English version of the Straw Bale Building Guidelines contribute to more straw bale building!

Benedikt Kaesberg (chairman translation)

Britta Imhoff (Board of FASBA)

Barbara Jones (proof reading)

1 GENERAL

The Straw Bale Building Guidelines are to be used in addition to the accepted technical rules.

The use of the following verbs refers to the meanings set out here:

Must: A provision with 'must' is mandatory.

Should: A provision with 'should' is to be complied with or, otherwise, reason is to be given why it is not being observed.

Can: A phrase with 'can' is used to set out options (for actions).

1.1 Terminology *Strohbau*

Strohbau ('straw building') refers to building with straw in general. Since building work with straw is usually carried out in the form of bales, the term *Strohballenbau* (straw bale building) is also commonly used.[2] In English, the term straw bale building is used, 'straw building' is not common.

1.2 Scope of these Guidelines

The Straw Bale Building Guidelines apply to straw as a building material within the meaning of the State Building Codes (*Landesbauordnungen*).[3] They require recognised construction products to be used. For straw in bale form, this is stated in ETA-17/0247 Building Straw or other approval document.

Alternatively, approval may also be obtained on a case-by-case basis (*Zustimmung im Einzelfall*).[4]

1.3 General requirements

Proper planning and implementation of straw-insulated buildings requires special physical, technical and manual construction knowledge. This should be carried out by experts who have received the appropriate training or are experienced.

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[2] Straw can also be used as a blown-in insulating material and as a bound insulating panel. Unlike with straw in bale form, this only carries out two of the three functions as thermal insulation, wall structure and base for plaster. It does not constitute a separate construction method. Rather, these building materials are versions of blown-in insulating materials and/or composite thermal insulation systems.

[3] Germany is a federal republic consisting of States (*Land* (sg), *Länder* (pl)) of whom each one has its own State Building Code (*Landesbauordnung*).

[4] The approval on a case-by-case basis (*Zustimmung im Einzelfall*) is an option for approval laid down in the State Building Codes. It applies only rarely and was initially the only way to obtain a building permit for a straw bale house in Germany. FASBA succeeded in establishing an easy approval for straw bale building with the recognition of the construction product "Building Straw". Regardless of that, the approval on a case-by-case basis remains possible.

2 STRAW AS A BUILDING MATERIAL

2.1 Definition of the term ‘straw’

Straw is defined as the dry stalks of cereals. The threshed ears usually remain on the stalks and are also part of the straw.

2.2 Grain varieties

To date, the domestic grain varieties of wheat, rye, spelt, wheat-rye hybrid and barley have been used for construction purposes. According to current knowledge, wheat and rye are particularly well-suited, whereas oat must be viewed as unsuitable.

2.3 Properties of the stalks

The natural properties of the stalks, in particular the length thereof, should be changed and/or damaged as little as possible by cultivation, harvesting and further processing.

The straw should be golden yellow to pale yellow. Straw which is somewhat grey and has isolated darkish areas as a result of mould which is no longer active can be seen as non-critical. The straw must not smell earthy or mouldy. The moisture content must be below the growth limit for mould.

The weed content of the straw is to be kept as low as possible.

2.4 Straw bale formats

In agriculture, straw is pressed into round or square bales to make transport, storage and further use easier. For straw bale construction, rectangular bales from agriculture are used. These are either made on the field during harvesting or re-baled at a later point in time.

Dimensions with a cross section of up to 40 cm by 50 cm are deemed small bales and bales which exceed these dimensions are deemed large bales. Small bales are currently most commonly used for construction with a width of approx. 48 cm and a height of approx. 36 cm depending on the baling type.

In the baling process, the width and height are generally not adjustable but the length is adjustable to a limited extent.

Large bales (e. g. mini-heston) can be installed faster, however they often require the use of machines and also more materials.

The dimensions of the straw bales must be used to determine the clear dimensions of the frame so that the straw bales can be installed tightly without any gaps.[5]

[5] For more information on this, see Chapter 5, Straw installation, and the Leaflet Instructions on processing Building Straw in the annex.

2.5 Storage and transportation of straw

Straw must be transported and stored in dry conditions. If necessary, it may only have brief contact with the ground and must be protected from rain.

When storing under tarpaulins, these must be permanently rainproof, including when subject to UV radiation and other stresses. There must not be any condensation dropping onto the straw from the underside of the tarpaulin, as this would affect the quality of the bale.

