Experiences and tests with strawbale houses and green roofs
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Abstract
The paper describes experiences with a loadbearing strawbale house carrying a heavy timber structure with a green roof built at Kassel in 2001 and reports experiences with the first strawbale house with green roof at Kaliningrad, Russia, built in summer 2002. Furthermore the ecological and economical advantages of inclined green roofs are explained. The experimental strawbale construction was built as a test house, 7x7 m in plan, to study the structural and thermal behaviour of loadbearing strawbale walls which carry a heavy green roof. Another aim was to develop an extreme lowcost construction which can be built by non professionals in self-help technique.

As the bales were poorly compressed and to fresh, the walls buckled and the roof had to be supported by columns. But after the bales were taken out, newly compressed and again built in, the columns could be taken away and the heavy roof which weighs 12 tons could rest on the bales safely. The walls were sprayed by a loam (mud) plaster from both sides. A fire test proved that these walls could withstand the flame of a burner which created a temperature of 1000°C on the surface over a period of 90 minutes.

The heat transfer coefficient was measured in a laboratory and reached 0,086 W/mK which results in an U-value for the walls of about 0,17 W/m²K. The material costs reached only about to 140 US$ per m² floor area.

The house for homeless and orphaned children is the first strawbale house in Oblast Kaliningrad and the first one with a green roof in Russia. It was designed by the authors and has been built within a summer workshop with german and russian students in August 2002.

Because of russian building codes a timber structure was chosen to carry the roof loads. The strawbales act as external thermal insulation. All interior walls are built of green (unburned) bricks.

Test structure
As the traditional loadbearing walls of the nebraska-style houses always had relatively lightweight roofs, the aim of the experimental strawbale house built in 2001 at the Experimental Field of the University of Kassel was to prove that buildings are also able to carry heavy green roofs.

The tested structure has a 6 by 6 m floor area, 50 cm thick strawbale walls and carries a roof weighing 12,000 kg. That means that each meter of wall length is transferring a load of more than 500 kg to the foundation. In order to save money with the foundation, point supports have been chosen as

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shown in fig. 1. On these foundations two tree trunks are positioned with cantilevering ends so that the deflection of these beams are minimized. The roof is constructed of rough timber trunks which are arranged in a mandala type geometry without inner support (see fig. 3 and fig. 4). The walls are constructed with 8 layers of bales measuring 2.40 m in height after being compressed by the load of the roof.

When the heavy roof was installed and the earth partially mounted the walls showed a dangerous buckling effect so that the process had to be stopped and the roof had to be supported by exterior posts. The analysis of this problems showed 4 mistakes:

- the straw was too fresh, it had been harvested just some days before
- the bales were poorly compressed
- the bales had no sufficient vertical stabilisation elements like pretentioning rods, rebars or bamboo rods.
- further more the wider opening of the door resulted in an asymmetrical loading of the walls.

So the bales were taken out, newly compressed to a specific weight of about 90 kg/m³ in a selfmade pneumatic press (see fig. 5) and built in again. To guarantee equal loading of the walls the door size also was shortened to the width of the windows.

But the most effective measure to prevent buckling was to insert two horizontal wooden planks after each three layers of bales which were interconnected with the adjacent bale layers by thin bamboo sticks. These planks were stabilized by a sliding tongue and groove detail at both ends to the window frame. When the preliminary posts were taken away the roof came down by about 20 cm which was within the provisioned tolerance. The window detail was designed to tolerate a settlement of 25 cm.

After six weeks when no more setting occurred the surface of the walls were smoothened by a hedge-trimmer and then covered with a first layer of thin earthplaster which was sprayed under a pressure of 5 atmospheres by a selfbuilt gun. Fig. 6 shows the container which was filled up to three quarter of its volume by the liquid plaster and the spraying. A compressor keeps a constant pressure within this container. The mortar is sprayed through a gardening hose without any mouthpiece. The end of the hose was deformed by fingerpressure. The second and the third layer of earthplaster was manually applied by trowels.

