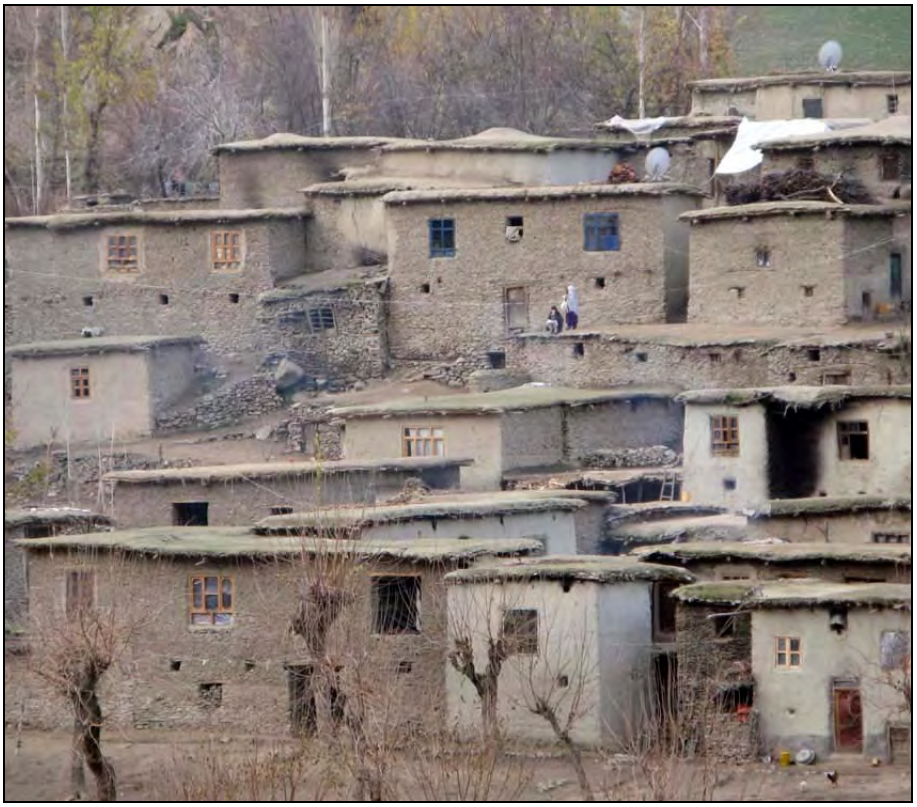
HUYS ADVIES

34 Examples of Roof Insulation

Technical Working Paper ~ Number 5

Thermal Insulation Values for Houses in High Mountain Areas in the Himalayas



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www.nienhuys.info

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Glossary

AAC	Autoclaved Aerated Concrete	GBM	General Building Materials (ε = 0.9)
EPS	Expanded Polyester	HRF	Highly Reflective Foil (ε = 0.04)
GI	Galvanised Iron	RFPE	Reflective Foil with 3 mm Polyethylene foam backing (ε = 0.1)
MDF	Medium Density Fibre Board		
PE	Polyethylene	Alum	Aluminium reflective foil (ε = 0.04)
PET	Polyethylene Terephthalate	ε = emissivity of material (= < 1)	
PP	Polypropylene (agricultural fibre bags)		

Calculations made in: PKR = Pakistan Rupees April 2011: Euro 1 = Rupee 120

Photo Front Page:

Typical adobe houses with flat roofs at the border of GBAO, Tajikistan.

INTRODUCTION

This document provides examples of insulation methods for ceilings/roofs in existing or new constructions. The designs are feasible in mountain areas where other types of more sophisticated thermal insulation materials are unavailable.

The minimum recommended insulation is based on the latitude of the Himalayan range (26°-40°North) and the altitude of the house location (1500–4000 m). This value needs to be increased when there is lack of sunshine in the winter. The insulation value is measured between the heated winter room and outside; this can include a buffer room upstairs.

The minimum recommendation is far below the currently obliged insulation values of Europe and North America where similar climate conditions exist. However, based on the current availability of insulation materials, the local resources in the mountain villages and the low-income level of the local inhabitants, the recommended insulation values and the design options have been chosen.

Straw or Wood Shavings
Because of similar insulation values, straw can be substituted with wood shavings. In the most rural areas, straw is the lowest cost option if the villagers supply the material. This needs to be dusted with lime powder to reduce insects. Especially when applied horizontally in non-compacted layers, the low-cost straw is one of the most economical insulation materials.

EPS or Glass Wool
Expanded Polystyrene (EPS) is one of the most cost-efficient imported materials. Medium- or high-density EPS is advised when the roof needs to be walked upon. Low-quality glass wool can absorb moisture and become less effective as a thermal insulator. Glass wool can cause skin and eye irritation and needs to be handled with gloves and protective goggles.