2.6 Straw as a building product

Thermal insulation materials must be recognised building products in accordance with State Building Codes (*Landesbauordnungen*) because they perform key tasks for a construction component. Within the meaning of the State Building Codes (*Landesbauordnungen*), straw is an unregulated building product like lots of other thermal insulation materials because no accepted technical rules exist for the material. It is either defined as having certain properties with the CE mark in accordance with ETA-17/0247 Building Straw or, if applicable, another approval document, or the use is approved on a case-by-case basis with the corresponding justifications for use.

2.7 Sustainability of straw bale building

Straw is a by-product created during grain cultivation. It grows every year and is regionally available. Approximately 20% of the straw harvest produced in Germany is not required. This quantity could be used to build up to 350,000 family homes. Manufacturing straw bales is possibly associated with low costs. In addition, wood, straw and clay can be reused.

Building with straw protects the environment by storing CO_2 with growth, with minimal CO_2 emissions being released during the manufacturing of straw bales and as thermal insulation in building operation thanks to the prevention of CO_2 emissions.

The environmental effects of straw as a building material are documented, for example, in the Environmental Product Declaration for Building straw. A life cycle assessment study of the environmental performance of straw-insulated buildings can be found in the “Straw-insulated buildings” brochure, Chapter 2, published by the Fachagentur Nachwachsende Rohstoffe e. V.[6]

[6] See in the annex.

3 PHYSICAL CONSTRUCTION PROPERTIES

The following section covers the physical construction properties of straw and straw-insulated construction components.

The chapter is aligned with the general construction standards necessary under the following headings.

3.1 Fire protection

3.1.1 Building material class

In accordance with the State Building Codes (*Landesbauordnungen*), building materials may only be used if they can be classified as having at least normal flammability (B2) in accordance with DIN 4102 or Class E in accordance with DIN EN ISO 11925-2 or, in exceptional cases, if this can be achieved in an equivalent way by the method of installation.

Building straw is, in accordance with ETA-17/0247 Building Straw, to be assigned to building material class E. For this, the minimum straw density, in particular, must not fall below 85 kg/m³.

The surface flammability may, for example, be reduced with a plaster coat. By means of a clay plaster coat which is at least 8 mm thick, a straw-insulated wall can achieve “B, s1, d0” in accordance with DIN EN 13501-1:2007. Due to the additional usability proof which is required in Germany in accordance with DIN 4102 for this testing type which is regulated on a European basis, Building straw is, however, only classified as having a normal level of flammability, even with this finish.

3.1.2 Resistance to fire

The fire-resistance class states the duration in minutes that the classified construction component can withstand during a full fire in standardised testing. Key criteria are the maintenance of the room seal, the structural stability and temperature protection.

A load-bearing straw-insulated timber stud wall can be classified in fire-resistance classes in accordance with DIN 4102-2:1977-09. For this, it must meet all the conditions of the General Building Inspectorate Test Certificate (*allgemeines bauaufsichtliches Prüfzeugnis*) set out below. With clay plaster that is at least 8 mm thick, F 30-B is achieved, and F 90-B is also achieved with lime plaster.

Load-bearing fire-resistant external wall F 30-B and F 90-B in accordance with the General Building Inspectorate Test Certificate (*allgemeines bauaufsichtliches Prüfzeugnis*) P-3048/817/08-MPA BS, 2014, updated in 2019.[7]

Fire-resistant straw-insulated construction components can also be created if corresponding proof is provided by the covering alone and without the specification of other components.

3.2 Thermal insulation

3.2.1 Thermal conductivity

The thermal conductivity λ [W/(m·K)] of a material denotes the heat (J) which is transmitted through one square metre of a material which is 1 m thick, at a temperature difference of one degree kelvin, per second.

For the approved building product of "Building Straw" in accordance with ETA-17/0247 Building Straw, the declared value of the thermal conductivity, valid throughout the EU, is:

λ_D = 0.048 W/(m·K) according to ETA-17/0247 Building Straw

The rated value of the thermal conductivity, defined differently by a national calculation procedure in each of the EU member states, to be used for the calculations for Germany is:

$\lambda_{R,\ Germany}$ = 0.049 W/(m·K) according to ETA-17/0247 Building Straw[8]

This value applies for the orientation of the stalks within the construction component in a direction predominantly vertical to the heat flow. Therefore, bales are installed either horizontally or vertically on edge. (See figures in 4.1.7) A recognised rated value for the orientation of the stalks in the direction of the heat flow currently does not exist.

