

Straw Bale Houses - design and material properties



Jørgen Munch-Andersen

Birte Møller Andersen

Danish Building and Urban Research
(Statens Byggeforskningsinstitut)



Research Project



Aim: to demonstrate how straw bale houses can be build as durable and well performing structures

Two part project:

1. Material properties
2. Design guideline

Supported by the Danish Energy Agency, special programme for environmentally friendly insulation

Material Properties



Thermal insulation properties

Moisture transport and condensation

Settlements

Fire properties

Sound insulation

Working environment

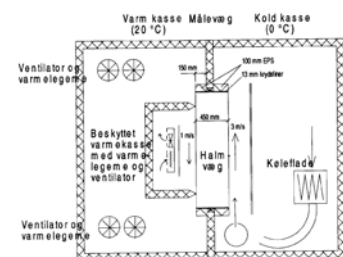


Heat insulation



Two test types

1. Thermal conductivity (λ -value) from standard tests
2. Direct U-value from guarded hot box test



Thermal conductivity



Material property depending on straw type, straw direction and density. Mineral wool has $\lambda \sim 0,035 \text{ W / mK}$

Table 1. Thermal conductivity for straw bales according to different sources.

Reference	Density, kg/m ³	Thermal conductivity, λ , W/mK	
		Straw parallel to heat flow	Straw perpendicular to heat flow
Present study	75	0.057	0.052
Present study	90	0.060	0.056
Haus der Zukunft ¹	100		0.038
Christian et al. (1998)	62 resp. 81	0.082	0.057
McCabe (1993)	approx. 150	0.060	0.048
Sandia National Lab. (1994)	90	0.05-0.06 ²	0.05-0.06 ²

1. Österreichischen Strohballen-Netzwerk (2000). 2. Unspecified straw direction.

U-value



Property of wall, depending mainly on thickness and λ .

200 mm mineral wool gives $U \sim 0,18 \text{ W / m}^2\text{K}$

Table 2. U-value for stuccoed straw bale walls.

Straw orientation	Thickness of straw	Surfaces	U-value, W/m ² K
Present study ¹			
parallel to heat flow	385 mm	34 + 42 mm stucco	0.208
perpendicular to heat flow	365 mm	26 + 26 mm stucco	0.196
Christian et al. (1998) ¹			
parallel, with cavities	470 mm	Stucco + 13 mm board	0.365
parallel, without cavities	480 mm	Stucco + 13 mm board	0.210 ³
Watts et al. (1995) ² , parallel	460 mm	Stucco	0.21

1. Guarded hot box test excluding air film resistance. 2. In situ test. 3. Value determined from data in (Oak Ridge National Laboratory, 1998).

U-values from λ -values



Measured for 385 mm straw parallel to heat flow, 75 kg / m³ with 80 mm clay plaster: $U = 0.21 \text{ W / m}^2\text{K}$ (excl. air film resistance)

Calculating from λ -measurement:

Heat flow parallel to straw, 75 kg / m³: $\lambda = 0.057 \text{ W / mK}$

Clay plaster, assumed: $\lambda = 0.8 \text{ W / mK}$

0,39 m straw + 0,08 m plaster $\Rightarrow U = 0,15 \text{ W / m}^2\text{K}$

Direct measurement about 50% higher than calculated!

Reasons for difference in U-value



- Convection: American calculations by CFD indicates serious effect, increase U from 0.15 to 0.17
- Intrusion of plaster into straw might reduce effective thickness of straw by some 2 x 10 mm, increase U by 0.01 to 0,18
- Intrusion of plaster in cavities at rounded corners will further decrease effective thickness of straw. Assuming an effective average of 2 x 25 mm changes U to 0.19
- Difference not explained fully

Conclusions, U-value



Danish standard bales, 450 mm in straw direction and 360 mm perpendicular to straw direction

Design U-values can be taken as:

- Walls with straw parallel to heat flow:
 $U = 0,18 \text{ W / m}^2\text{K}$
- Low pitch roofs with straw perpendicular to heat flow:
 $U = 0,18 \text{ W / m}^2\text{K}$
(low pitch prevents convection caused by air flow)

Moisture and condensation



Two test types

1. Water vapour resistance of plaster and straw
2. Hot-cold box



Water vapour resistance



Material property for resistance against water vapour penetration, Z-value. A vapour barrier has $Z \sim 100$

Amount of water transport depends on Z and difference in partial water vapour pressure

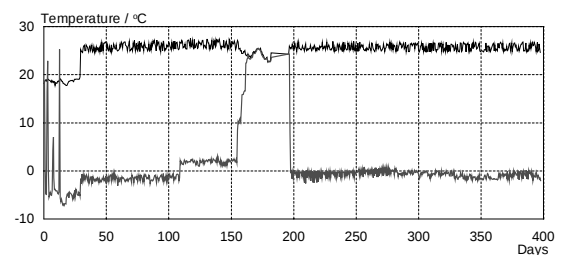
Sample	For 40 mm layer	Z, GPa s m ² /kg	
		Wet	Dry
1 Clay plaster		1.6	2.4
2 Clay plaster with 5 layer of whitening		1.7	2.4
3 Clay plaster painted with linseed oil		2.6	3.5
4 Clay plaster mixed with linseed oil, 1%		2.5	3.1
5 Lime, coarse (0-4 mm)		2.1	2.2
6 Lime, fine (0-2 mm)		3.0	-
7 Clay plaster mixed with chopped paper, 5%		1.8	-
8 Clay plaster mixed with chopped straw, 30%		1.8	-
9 Clay plaster mixed with cow manure, 25%		1.5	-
10 Clay plaster painted with silicate paint system, four layers		2.5	-

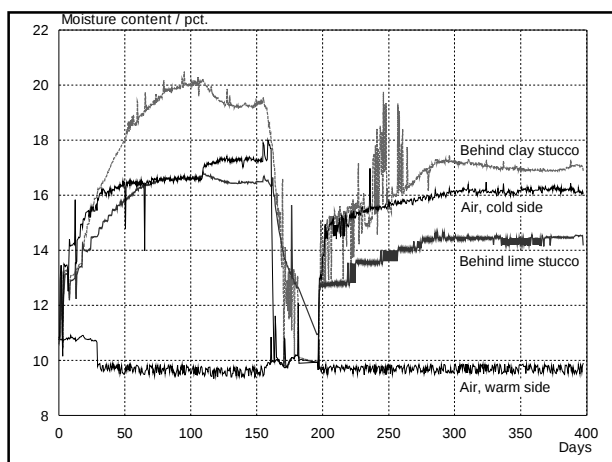
Hot-cold box



Simulation of winter conditions, 0°C outside, 25° C inside

Clay plaster inside, clay and lime plaster outside





Difference in partial water vapour pressure

Period Days	Warm side				Cold side				Difference Δp_v , Pa
	T , °C	p_s , Pa	RH, pct.	p_v , Pa	T , °C	p_s , Pa	RH, pct.	p_v , Pa	
73-102	24,8	3132	46,3	1450	-1,8	526	85,0	447	1003
103-108	25,0	3169	48,0	1521	-1,5	540	83,9	453	1068
110-134	25,3	3245	45,1	1463	1,7	392	88,8	614	822
229-259	25,0	3169	44,0	1394	-1,1	558	83,5	466	928
260-285	24,9	3151	44,8	1412	-1,0	562	84,7	476	936
286-316	24,6	3095	43,5	1346	-1,0	562	86,0	483	863
349-379	24,8	3132	43,2	1353	-1,4	544	85,2	463	890