Moisture Barrier
For nearly all inside constructions, a fully sealed moisture or humidity barrier on the warm side of the ceiling construction will be necessary; otherwise, condensation will occur inside the insulation material or on the inside of the roof. Both (recycled) plastic foils and reflective foils are moisture barriers. Roofs need to be completely waterproof to avoid leakage into the house.

Roof Insulation Examples
The number of designs provided is only a sample and can be extended. All the cost options need to be recalculated based on the location and taking self-help or the supply of materials by the house owner into consideration. By comparing different designs with similar insulation values, the Cost/R_C value will indicate which design is more cost-effective.

For the “old situation”, basic roofs have been used. This will naturally differ per individual situation and the insulation value will need to be adjusted accordingly. The Cost/R_C value of the examples is calculated based on the total insulation (old and new together) as should be undertaken in each individual case.

Calculation Sheets
It would be beneficial to make a booklet with the 100 most common thermal insulation methods for the various altitudes (walls, roofs, floors, windows and doors). The client can then easily choose the insulation method and finishing that best suits his/her situation.

Condensation Point
The calculation sheets have a temperature column. This column can be filled out according to the expected temperatures in the housing area of the client. Based on these temperatures, a temperature line can be drawn in the construction drawing. With the aid of the Mollier diagram, the condensation point can then be determined. Details of the calculation method are presented in HA Technical Working Paper #2 ~ Calculation TI (February 2012).[1]

Cost Reduction
When applying thermal insulation, good quality tools (such as staple machines and nail guns) can substantially reduce the installation cost. Efficient working with adequate scaffolding is important.

[1] See: www.nienhuys.info

Calculation Methods

For basics on thermal insulation, calculation methods of thermal insulation values and detailed tables of various values of materials, see: www.nienhuys.info (page thermal insulation).

The calculations in the tables are based on the situation during the winter. Snow will accumulate on the roof in the coldest areas, creating some insulation against the cold. The inside warmth of the house, however, will slowly escape through the outside surfaces of the building.

Melting snow water will soak into the stabilized clay-soil roof surface of the traditional roof designs. Because the melting water gets into the roof, the top layer above the waterproofing is considered as wet for calculating the thermal insulation value. A cemented cover is to be considered wet as well.

For houses with a galvanised sheet roof, the insulation material under the roof will remain dry.

Making the roof waterproof is an important means of maintaining a high thermal insulation value.

Waterproofing a flat roof can be done with thick plastic foils (0.2 mm), asphalt paper or butyl foils (rubber), making sure the water runs towards drainage points.

The (recycled) plastic and asphalt paper need to be fully covered to protect it from ultra violet (UV) sunlight and from damage by walking on the roof.

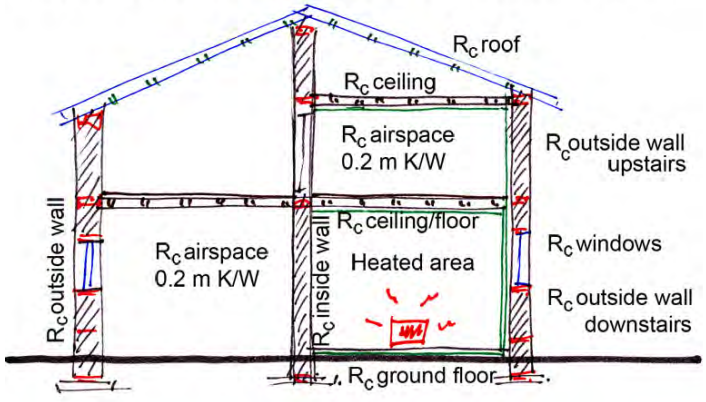
Ceiling/roof insulation is often one of the most important elements of the house. The heat loss from the ceiling is usually large because the air temperature near the ceiling is much higher than by the floor, especially in houses using a space-heating stove.

Traditional roofs are open and ventilated from below. The low insulation value causes condensation on the inside, which increases the humidity level inside the roof and further lowers the thermal insulation value. When waterproofing the roof on the outside, it needs to be well sealed below the insulation (on the warm side) to prevent air humidity from entering the roof and condensate. Ventilating above the damp-proofing layer with inside air is not allowed as it will again bring in humidity that will condense.

Because people often sit on the floor, insulating the floor has a positive effect on the comfort of the person due to less heat loss by contact. As a result, people lower the space-heating stove. However, the heat loss from the room through the floor is usually less than half the amount lost through the ceiling because the soil temperature under the house is much higher (warmer) than the outside winter air temperature above the roof. The amount of heat loss is directly related to the temperature difference between the inside and outside; the largest difference being at the roof.

For houses with a second storey, insulation is created by the additional upper rooms and the insulation value of the ceiling/floor in between. If the ceiling/floor is well insulated, the temperature in the upper rooms will be lower than when the ceiling is less insulated. If there is a room above the ceiling insulation, the space in between (R_C = 0.2 m^2.K/W) and the roof insulation can be added together to obtain the total ceiling/roof insulation of the building.