3.2.2 Thermal transmittance coefficient

The thermal transmittance coefficient U [W/(m²·K)] denotes the thermal flow in watts with a temperature difference of one degree kelvin through one square metre of the surface area of the construction component. This is a result of the properties of the layers of the construction component.

[7] See English version in the annex.

[8] The calculation takes place in accordance with the Model Administrative Provisions – Technical Building Rules (*Muster-Verwaltungsvorschrift Technische* Baubestimmungen (MVV TB)), Annex A 6.2/3, as follows:

$\lambda_R = \lambda_{10,dry,\ 90/90} \cdot F_{m\ (dry\ -\ 23/80)} \cdot 1.03 = 0.043\ W/(m\cdot K) \cdot 1.1 \cdot 1.03 = 0.048713\ W/(m\cdot K) \approx 0.049\ W/(m\cdot K)$

Straw-insulated components achieve U values of 0.155 W/(m²·K) and below. Thus the standard requirements are met or exceeded.

3.2.3 Specific heat capacity

The specific heat capacity c [kJ/(kg·K)] of a material denotes the energy that is required to heat one kilogram of the material by one degree kelvin.

The specific heat capacity of typical cereal straw is:

c = 2.0 kJ/(kg·K) TGL 35424/02 Bautechnischer Wärmeschutz (Structural heat insulation. Values, Units, Characteristics.), 1981.

3.2.4 Specific flow resistance

The specific flow resistance Rs [Pa s/m] refers to the ratio of the pressure difference Δp [Pa] in front of and behind a material layer to the speed of the air passing through. This property of a building material influences the thermal conductivity and the airborne sound insulation.

The specific flow resistance of Building straw can be assumed with:

Rs = 181 Pa s/m according to IAB Messbericht (test report) A 59829/3950, 25.9.2009

3.3 Acoustic insulation

3.3.1 Airborne sound insulation index of a straw-insulated external wall

The airborne sound insulation index R'_W is a logarithmic measure and describes the ability of a construction component to insulate sound. The airborne sound insulation values measured in the 16 1/3-octave bands between 100 Hz and 3150 Hz for a construction are entered into a diagram by frequency. In order to determine the airborne sound insulation index R'_W, this curve is used to determine a single-number value using a standardised reference curve.

Example wall I with plaster at 1 cm thickness, 36 cm straw, 6 cm/30 cm posts with 2 cm of wood fibre insulation board as the plaster base on each side

$R_{w,R}$ = 43 dB (calculation value according to DIN 4109:1989 Tab. 11)

IAB Messbericht (test report) A 59829/3950, 25.09.2009

Example wall I with plaster at 1 cm thickness on one side and 2 cm on the other side, 36 cm straw, 6 cm/30 cm posts with 2 cm of wood fibre insulation board as the plaster base on each side

$R_{w,R}$ = 44 dB (calculation value according to DIN 4109:1989 Tab. 11)

IAB Messbericht (test report) A 59829/3950, 25.09.2009

The values which are given are only examples. Property-related investigations and proof are recommended for compliance with specific sound insulation requirements for straw-insulated external walls.

3.4 Moisture protection

3.4.1 Water vapour diffusion resistance factor

The dimensionless water vapour diffusion resistance factor μ specifies by which factor the material in question that protects against water vapour is less permeable than a stationary air layer of the same thickness.

μ = 2 according to ETA-17/0247 Building Straw

The air layer thickness s_d [m], which is equivalent to the water vapour diffusion, is the product of the water vapour diffusion resistance factor μ and the material thickness d.

s_d = μ x d

3.4.2 Proof of suitability for providing moisture protection

From a technical moisture perspective, a straw-insulated construction component can be proven by means of a biohygrothermal evaluation of the annual moisture and temperature curve at a depth of 5 cm, measured from the straw edge on the external side.

In order to determine a safe and mould-free area of application, according to Sedlbauer, temperature, moisture content and substrate are taken into account as growth factors. Straw is assigned to substrate class I. The temperature and moisture curve within the straw insulation is determined by means of transient modelling (e.g. with WUFI®) (or metrologically on existing components). The values which are obtained are then subject to a mould risk evaluation with WUFI-Bio.[9]

In Annex B ETA-17/0247 Building Straw, layer properties are described for straw-insulated construction components. These have been determined using this procedure. See Section 4.2.