Settlements of plastered walls

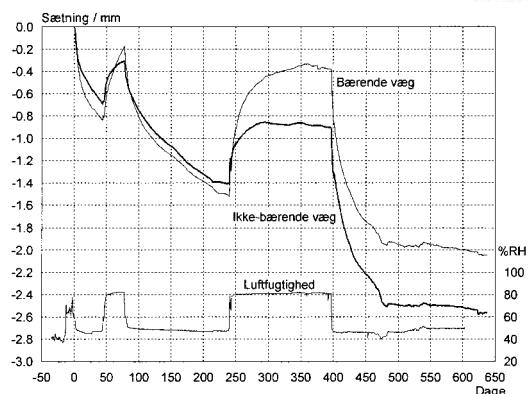


Two walls, Relative humidity varied between 50 and 80 %

1. Non-load bearing, normal straw bales (75 kg/m³)
2. Load bearing, 5 kN/m, big bales (125 kg/m³)



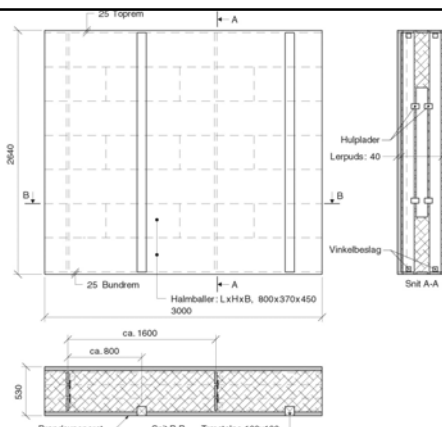
Measured settlements



Fire tests

Two test types:

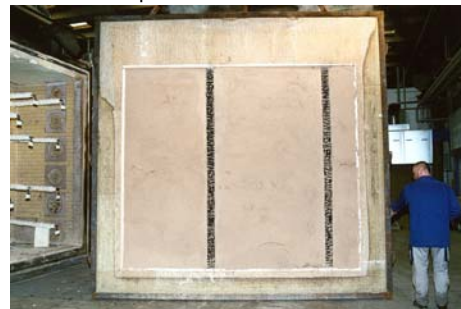
1. Resistance ('wall')
BD 30 ~ EI 30
2. Protection ('ceiling')
kl A ~ B-s1,d0



Resistance, after test



Fire put out after 30 min, most likely that EI 60 is fulfilled
Plaster protected sides of posts well



Protection, after test

Plaster remained on straw for 10 min
Protruding straw burned - ok

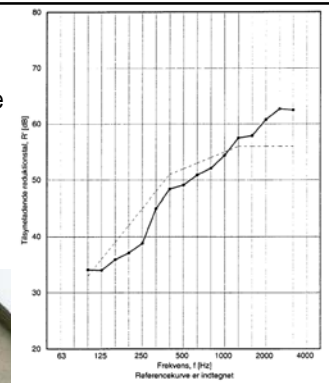


Sound reduction

Internal plastered straw bale wall measured on-site

$R'_w = 52 \text{ dB}$

Requirement for terraced housing: 55 dB



Working environment

- High level of organic fine particle dust, severely affected by in-door work
- Low level of fungi thanks to fresh and yellow straw



Mussel shells as floor slab insulation

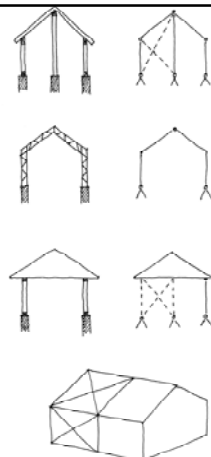
Thermal conductivity and capillary suction measured for whole shells, crushed shells and the coarse fraction of the crushed shells.