ADDING UP INSULATION VALUES OF ALL COMPONENTS



Reflective Metalized Plastic foils

The use of metalized plastic or Highly Reflective Foils (HRF) in combination with horizontal cavities inside the ceiling or roof will greatly increase the insulation value of that construction.

The following table gives the calculated insulation values of horizontal cavities when the heat flow is from below upwards. These R_C values are lower than when the heat flow is from above downwards, like with floors, and the values do not increase after 1.5 cm.

For flat roofs such as reinforced concrete roofs, two different calculations can be made; one on the insulation value in the winter with heat flow upwards and another for the summer when the sun-exposed reinforced concrete roof becomes very hot.

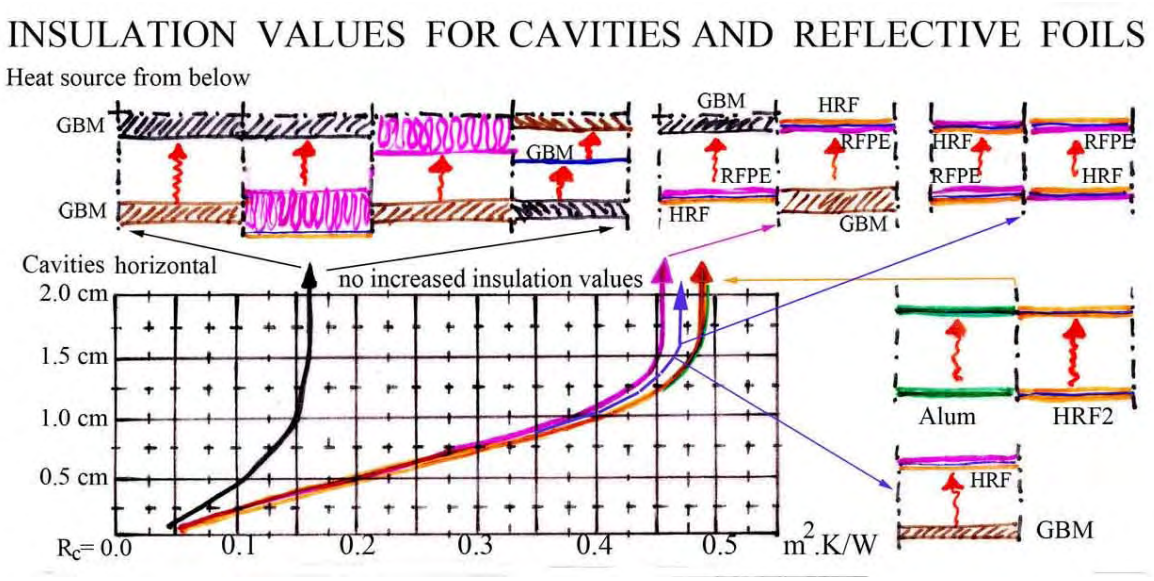
For the summer calculation, the chart in Technical Working Paper #4 for floors needs to be used.

However, when a reinforced concrete or metal roof is adequately insulated for the winter, it is also well insulated for the summer situation.

Insulation values for horizontal cavities with heat flow from below, such as ceilings.

Height in cm	GBM-GBM Black Line: R_C = m^2.K/W	GBM-RFPE RFPE-GBM Pink Line: R_C = m^2.K/W	GBM-HRF, HRF-RFPE HRF-GBM Blue Line: R_C = m^2.K/W	HRF-HRF HRF-Alum Alum-Alum, Alum-HRF Orange and Green Lines: R_C = m^2.K/W
0.1	0.035	0.04	0.04	0.04
0.5	0.11	0.2	0.2	0.2
0.7	0.13	0.27	0.28	0.28
1.0	0.15	0.38	0.39	0.4
>1.5	0.16	0.45	0.47	0.48

The above figures for roofs/ceilings are presented in the following graph with a sketch of the type of cavity.

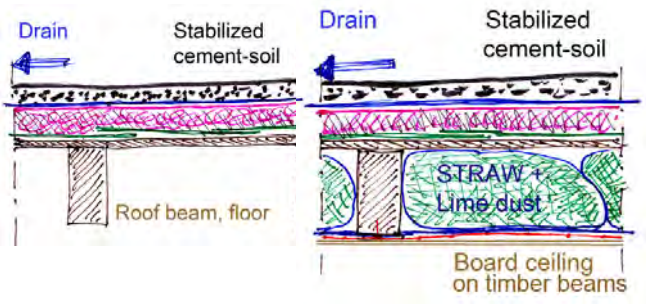


The red arrows indicate the direction of the heat flow.

Foils and surfaces without special reflective quality, such as all General Building Materials, are represented by the **Black line**. The values are subject to the reflective quality of the foils. Foils with a lesser reflective quality will have a line in between the **Black** and **Pink** lines.

Thermal Insulation Example Roof #1 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the support structure of the roof.

