Straw Bale Houses - design and material properties

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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

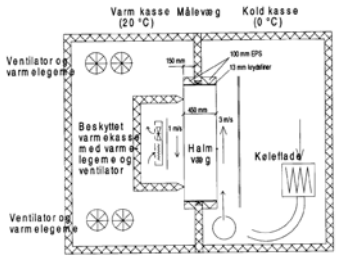
Material Properties

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 λ ~ 0,035 W / mK

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

	Density, kg/m³	Thermal conductivity, λ, W/mK	
Reference		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 ~ 0,18 W / m²K

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

Straw orientation	Thickness of straw	Surfaces	U-value, W/m²K
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 / m^3 with 80 mm clay plaster: U = 0.21 W / m^2K (excl. air film resistance)

Calculating from λ-measurement:

Heat flow parallel to straw, 75 kg / m^3: λ = 0.057 W / mK

Clay plaster, assumed: λ = 0.8 W / mK

0,39 m straw + 0,08 m plaster => U = 0,15 W / m^2K

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 W / m^2K
- Low pitch roofs with straw perpendicular to heat flow:
  U = 0,18 W / m^2K
  (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 ~ 100

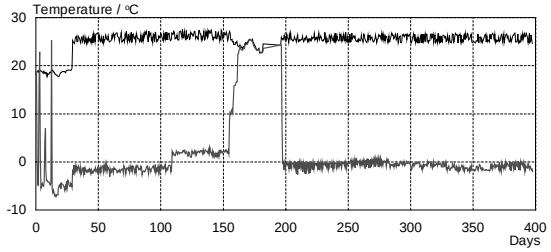
Amount of water transport depends on Z and difference in partial water vapour pressure

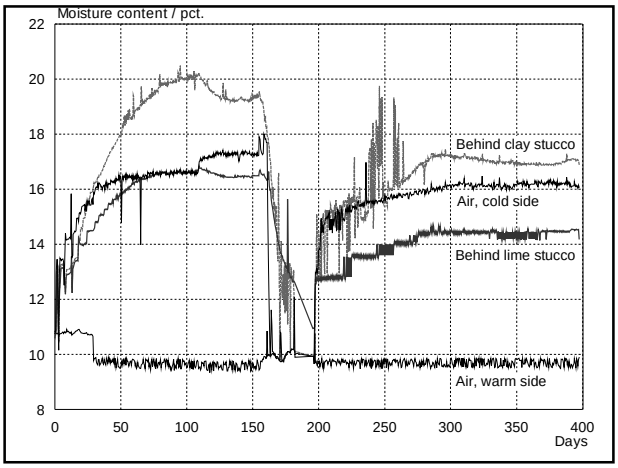
	Sample	For 40 mm layer	Z, GPa s m^2/kg	
			Wet	Dry
1	Clay plaster		1.6	2.4
2	Clay plaster with 5 layer of whitening		1.7	2.4
3	Clay plaster painted with linseed oil		2.6	3.5
4	Clay plaster mixed with linseed oil, 1%		2.5	3.1
5	Lime, coarse (0-4 mm)		2.1	2.2
6	Lime, fine (0-2 mm)		3.0	-
7	Clay plaster 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

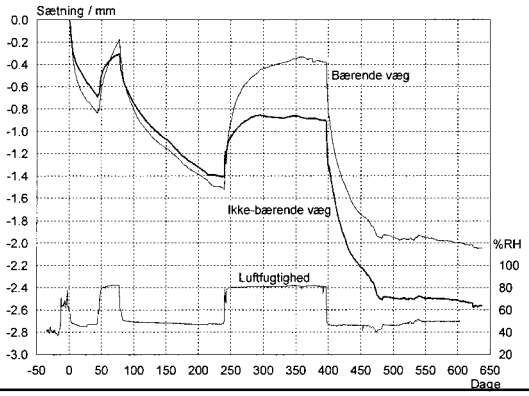
Period	Warm side				Cold side				Difference
Days	T, °C	p_s, Pa	RH, pct.	p_v, Pa	T, °C	p_s, Pa	RH, pct.	p_v, Pa	Δp_v, Pa
73-102	24,8	3132	46,3	1450	-1,8	526	85,0	447	1003
103-108	25,0	3169	48,0	1521	-1,5	540	83,9	453	1068
110-134	25,3	3245	45,1	1463	1,7	392	88,8	614	822
229-259	25,0	3169	44,0	1394	-1,1	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/m^3)
2. Load bearing, 5 kN/m, big bales (125 kg/m^3)

Measured settlements

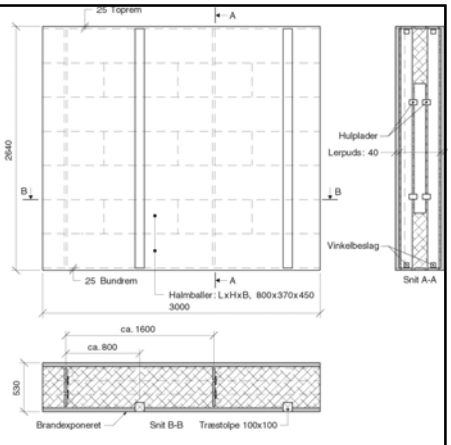


Fire tests

Two test types:

1. Resistance ('wall')
BD 30 ~ EI 30

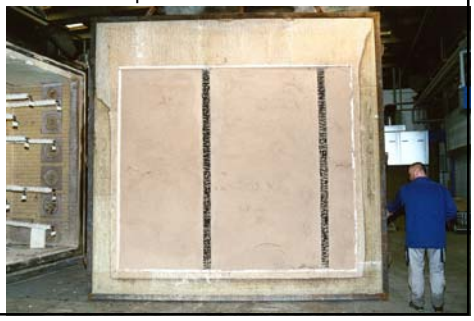
2. Protection ('ceiling')
kl A ~ B-s1,d0



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

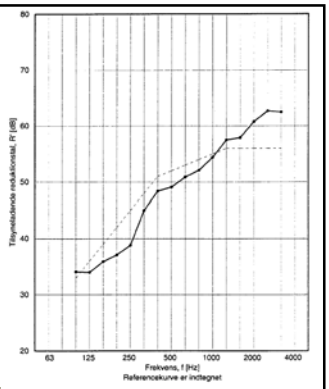
Protruding straw burned - ok

Sound reduction

Internal plastered straw bale wall measured on-site

R'_w = 52 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

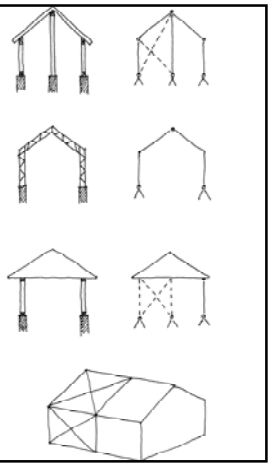
Mussel shells as floor slab insulation

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

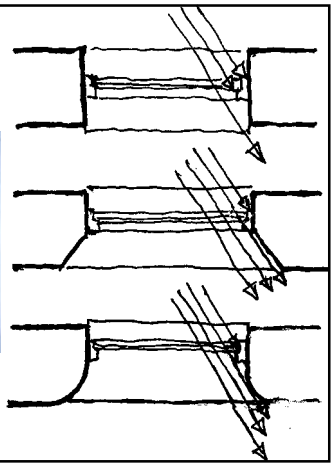
λ ~ 0,12 W / mK

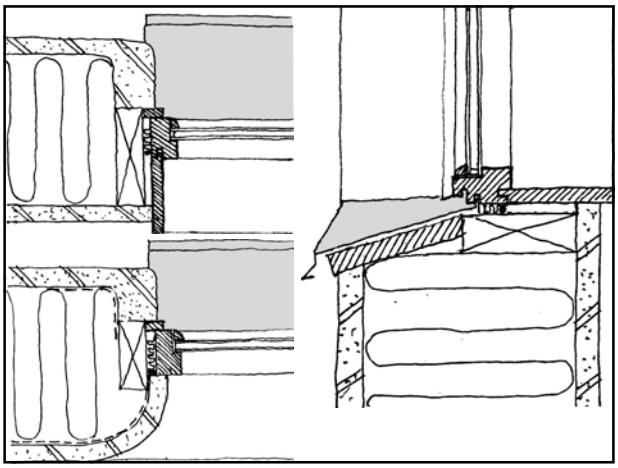
Capillary suction height < 25 mm

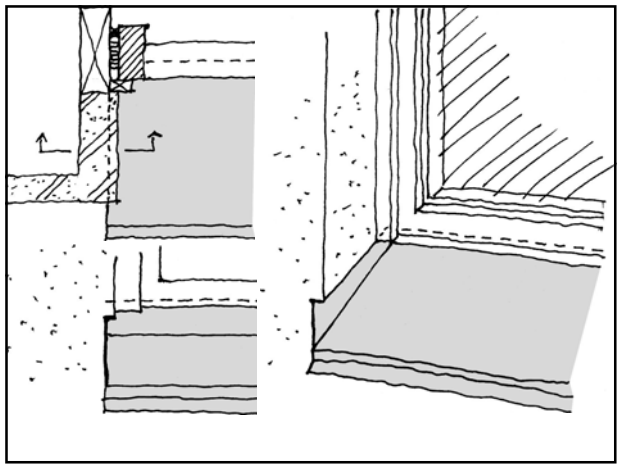
Design guidelines



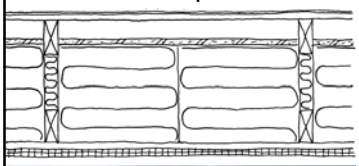
Windows and daylight





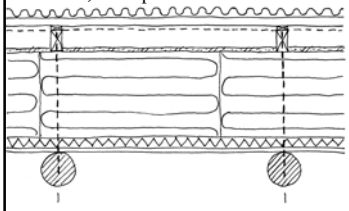


Roofs, example 1



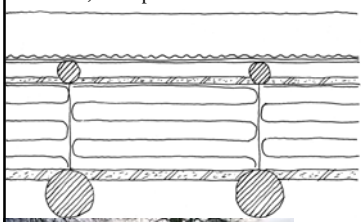
Roof felt on boards
Trussed beam
Ventilated cavity
Plaster
Straw bale
19 mm boards at 300 mm
2 x 13 mm plasterboard