$\lambda \sim 0,12 \text{ W / mK}$

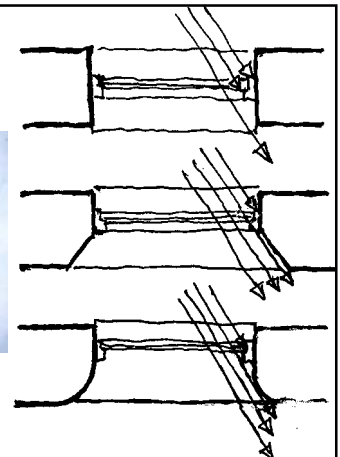
Capillary suction height
< 25 mm

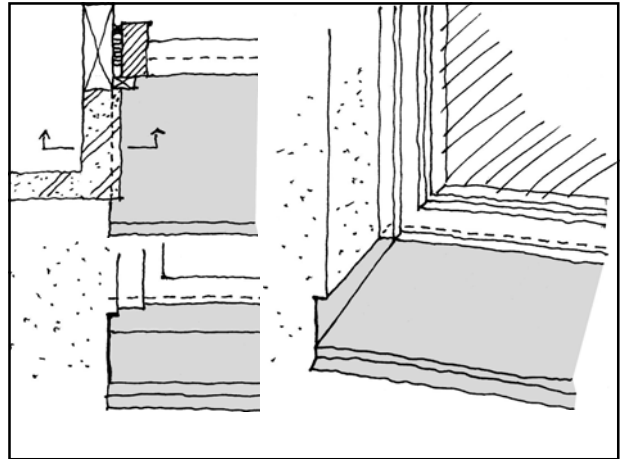
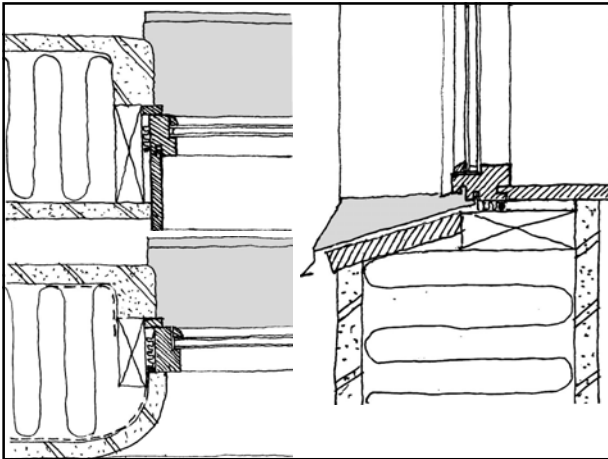


Design guidelines



Windows and daylight





Roofs, example 1

BY OG BYG

- Roof felt on boards
- Trussed beam
- Ventilated cavity
- Plaster
- Straw bale
- 19 mm boards at 300 mm
- 2 x 13 mm plasterboard

Roofs, example 2

BY OG BYG

- Roof cladding / battens
- Foil membrane
- Secondary beams
- Ventilated cavity
- Plaster
- Straw bale
- 50 mm Class A insulation
- Boards, notched
- Primary beams
- Connection btw. beams

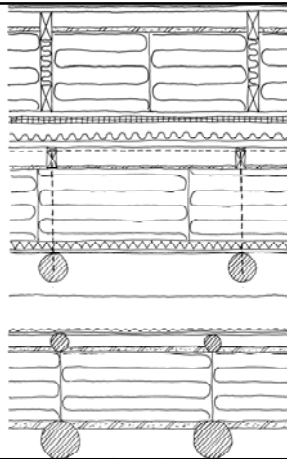
Roofs, example 3

BY OG BYG

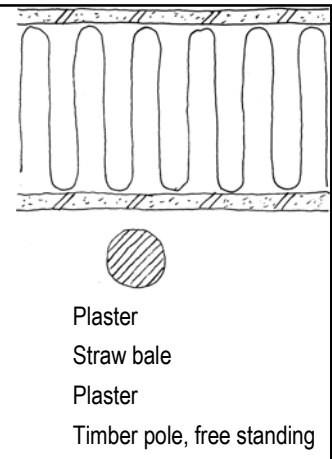
- 'Green roof'
- Drainage membrane on plywood board
- Secondary beams
- Ventilated cavity
- Plaster
- Straw bale
- Plaster
- Primary beams