Roof #1: Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags, plastic, Wire-mesh, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Straw + lime mix in bags	0.15	12.5	1.875		*150*	*100*	*50*
11	Fixing materials wire-mesh	-	-	-		*150*	*100*	*50*
12	Plastic foil moisture barrier	-	-	-		*100*	*50*	*20*
13	Board directly on beams	0.004	7	0.028		*250*	*100*	*50*
	Subtotal Newly Added Value R_C			**1.903**		*650*	*350*	*170*
	Total Existing and New R_C Values			**2.36**		***Total Cost 10 m^2***		***1170***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***496***

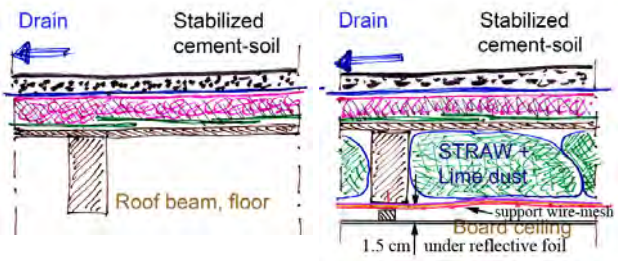
Insulation is suitable for altitudes up to 1800 m, according to recommendation.

Remarks:

- The existing roof is far below the minimum requirements.
- Wire-mesh not essential, but will facilitate placing and stuffing of the plastic bags with straw-lime.
- Insulation value will be increased with R_C= 0.16 m^2.K/W with a 1.5 cm cavity above the board.
- As an alternative, a reflective foil can be applied; increasing the value. See roof #2.
- Cost of the straw is low because it is supplied by the house owner. Bags + lime by craftsman.
- Plastic moisture barrier under the bags is necessary to avoid condensation inside the roof.
- Painting or other finishing costs of the ceiling are not included.

Thermal Insulation Example Roof #2 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the support structure of the roof.

Roof #2: Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags,1 x RFPE, wire-mesh, strips, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Straw + lime mix in bags	0.15	12.5	1.875		*150*	*100*	*50*
11	Fixing materials wire-mesh	-	-	-		*150*	*100*	*50*
12	RFPE is moisture barrier	0.003	22	0.066		*600*	*50*	*20*
13	Cavity horiz. HRF-GBM	>0.015	Pink	0.45		-	-	-
14	Board on timber strips	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**2.419**		*1200*	*350*	*170*
Total Existing and New R_C Values				**2.876**		***Total Cost 10 m^2***		***1720***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***598***

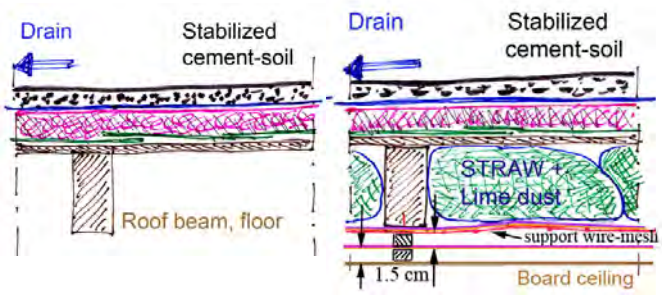
Insulation is suitable for altitudes up to 2300 m, according to recommendation.

Remarks:

- The existing roof is far below the minimum requirements.
- With the single reflective foil, the total insulation value of the roof increases, but the ratio increases only a little.
- Cost of the straw is low because it is supplied by the house owner. Bags + lime by craftsman.
- RFPE moisture barrier under the bags is necessary to avoid condensation inside the roof.
- The wire-mesh is necessary to ensure that 1.5 cm between board and RFPE is maintained.

Thermal Insulation Example Roof #3 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the support structure of the roof.

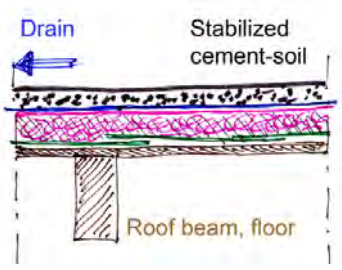
Roof #3: Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags, 1 x RFPE, wire-mesh, 1 x RFPE, strips, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Straw + lime mix in bags	0.15	12.5	1.875		*150*	*100*	*50*
11	Fixing materials wire-mesh	-	-	-		*150*	*100*	*50*
12	RFPE is moisture barrier	0.003	22	0.066		*600*	*50*	*20*
13	Cavity horiz. RFPE-GBM	>0.015	**Pink**	0.45		-	-	-
14	Timber support strips	0.015	-	-		*50*	*50*	*20*
15	RFPE is moisture barrier	0.003	22	0.066		*600*	*50*	*20*
16	Cavity horiz. HRF-GBM	>0.015	**Pink**	0.45		-	-	-
17	Board on timber strips	0.004	7	0.028		*300*	*100*	*50*
	Subtotal Newly Added Value R_C			**2.935**		*1850*	*450*	*210*
	Total Existing and New R_C Values			**3.392**			***Total Cost 10 m^2***	***2510***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***740***

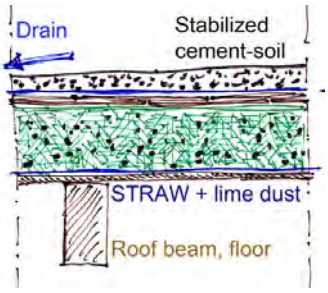
Insulation is suitable for altitudes up to 2700 m, according to recommendation.