The floor consist of a layer of bales layed on a thin sand bed. In order to avoid raising humidity a polyethylene film was put underneath the bales. A layer of oriented strand board (OSB) elements was layed on top of the bales forming a “floating floor”. So an extremely cheap solution was reached. The windows, situated at the corners, were erected first so that no additional endstabilization of the bale walls was needed.

The roof beams were covered by normal timber boards on which a 3 mm felt layer was put to protect

Figure 4: Mandala type roof construction

Figure 5: Selfmade pneumatic press

Figure 6: Plastering the straw bale walls
the roof membrane against damage. The membrane consists of a PVC-coated polyester fabric and acts as rootproof and waterproof cover. The green roof consists of a layer of 12-15 cm earth mixed by 50% expanded clay resp. expanded glass (foamglass) and a vegetation of wild grasses. As the inclination of the roof is more than 20 degrees, horizontal barriers were installed to prevent the earth of slipping down. The room is illuminated by the central skylight and the three corner windows. The total material costs incl. transportation of this building were about 140 US$ per m².

A fire test done with a sample of a plastered strawbale wall proved that this wall could withstand the flame of a burner which created a temperature of up to 1000 degrees Celsius on the surface over a period of 90 minutes, due to the German norm DIN 1042. The heat transfer coefficient (λ-value) was measured in a laboratory test and reached 0.086 W/mK, which results in an U-value of about 0.17 W/m²K for the wall. As the bales were not yet dried out completely the measured values were higher than stated in other tests.

**Children’s home**

The 270 m² house for homeless and orphaned children which was built near Kaliningrad, Russia, in 2002 was the first strawbale house in Oblast Kaliningrad and the first one with green roof in Russia. In this case it was built as a non-loadbearing system. The bales were positioned between a timber structure as shown in fig. 8 and fig. 9.

In order to mount the last layer of bales underneath the roof beam the first layers had to be extremely pressed down. This was done by pulleys with a force of about 300 kg each. When the top layer of bales was brought in, the pulleys were relieved, the layer came up and pressed the top layer against the roof beam. So a very strong wall was constructed which
did not need any rebars or pins for additional stabilization. The surface was smoothened by a hedge-trimmer. The joints of the bales were filled with straw resp. with a mixture of straw covered by a thin clay plaster. The roof is built by normal rectangular rafters, resting on horizontal beams, covered by timber boards. The green roof consists of the same elements described in the first project but has an additional thermal insulation of 20 cm of rockwool.

**Ecological and economic advantages of inclined green roofs**

In both buildings a green roof system was used, which was developed by Gernot Minke and applied in all his architectural designs since 24 years. Characteristic for this system are four aspects:

- The height of the substrate is always 12-16 cm, it consists of a mixture of 50 % lightweight mineral aggregates like expanded clay, expanded slate, expanded glass or pumice and 50 % of “poor” earth with little nutrient content.
- The minimum inclination of the roof must be 3 degrees so that a sufficient drainage effect is given.
- With inclinations of more than 20 degrees special elements have to be installed to prevent the earth from slipping down.
- The vegetation is a special mixture of dense and low growing wild grasses and some special herbs which are resistant against frost and dryness. They keep off the wind from the roof and form a dense “fur” with a high thermal insulation effect.

**Ecological effects**

In the centre of big cities we can observe several negative effects due to sealing of the surface, density of buildings, traffic and heating of the buildings: Increased pollution and the decreased oxygen content of the air, increased temperature of the ambient air and dust clouds over the city. It is well known that green parks, dense trees in alleyes and other green areas in cities reduce these negative effects considerably. The optimized green roofs desveloped, with a green leaf area 5 to 10 times higher as the one of a green park, are an effective and economic means to create better climatic living conditions in cities. Besides this advantage for the microclimate of cities there are more positive effects for the users of buildings with green roofs. The most interesting are: the cooling effect in summer, the warming effect in winter and the increase of lifespan for the roof.