[9] See Krus, Künzel and Sedlbauer, applied in Klatecki.

4 BUILDING WITH STRAW

4.1 Requirements for planning and construction

4.1.1 General requirements

The general requirements for construction, e.g. safety on the building site, structural stability, fire, moisture, heat and sound protection, as well as protection against harmful influences, must be observed.

4.1.2 Fire protection

The requirements regarding the fire protection properties of building materials and construction components are set out in the respective State Building Code (*Landesbauordnung*). As an insulating material with a normal flammability level, straw meets the minimum requirements for building materials. When clad with suitable building products, straw-insulated construction components can achieve the fire-resistance class F 30-B fire-resistant and/or F 90-B according to DIN 4102-2 provided that General Building Inspectorate Test Certificates are available for the respective combination of building materials and are observed during construction. (For more details, see Section 3.1.2.)

4.1.3 Weather protection and moisture protection

Straw-insulated construction components must provide permanent protection against weather conditions from the outside. With external walls, this is ensured using back-ventilated cladding or crack-proof, weather-proof lime plaster with a breathable, hydrophobic coating to provide protection against driving rain.

External walls can also be protected additionally against weather conditions using roof overhangs.

Base areas of external walls with straw insulation must be permanently sealed to protect against rising moisture. The straw and the lowest parts of the wooden construction must be above the areas which are exposed to splashing water.

Windows and window sills must be installed such that rainfall and splashing water running down the facade cannot get in at the joints. Underneath the windowsill, a sealing layer which has raised edges below the window frame and in the recesses must be installed.

Further requirements can be found in DIN 68800.

4.1.4 Air-tightness and wind-tightness

For all external construction components, the air-tight level on the inside and the wind-tight level on the outside, including connections, gaps and penetrations of all construction

components (for example due to installations), must be carefully planned and installed in accordance with DIN 4108-7:2011-01 to ensure long-term safety.

A blower door test with leakage location should be carried out to prove the implementation quality.

4.1.5 Thermal bridge reduction

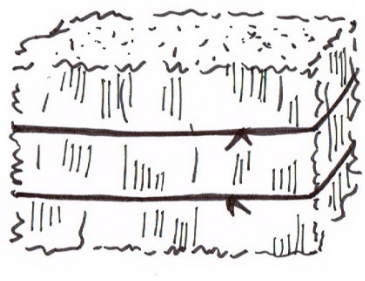
Thermal bridges are to be reduced using suitable measures, for example by sufficiently insulating each of the construction components. This applies, in particular, to connections of external wall to windows and doors, but also to the integration of false ceilings into the external wall, as well as to all other transitions between construction components.

4.1.6 Moisture transport

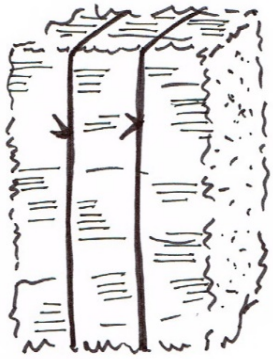
In the external area of a straw-insulated construction component in particular, moisture transport must be ensured between the individual layers of the construction component. In order to ensure that no condensation accumulates on the outside of the straw insulation in unspecific construction cavities, the construction component must be insulated without any gaps and the cladding must be sealed and not have any cavities. The external side of the straw surface should not be covered directly with a membrane but, rather, with a capillary absorbent building material, e.g. plaster or wood fibre insulation boards.

4.1.7 Stalk direction

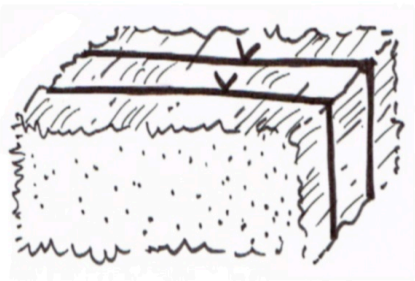
Optimum thermal insulation of straw is achieved with a stalk direction which is predominantly vertical to the heat flow. Straw bales must therefore be installed in vertical construction components with the edge upright or horizontal and lying flat in ceilings and roofs.



vertical on edge



horizontal on edge



flat

Installation with a stalk direction in the direction of the heat flow is technically possible; ETA-17/0247 Building Straw does not include a value for thermal conductivity for this.