Same other remarks as per example roof #2.

Thermal Insulation Example Roof #4 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W





For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the roof support structure.

Roof #4: Planks, tree bark, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-4	Remove straw clay-soil	0.08	1.67	-0.134		-	-	-
-5	Remove tree bark	0.005	7	-0.035		-	-	-
10	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
11	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
12	Plastic foil moisture barrier	0.002	-	-		*100*	*50*	*20*
13	Replace cement-soil cover	0.06	-	-		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**1.981**		*650*	*350*	*170*
Total Existing and New R_C Values				**2.438**		***Total Cost 10 m^2***		***1170***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***480***

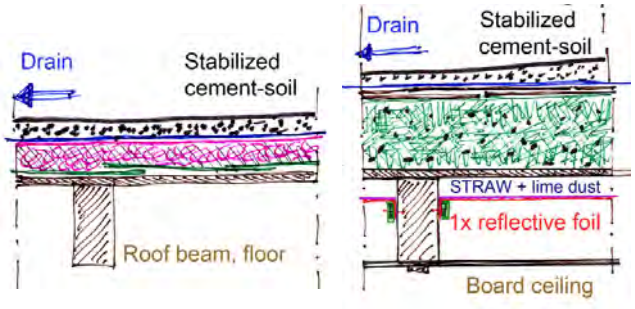
Insulation is suitable for altitudes up to 1900 m, according to recommendation.

Remarks:

- This roof is almost entirely reconstructed by removing the whole top layer and applying straw.
- Reducing the weight of the roof is very important in high earthquake risk areas.
- A double layer of cardboard or hardboard is laid over the straw to spread any point load on the roof. Such a roof, however, is not very firm and cannot be walked upon or used for storage.
- Plastic moisture barrier directly on the timber roofing floor is necessary to avoid condensation.
- Painting or other finishing costs of the ceiling are not included.

Thermal Insulation Example Roof #5 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the roof support structure.

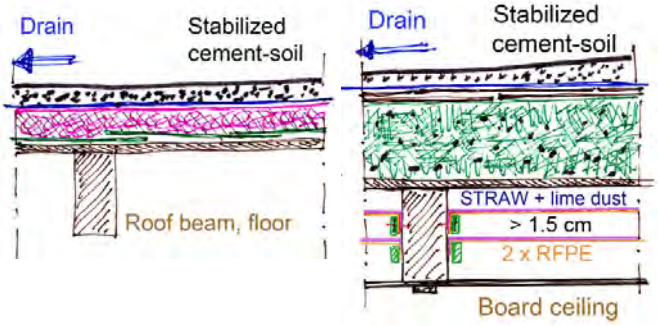
Roof #5: Board, cavity, 1 x RFPE, cavity, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134		remove		
5	Tree bark	0.005	7	0.035		remove		
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-4	Remove straw-clay layer	0.08	1.67	-0.134		-	*self*	-
-5	Remove tree bark	0.005	7	-0.035		-	*self*	-
2	Remove/replace top layer	-	-	-		*300*	*200*	*100*
10	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
11	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
12	Plastic foil waterproofing	0.0002	-	-		*100*	*50*	*20*
13	Cavity horizontal under the planks GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
14	RFPE moisture barrier	0.003	22	0.066		*600*	*100*	*50*
15	Cavity horizontal above the board GBM-HRF	>0.015	**Pink**	0.45		-	-	-
16	MDF, hardboard, plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**2.975**		*1650*	*650*	*320*
Total Existing and New R_C Values				**3.432**		***Total Cost 10 m^2***		***2620***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***763***

Insulation is suitable for altitudes up to 2900 m, according to recommendation.

Remarks:
A double layer of cardboard or hardboard is laid over the straw to spread any point load on the roof. Such a roof, however, is not very firm and cannot be walked upon or used for storage.

Thermal Insulation Example Roof #6 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

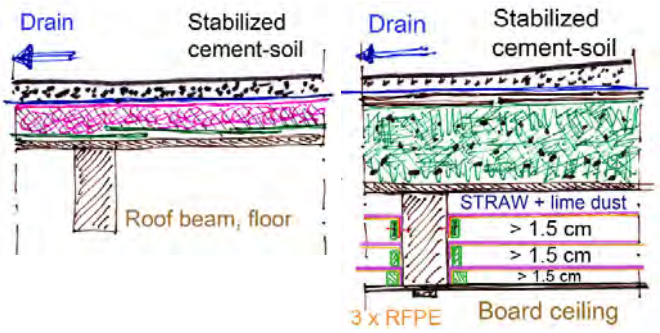
Cost calculation does not include the roof support structure.