**Cooling effect in summer**

The heat transmission through a roof from outside to inside can be reduced by more than 90 % through a green roof. In Germany measurements in summer showed that at even in extreme hot periods with daytime temperatures of 35°C, the temperature underneath a grass roof never exceeded 25°C.

![Figure 10: Temperature of a green roof in Germany during autumn](image)

![Figure 11: Temperature of a green roof in Germany during winter](image)

![Figure 12: Amount of rainfall and drain at an inclined green roof after a heavy 18 hours lasting rain in September 1989 in Germany](image)

In Fig. 10 the temperatures of a period in autumn are shown within the green roof of the described type in Kassel, Germany, which exists of 16 cm of earth covered by wild grasses. When the air temperature reached 30°C the temperature underneath the earth was only 17.5°C. This cooling effect is derived mainly by the evaporation and shading effect of the vegetation, but also by its ability to reflect sun radiation and the energy consumption through photosynthesis and heat storage by its embedded water.
Heating effect in winter
If the vegetation is forming a thick layer like a fur it increases the thermal insulation effect of the roof effectively. In Figure 11 the temperatures during one week in January are shown of the same roof as measured in fig. 10. When the air temperature reached –14°C the temperature underneath the 16 cm of earth was only 0°C. At the same time the the temperature above the earth, i.e. underneath the grass, was about –3°C at the lowest. These effects come mainly from the thermal insulation effect of the air cushion within the vegetation and the fact that the cold wind does not hit the earth surface. Some minor effects are the thermal mass of the earth layer, the reflection of infrared radiation from the building by the plants and the heat production if dew is formed in the morning (the condensation of 1 g water releases 530 calories of heat).

Retardation of drain
Due to the German Standard DIN 1986 it is allowed to calculate that a green roof with at least 10 cm of earth releases only 30 % of precipitation, the rest is stored and evaporated. That may mean a considerable reduction of the dimensions of the sewage system. But much more important is the retardation effect of drain. Fig. 12 shows the amount of drain of a green roof with 14 cm substrate and 12° inclination after a heavy 18 hours lasting rain. The drain only started after 12 hours of rain.

Sound absorption
Whereas the vegetation of a green roof absorbs sound only by 2-3 dB, the earth acts as a strong acoustic barrier. Humid earth 12 cm thick reduces sound transfer by about 40 dB. A 20 cm thick layer even about 46 dB.

Fire resistance
In Germany green roofs are counted as "solid roofing" which means they do not burn and are fire resistant as long as the earth layer is at least 3 cm thick.

Shelter effect for roof cover
Covers like bitumen or tar felt, bitumen or wood shingles, wooden planks or plastic sheets deteriorate under uv-light and high temperature difference. This is eliminated by a cover of substrate and vegetation, and therefore green roofs, if well designed, have an extreme long lifespan and create hardly any care or repair.

Significance of leaf surface area
The positive effects of green roofs are stronger the denser and thicker the vegetation layer is. This usually corresponds with its leaf surface area. Investigation of the BRI showed that a common park lawn in Germany with 5 cm of average height has about 9 m² of leaf surface area per 1 m² of park area, whereas a low inclined earth roof with a dense cover of wild grasses has about 100 m² of leaf surface per m² of roof surface in summer. These dense vegetation can only be reached in middle-european climate if the substrate is 12-16 cm high and the inclination of the roof 5 to 40 % (3 to 22°).
A dense sedum vegetation on 8 cm of substrate only reaches about 2,4 m² of green leave surface.

Conclusion
In Germany in the last 20 years hundreds of inclined green roofs were built for private houses as well as for public buildings. (fig. 12 and fig. 13). In some master plans for new settlements green roofs are nowadays compulsory as it was found that settlements with green roofs not only improve microclimate, but also reduce costs for drainage / sewage system. Besides they also safe heating and cooling costs and improve indoor comfort for inhabitants. With public buildings it was stated that green roofs reduce maintenance cost drastically.