4.1.8 Support structure and reinforcement

The proof of structural stability and the usability of a building (*Nachweis der Standsicherheit und der Gebrauchstauglichkeit*), including the reinforcement requirements, do not take straw into consideration. With timber and board constructions, horizontal forces are absorbed by suitable, approved board materials, or by diagonally installed compression and/or tension elements out of timber (struts/braces/shores) or metal (steel strap). They can also be diverted via an engineered connection to reinforcing construction components, for example internal walls.

4.1.9 Straw bale formats and frame size

The internal frame size should be determined in accordance with the dimensions of the straw bales.[10] Other sizes are possible. The determination of the suitable internal frame span as a grid should take place at an early stage and in a precise and reliable manner. Planning deficiencies would cause significant additional work here. See 5.1.2.

4.1.10 Installations

Electrical installations should not be laid through the straw but, rather, covered with non-flammable materials, e.g. plaster.

In order to prevent moisture damage, water-carrying installations should be installed outside straw-insulated construction components.

4.2 Suitable construction components

4.2.1 General

Building straw is used as thermal insulation for filling within load-bearing or non-load-bearing constructions.

It must not carry compressive loads and must not perform any structural stability of the construction or parts thereof.

Building straw is installed with a support spacing of less than one metre inside clear width.

Plaster can be applied directly to the surfaces made from compressed straw.

Straw can be used both for new constructions and for the renovation of existing buildings.

4.2.2 Components

Straw is used in external walls, back-ventilated roofs and final storey ceilings. The frame can be formed by the load-bearing structural components. For external walls, solid timbers have

[10] For more information, see the Leaflet Instructions on processing Building Straw in the annex.

become widely used for this, the clear distance of which results from the dimensions of the straw bales and does not exceed 1.0 m. Their depth corresponds to the insulation thickness, and can be doubled if required. This also applies for roofs and the final storey ceilings allowing for the respective requirements for the construction components.

4.2.3 Allowable layer properties

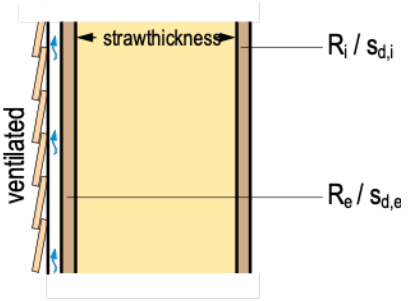
The suitability of straw-insulated construction components is largely dependent on their moisture proofing quality. There must be no harmful mould growth within these components. Depending on the temperature, the moisture quantities must be kept sufficiently low by means of compliance with certain layer properties. It can be assumed that straw-insulated construction components are suitable if the properties of the individual layers correspond with the specifications set out in Annex B ETA-17/0247 Building Straw.

Note: According to Annex A ETA-17/0247 Building Straw, this is valid for climate conditions in Germany. Climate conditions elsewhere must not, but can restrict these allowable layer properties. Suitability for providing moisture protection can be proven with the procedure described in 5.2.4 by taking other climate conditions into consideration.

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

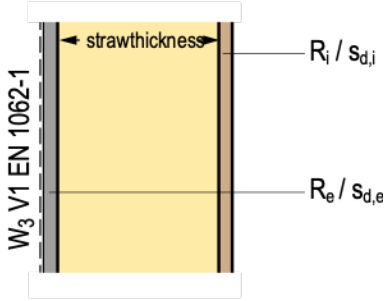
a) Exterior wall structures with back-ventilated external cladding for weather protection

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**



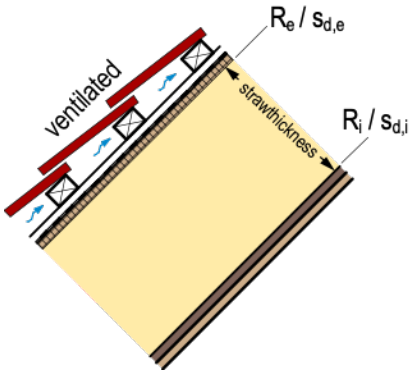
b) Plastered exterior wall structures with no weather protection
Plaster in accordance with EN 998-1 with water-repellent coating in accordance with EN 1062-1 in W_3 and V_1

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* $\boldsymbol{s_{d,e}}$ ***= 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* $\boldsymbol{s_{d,i}}$ ***= 0.1 m*** *and a thermal resistance of a maximum of* $\boldsymbol{R_i}$ ***= 0.35 m²·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* $\boldsymbol{s_{d,i}}$ ***= 0.76 m****. The straw thickness may be no more than d = 0.48 m for this.*

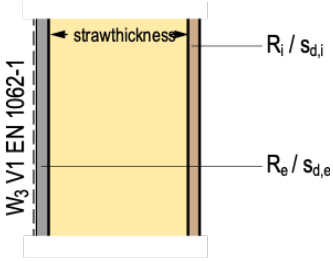
[11] Convective entry is to be excluded anyway. (See ETA-17/0247 Building Straw, Annex A, 4) on joint tightness of the inner cladding.)