Roof #6: Board, 3 x cavity, 2 x RFPE, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134		remove		
5	Tree bark	0.005	7	0.035		remove		
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-4	Remove straw-clay layer	0.08	1.67	-0.134		-	*self*	-
-5	Remove tree bark	0.005	7	-0.035		-	*self*	-
2	Remove/replace top layer	-	-	-		*300*	*200*	*100*
10	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
11	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
12	Plastic foil waterproofing	0.0002	-	-		*100*	*50*	*20*
13	Cavity horizontal under the planks GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
14	RFPE moisture barrier	0.003	22	0.066		*600*	*100*	*50*
15	Cavity horizontal between HRF-RFPE	>0.015	**Blue**	0.47		-	-	-
16	RFPE moisture barrier	0.003	22	0.066		*600*	*100*	*50*
17	Cavity horizontal above the board GBM-HRF	>0.015	**Pink**	0.45		-	-	-
18	MDF, hardboard, plywood	0.004	7	0.028		*350*	*150*	*50*
Subtotal Newly Added Value R_C				**3.511**		*2300*	*800*	*370*
Total Existing and New R_C Values				**3.968**		***Total Cost 10 m^2***		***3470***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***874***

Insulation is suitable for altitudes up to 3400 m, according to recommendation.

Thermal Insulation Example Roof #7 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

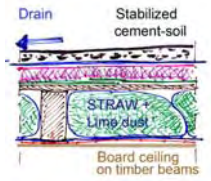
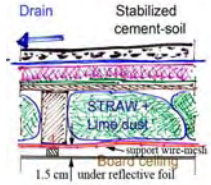
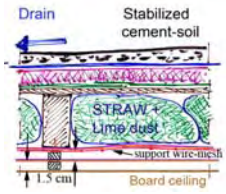
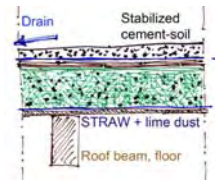
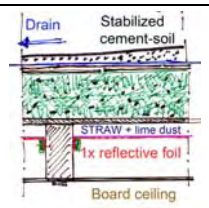
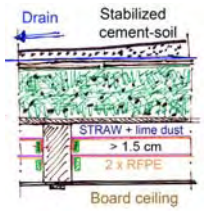
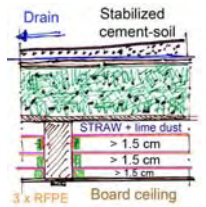
Cost calculation does not include the roof support structure.

Roof #7: Board, 4 x cavity, 3 x RFPE, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134		remove		
5	Tree bark	0.005	7	0.035		remove		
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-4	Remove straw-clay layer	0.08	1.67	-0.134		-	*self*	-
-5	Remove tree bark	0.005	7	-0.035		-	*self*	-
2	Remove/replace top layer	-	-	-		*300*	*200*	*100*
10	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
11	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
12	Plastic foil waterproofing	0.0002	-	-		*100*	*50*	*20*
13	Cavity horizontal under the planks GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
14	3 x RFPE moisture barrier	0.009	22	0.198		*1800*	*300*	*150*
15	2 x Cavity horizontal between HRF-RFPE	>0.015	**2x Blue**	0.94		-	-	-
16	Cavity horizontal above the board GBM-HRF	>0.015	**Pink**	0.45		-	-	-
17	MDF, hardboard, plywood	0.004	7	0.028		*350*	*150*	*50*
Subtotal Newly Added Value R_C				**4.047**		*2900*	*900*	*420*
Total Existing and New R_C Values				**4.504**		***Total Cost 10 m^2***		***4220***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***937***

Insulation is suitable for altitudes up to 4000 m, according to recommendation.

COMPARISON TABLE OF EXAMPLE ROOFS #1 – #7

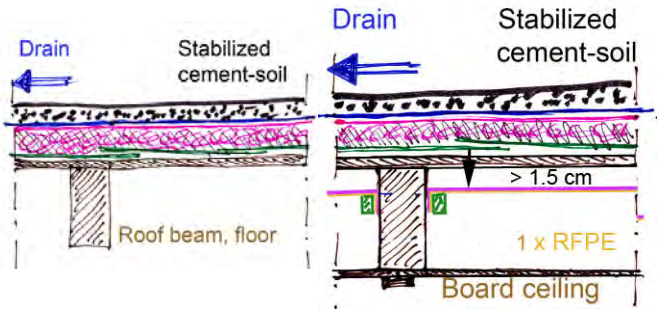
Roof designs with **additional insulation**.