Roofs, example 2



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

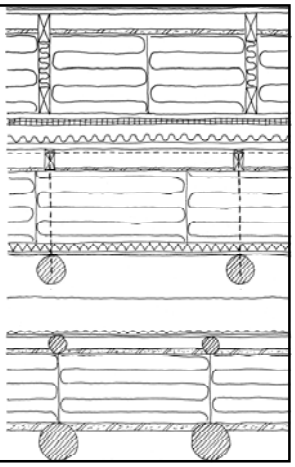
Roofs, example 3



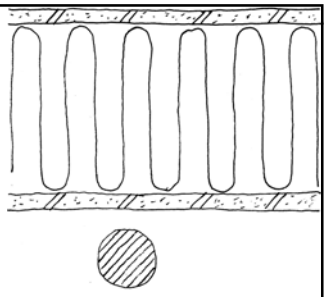
'Green roof'
Drainage membrane on plywood board
Secondary beams
Ventilated cavity
Plaster
Straw bale
Plaster
Primary beams

Roofs, summary

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

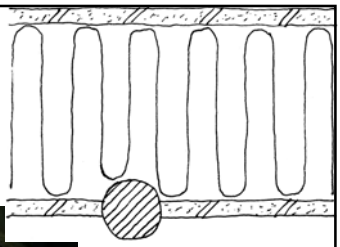


Walls, example 1



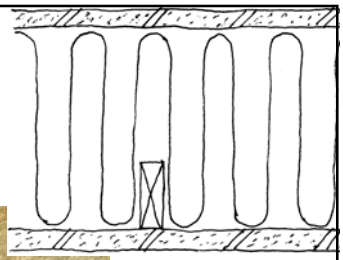
Plaster
Straw bale
Plaster
Timber pole, free standing

Walls, example 2



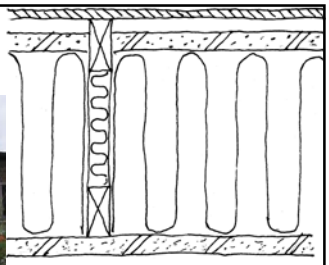
Plaster
Straw bale
Plaster
Timber pole, partly build in

Walls, example 3



Plaster
Straw bale
Plaster
Timber pole, build in

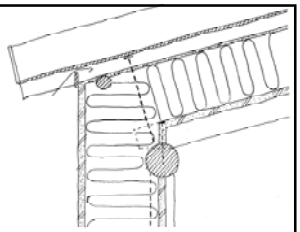
Walls, example 4



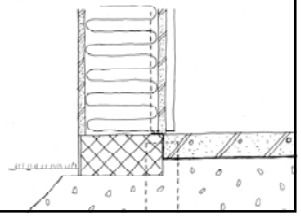
Timber cladding
Ventilated cavity
Plaster
Straw bale
Plaster
Timber truss beam

Structure 1

Ventilation of roof
Load distribution on wall
Head beam allows openings



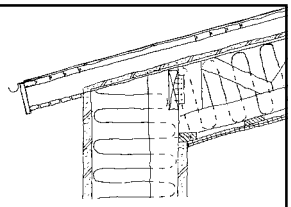
Point foundation of poles
LWC-block, preventing capillary suction
Membrane to protect against radon intrusion



Structure 2

Ventilation of roof

Head beam allows close spacing of roof trusses

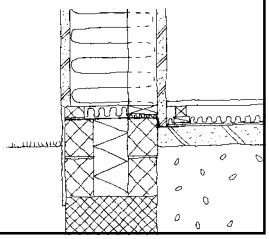


Line foundation

Moisture barrier

LWC-block with insulation

Membrane to protect against radon intrusion



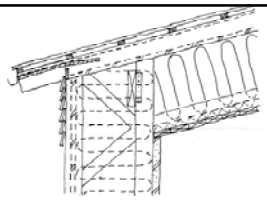
Structure 3

Foil membrane to gutter

Ventilation of roof

Frame structure with cladding

Allow every 3rd or 4th leg to be cut away



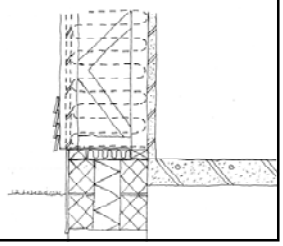
Line foundation

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