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* ***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 $s_d = d \cdot \mu$ [m]
External: $s_{d,\,e,\,present} = 10 \cdot 0.03$ m + 0.13 m= 0.43 m ≤ $s_{d,\,e,\,allowable}$ = 0.5 m
Internal: $s_{d,\,i,\,present} = 10 \cdot 0.03$ 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

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.

4.3 Further construction components

4.3.1 Miscellaneous

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.);
- Attached external wall insulation: 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);
- Internal walls: When straw is to be installed in internal walls (behaviour in a permanent indoor climate without guaranteed joint tightness to the indoor environment);
- Non-ventilated roof areas: When straw is to be installed in non-ventilated roof spaces (moisture-proofing suitability);
- Top-floor ceilings: When straw is to be installed above upper storey ceilings without defined compartment formation and/or pressurised (mechanical strength);
- Floor panels and basement ceilings: 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 Load-bearing construction

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. The request for this can be made to the respective Highest Building Inspectorate (*Oberste Bauaufsicht*) in the State.[12]

[12] The state of the art in terms of knowledge about load-bearing construction with straw in Germany is documented at: http://fasba.de/wp-content/uploads/2016/05/Lasttragendes-Bauen-Stand-des-Wissens-2009-2014.pdf
There is no English version available.

5 STRAW INSTALLATION

5.1 Requirements for straw installation

5.1.1 Straw bales suitable for building

Straw bales suitable for building have a golden yellow to pale yellow appearance. The surfaces are even and perpendicular to one another. The edges are straight and not rounded. The strings must be tight, the front side may be dented somewhat and must not come out of the bale during transport.

They are baled in a compact manner and hold their shape. A flat hand cannot, or can only with difficulty, be pushed between the individual courses of a bale. The straw bales must be installed according to ETA-17/0247 Building Straw with a density of between 85 kg/m^3 and 115 kg/m^3 in a reference climate of 23 °C and 50% relative humidity.

Bales which are not suitable for building would require significant extra work, such as re-baling or stuffing remaining cavities after installation. In addition, this would cause uneven compression, and/or dents and bulges in the straw surfaces, and therefore also increased thickness for plaster application.

Damp, mouldy straw which smells earthy or has active mould growth must not be used for installation.

These properties are identified for an approved building product of Building straw; if other straw bales are used within the framework of approval on a case-by-case basis, these must be checked for suitability.

5.1.2 Installation situation

The support distance and wall thickness should be suitable for the straw bale dimensions.
For special geometric installation situations (e. g. pediment, special compartments), straw bales can be made shorter and notched or beveled.

5.1.3 Seasonal conditions

In principle the installation of straw is possible throughout the year if there is sufficient moisture protection during construction.

The seasonal conditions for drying are to be taken into account for plastering.

5.2 Requirements for installed straw

5.2.1 Installation

Straw must be installed without any gaps and with no possibility of settlement. In order to ensure this, straw should be compressed during installation. Any remaining cavities are to be tightly packed and well stuffed with loose straw.

In a frame, straw must be secured using suitable means to ensure that it does not become detached or fall out.

Straw must be installed with a density of between 85 and 115 kg/m³ for a normal climate (23 °C/50% relative humidity).

Any other densities constitute a defect and require approval on a case-by-case basis because no recognised rated value for thermal conductivity is available for this. If the density is too low, it is also no longer recognised as a building material with normal flammability (class E).[13]

5.2.2 Evenness of straw surfaces

The straw surfaces should be made flat and straight after installation. Any major unevenness must be corrected first. Then the straw surfaces are trimmed identically.

Major unevenness requires extra work and may cause problems that reduce the quality of the cladding.[14]

5.3 Protecting straw-insulated components during construction

5.3.1 Protection against precipitation

Straw-insulated construction components must be protected in a proper manner (e.g. with tarpaulins) until the cladding which provides protection against rainfall and splash back has been finished.

Unfinished base areas and wall openings must also be protected against rainfall.