#	Mini Picture of Construction Design	Description	Added R_C = m^2.K/W	Total Insulation Value	Total Cost of Added Insulation	Ratio = Total Cost / R_C Total
Roof # 1		Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags, plastic wire-mesh, hardboard.	**1.90**	**2.36**	**1170**	**496**
Roof # 2		Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags,1 x RFPE, wire-mesh, strips, hardboard.	**2.42**	**2.88**	**1720**	**598**
Roof # 3		Planks, tree bark, clay-soil straw mixture, plastic, stabilized cement-soil, infill straw + lime in bags, 1 x RFPE, wire-mesh, 1 x RFPE, strips, hardboard.	**2.94**	**3.39**	**2510**	**740**
Roof # 4		Planks, tree bark, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil.	**1.98**	**2.44**	**1170**	**480**
Roof # 5		Board, cavity, 1 x RFPE, cavity, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil.	**2.98**	**3.43**	**2620**	**763**
Roof # 6		Board, 3 x cavity, 2 x RFPE, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil.	**3.51**	**3.97**	**3470**	**874**
Roof # 7		Board, 4 x cavity, 3 x RFPE, planks, straw + lime mixture, cardboard, waterproof plastic, stabilized cement-soil.	**4.05**	**4.50**	**4220**	**937**

Compare the various designs with the insulation values and costs suitable for a given altitude.

Thermal Insulation Example Roof #8 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the supporting roof structure.

Roof #8: Planks, tree bark, clay-soil straw mixture, waterproof plastic, stabilized cement-soil, 1 x RFPE, 2 x cavity, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
11	1 x Fixing materials	-	-	-		*50*	*50*	*50*
12	1 x RFPE moisture barrier	0.006	22	0.132		*600*	*100*	*50*
13	Cavity horiz. GBM-HRF	>0.015	**Pink**	0.45		-	-	-
14	Board MDF or plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**1.06**		*950*	*250*	*150*
Total Existing and New R_C Values				**1.517**		***Total Cost 10 m^2***		***1350***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***890***

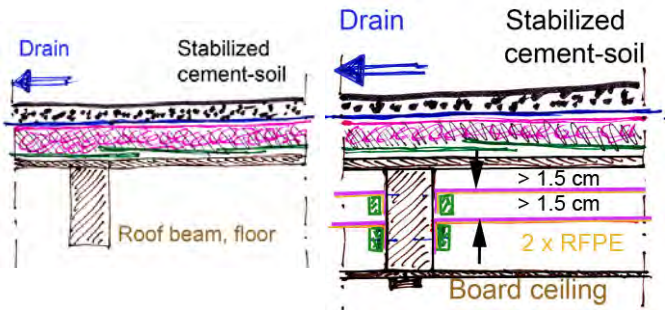
Insulation is much below the recommended insulation for 1500 m altitude.

Remarks:

- Keeping the existing waterproofing (old plastic) is not recommended because it puts the quality of the roof at serious risk as leakage water will not be detected due to the new moisture barrier inside the ceiling.
- If soil layers are thick, they need to be removed to reduce the occurring earthquake loads.
- Good stapling or nailing tools will speed up application.
- Painting or other finishing costs of the ceiling are not included.

Thermal Insulation Example Roof #9 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the supporting roof structure.

Roof #9: Planks, tree bark, clay-soil straw mixture, waterproof plastic, stabilized cement-soil, 2 x RFPE, 3 x cavity, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
11	2 x Fixing materials	-	-	-		*100*	*100*	*50*
12	2 x RFPE moisture barrier	0.006	22	0.132		*1200*	*100*	*50*
13	Cavity horiz. HRF-FRPE	>0.015	**Blue**	0.47		-	-	-
14	Cavity horiz. GBM-HRF	>0.015	**Pink**	0.45		-	-	-
15	Board MDF or plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**1.53**		*1600*	*300*	*150*
Total Existing and New R_C Values				**1.987**		***Total Cost 10 m^2***		***2050***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***1032***

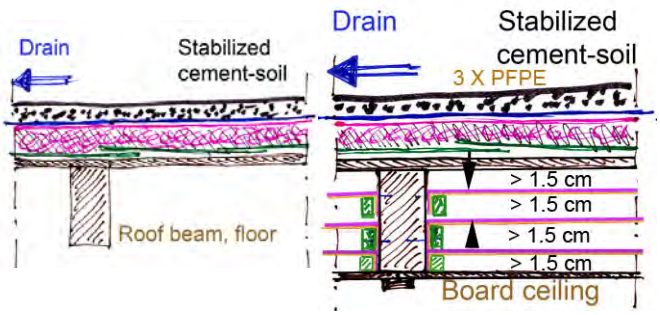
Insulation is just below the recommendation for 1500 m altitude.

Remarks:

- Keeping the existing waterproofing (old plastic) is not recommended because it puts the quality of the roof at serious risk as leakage water will not be detected due to the double moisture barrier inside the ceiling.
- If soil layers are thick, they need to be removed to reduce the occurring earthquake loads.
- Good stapling or nailing tools will speed up application.
- Painting or other finishing costs of the ceiling are not included.

Thermal Insulation Example Roof #10 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the supporting roof structure.