Roofs, summary

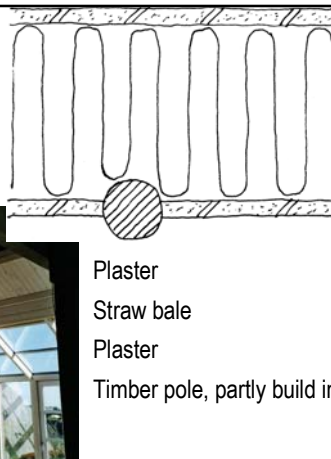
- Fire requirements fulfilled in 3 different ways
- Plaster on upper side improves fire safety and heat insulation
- Extra insulation advisable



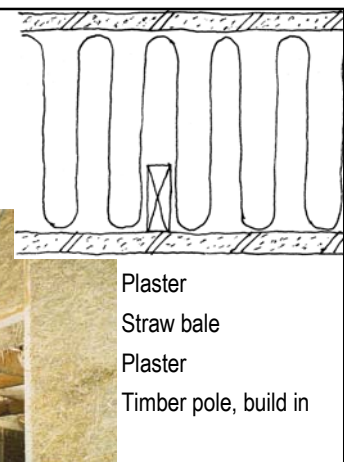
Walls, example 1



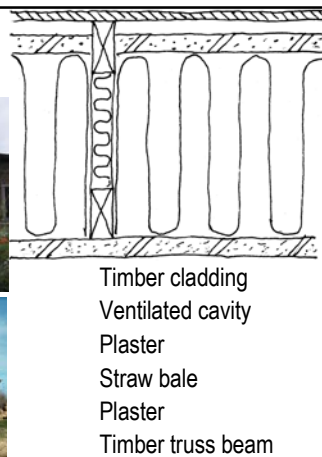
Walls, example 2



Walls, example 3

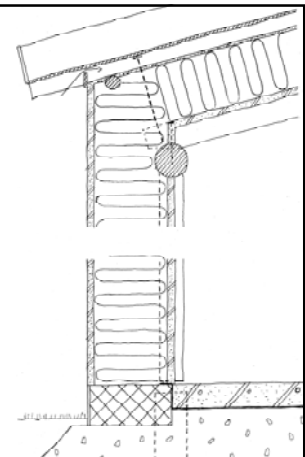


Walls, example 4



Structure 1

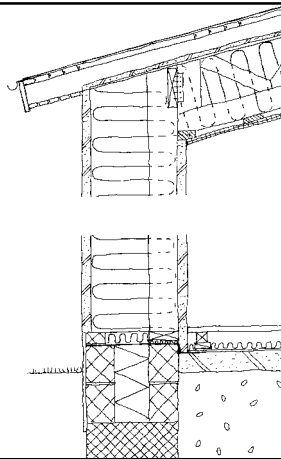
- Ventilation of roof
- Load distribution on wall
- Head beam allows openings



- Point foundation of poles
- LWC-block, preventing capillary suction
- Membrane to protect against radon intrusion

Structure 2

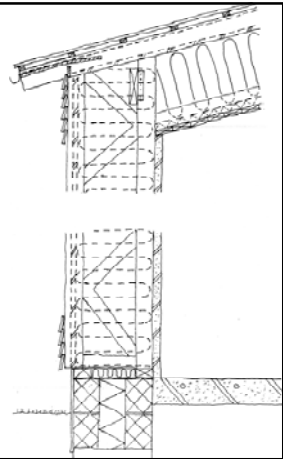
Ventilation of roof
Head beam allows close
spacing of roof trusses



Line foundation
Moisture barrier
LWC-block with insulation
Membrane to protect against
radon intrusion

Structure 3

Foil membrane to gutter
Ventilation of roof
Frame structure with cladding
Allow every 3rd or 4th leg to be
cut away
Line foundation
Frame only supported at inside
Moisture barrier
LWC-block with insulation
No membrane to protect
against radon intrusion



Conclusions



- Straw bale houses can fulfil all requirements to houses
 - especially fire regulations
- Detailing very important to avoid damage from water vapour, moisture and rain
 - Inside must be airtight
 - External cladding by eg. boards reduces sensitivity to maintenance
- Heat insulation only fair
 - Methods to reduce convection should be studied