Observe DIN 68800 Parts 1-4.

5.3.2 Fire protection on building sites

Stored, as well as installed, straw bales which have not yet been clad, plus loose straw, must be protected against fire and sparks.

Smoking is prohibited on the building site during straw installation and until the straw surfaces have been covered.

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[13] See Section 3.2.1 Thermal conductivity and ETA-17/0247 Building Straw.
[14] See Section 6.2 Plaster .

Any loose straw is to be placed in closed sacks or containers, temporarily stored at a sufficient distance from the building site and disposed of at least once a week.

In order to improve the fire protection, the first layer of covering should be applied to straw-insulated construction components as early as possible.

6 FINISHES FOR STRAW

6.1 Tasks and requirements

6.1.1 General

Finishes of construction components are necessary to achieve and comply with all general protection targets relating to the field of construction, e.g. fire protection, thermal insulation, moisture-proofing and durability, as well as, in particular, requirements in terms of air-tightness and wind-

rtightness and weather protection. This must be carefully planned and installed in a professional manner.

Internal and external finish of straw-insulated construction components must comply with Annexes A and B ETA-17/0247 Building Straw or require other proof of suitability, e.g. approval on a case-by-case basis.

6.1.2 Protection against infestation by rodents and insects

Straw-insulated buildings which have been installed in a professional manner are not at particular risk of infestation by small animals and insects.

Finishes on straw insulation can be counted as sufficient protection against infestation by rodents and insects if it is free of cracks, air-tight and wind-tight and has a sufficient thickness and mechanical strength. When observing recognised rules and manufacturer specifications, in accordance with previous experience, this corresponds to the following layer thicknesses, for example:

Lime plaster: ≥ 2 cm, clay plaster: ≥ 2 cm, wood: ≥ 1.5 cm, medium density wood fibre boards: ≥ 1.5 cm, wood fibre insulation boards: ≥ 2 cm

6.1.3 Surfaces

Finishes seal straw-insulated construction components from the inside and outside and provide surfaces which have an aesthetic and are usable. They shape the appearance of rooms and buildings. Finishes must be installed such that they can withstand long-term use. Fixing is to be carried out according to the materials being used and, with heavy objects, timely planning and preparation is required.

6.1.4 Regulating the indoor climate

The internal finish of straw-insulated construction components has a significant influence on the room temperature and the room air humidity and therefore affects the indoor climate. Hygroscopic structural materials (especially clay) store moisture and emit this again over time.

They therefore create balance when the moisture level varies. Heavier structural materials store heat and emit this again over time. They therefore create balance when the temperature level varies in the summer and winter.

6.2 Plaster finishes

6.2.1 Tasks

Plaster serves as an air-tight or wind-tight layer of the construction component. With the appropriate installation in accordance with the General Building Inspectorate Test Certificate MPA BS P-3048/817/08, 2014,[15] updated 2019, together with the straw/wood construction, it can form a fire-resistant load-bearing external wall, protect against infestation by pests, provides a usable and aesthetic boundary and regulates the indoor climate.

6.2.2 Requirements

The straw must be sufficiently thick, installed securely and without any cavities. The straw surface must be as even as possible and free from loose straw parts.

Clay plasters have become widely used inside, as well as outside behind a mounted facade and lime plasters have become widely used outside. They should be relatively soft (compression strength class CSI according to DIN EN 998-1) so that they remain operational with minor and standard structural movements.

As a sole finish component, plasters must be rubbed, smoothed or sponged and be at least 2 cm thick.

6.2.3 Requirements for installation

Clay plasters must be used in a professional manner pursuant to DIN 18947 or in accordance with the Clay Construction Guidelines (*Lehmbauregeln*) or, for lime plasters, DIN 998-1. Among lime plasters, standard plastering mortars can be used as well as lightweight plastering mortar, both in the form of premixed, dry mortars.

For lime plasters, each layer must dry for a sufficiently long period of time and must carbonate sufficiently. If necessary, lime plaster must be watered. Sintered layers must be removed mechanically and in good time because they would impair the moisture transport and the adhesion.

The individual application layers of the plaster must not be too thick and suitable drying conditions must be provided.

[15] See the English version in the annex.

Plaster surfaces which serve as an air-tight or watertight layer of the construction component must be fully reinforced to ensure sufficient prevention of cracking. Fibres can be added to contribute to that. Connections to other finishes or construction components, such as ceilings or internal walls, must be air-tight and wind-tight.

In order to prevent moisture entry into the straw insulation from being too high, constructions with plaster must dry sufficiently quickly and comprehensively. Long drying times in weather conditions which are too cold should be avoided. Where necessary, the drying process must be supported with lots of ventilation or the use of fans, heaters, drying and dehumidification devices.

For layer thicknesses of the internal plaster of above 1.5 cm, a person should be appointed to be responsible for monitoring the drying process and documenting this accordingly.[16]

Weather-related and seasonal restrictions are to be taken into consideration.

6.2.4 Processing

Plaster adhesion on straw is achieved with a physical grip. The first plaster coat must be sufficiently rich in binding agents and liquid. It carries all the other plaster layers and must be applied carefully. On other plaster surfaces, such as wood, a base for plaster must be used (e.g. reed fabric, wood fibre insulation boards). The first plaster layer follows the contours of the straw surface and does not need to form an even surface.

An even surface is created with the body coat plaster. Reinforcement mesh must be embedded into this. The top coat plaster is then applied with an even thickness. The top coat plaster can be rubbed, smoothed or sponged. The adhesion of all plaster layers to each other is to be ensured. Sufficient plaster adhesion can be checked on the site.[17]

In addition, observe the manufacturer's specifications, DIN 18947:2013-08, the Clay Construction Guidelines (*Lehmbauregeln*) and the Technical bulletin Requirements for clay plasters *(Technisches Merkblatt Anforderungen an Lehmputze*) by the Dachverband Lehm e. V. and the professional practice for processing lime plasters.

6.3 Finishes made from boards, cladding and membranes

Straw-insulated external walls and roof surfaces can also be finished with boards, cladding or membranes. On their own or in combination, they must be air-tight and/or wind-tight, sufficiently breathable on the outside and feature back-ventilated cladding.

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[16] See *Technisches Merkblatt Anforderungen an Lehmputze*, 2009 (Technical bulletin Requirements for clay plasters), 2009.

[17] The French straw building regulations describe plaster adhesion tests which can be carried out on site (*Règles professionelles, Annexe 3*). See also Ehlers, 2012.

Unlike plaster finish which is applied wet, boards, cladding and membranes do not fully follow the contours and adapt to the straw insulation without leaving any gaps. Where the straw makes contact with these on the outside, condensation may temporarily form in any cavities after temperature changes. The finish must be able to absorb this and transport it away. Therefore, regardless of the level of breathability, no facade/facing or roofing membranes should be used directly against the straw insulation on the external side.

7 ADDITIONAL DOCUMENTS

7.1 ETA-017/247 Building Straw

The recognition of straw bale building according to the building regulations in Germany is based on the European Technical Assessment 017/247 Building Straw. This sets out the properties, such as thermal conductivity and normal flammability. Annex B also comprehensively specifies suitable construction components.

7.2 Leaflet Instructions on processing Building Straw

These instructions define the proper processing of Building straw bales.

7.3 General Building Inspectorate Test Certificate, its update and an expert opinion

In these three documents, construction components are specified with approved fire protection properties. The General Building Inspectorate Test Certificate (*allgemeines bauaufsichtliches Prüfzeugnis*) from 2014 expired in 2019, but was updated and is now applicable until 2024. An expert opinion also specifies deviations relating to the construction components of this certificate which have been deemed not significant.

7.4 EPD

The Environmental product declaration for Building Straw (Abbreviation: EPD) allows for a life cycle assessment (LCA) of straw-insulated buildings.

7.5 “Straw-insulated buildings” brochure

The “Straw-insulated buildings” brochure published by the Fachagentur Nachwachsende Rohstoffe e. V. provides comprehensive information about all aspects of building with straw. Amongst other things, it includes an environmental assessment of a straw-insulated building in comparison to other construction methods. This section is available in English, see the annex.

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9 ANNEXES

- **Fachagentur Nachwachsende Rohstoffe e. V. (Ed.): Straw insulated buildings, Chapter 2: Building with straw is particularly sustainable. 2017**
- **ETA-17/0247 Baustroh (Building Straw), European Technical Assessment thermal insulation made from straw bales.**
- **Leaflet Instructions on processing Building Straw**
- **P-3048/817/08-MPA BS. General Building Inspectorate Test Certificate. Load-bearing, enclosing wall construction of fire-resistance class F 30 or F 90. English translation. Braunschweig: iBMB TU Braunschweig. 8.12.2014.**
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