Roof #10: Planks, tree bark, clay-soil straw mixture, waterproof plastic, stabilized cement-soil, 3 x RFPE, 4 x cavity, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
11	3 x Fixing materials	-	-	-		*150*	*150*	*50*
12	3 x RFPE moisture barrier	0.009	22	0.198		*1800*	*150*	*50*
13	2 x Cavity hor. HRF-FRPE	>0.015	**Blue**	0.94		-	-	-
14	Cavity horiz. GBM-HRF	>0.015	**Pink**	0.45		-	-	-
15	Board MDF or plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**2.066**		*2250*	*400*	*150*
Total Existing and New R_C Values				**2.523**		***Total Cost 10 m^2***		***2800***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***1110***

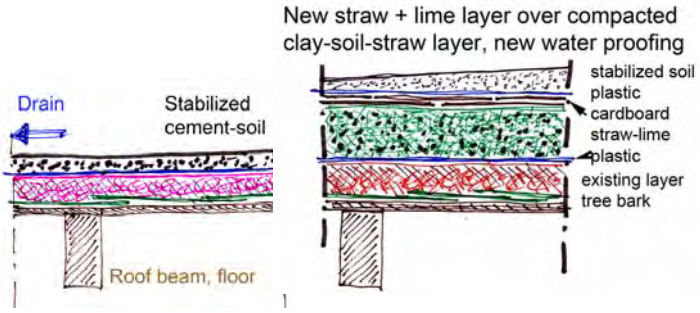
Insulation is suitable for 2000 m altitude, according to recommendation.

Remarks:

- Keeping the existing waterproofing (old plastic) is not recommended because it puts the quality of the roof at serious risk as leakage water will not be detected due to the triple moisture barrier inside the ceiling.
- If soil layers are thick, they need to be removed to reduce the occurring earthquake loads.
- The non-insulated roof will get a large amount of condensation against the ceiling.
- More than three foils with four cavities is not advised; other techniques should be used.

Thermal Insulation Example Roof #11 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the support structure.

Roof #11: New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036		replace		
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Plastic foil moisture barrier	0.0002	-	-		*100*	*100*	*50*
11	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
12	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
13	New plastic waterproofing	0.0002	-	-		*200*	*100*	*50*
14	Replace top layer	0.06	-	-		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**2.15**		*850*	*500*	*250*
Total Existing and New R_C Values				**2.607**		***Total Cost 10 m^2***		***1600***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***614***

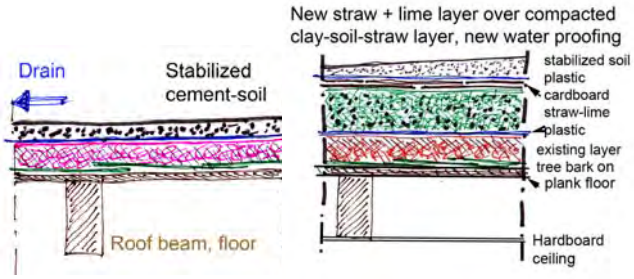
Insulation is suitable for altitudes up to 2100 m, according to recommendation.

Remarks:

- A double layer of cardboard or hardboard is laid over the straw to spread any point load on the roof. Such a roof, however, is not very firm and cannot be walked upon or used for storage. If the cardboard is still too flexible, one layer of hardboard should be used (higher cost).
- If the straw-lime is well compacted, the insulation value will be reduced.
- Only recommended when existing soil layer is rather thin and does not have large load. In such a case, the soil layer in the roof will act as a heat storage. Heat storage in the ceiling is not very effective in warming up the room air below.

Thermal Insulation Example Roof #12 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the support structure.

Roof #12: New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036		replace		
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Plastic foil moisture barrier	0.0002	-	-		*100*	*100*	*50*
11	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
12	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
13	New plastic waterproofing	0.0002	-	-		*200*	*100*	*50*
14	Replace top layer	0.06	-	-		*200*	*100*	*50*
15	Cavity horiz. GBM-GBM	>0.015	**Black**	0.16		-	-	-
16	Hardboard ceiling	0.004	6	0.024		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**2.334**		*1150*	*600*	*300*
Total Existing and New R_C Values				**2.791**		***Total Cost 10 m^2***		***2050***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***735***

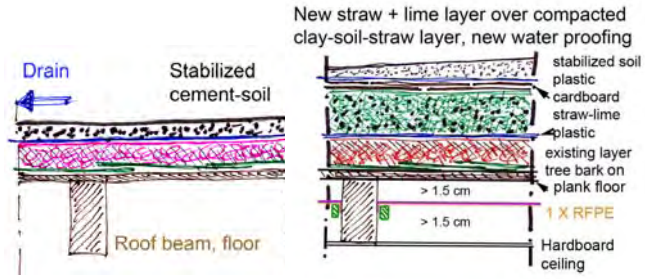
Insulation is suitable for altitudes up to 2300 m, according to recommendation.

Remarks:

- Although the insulation value increases a little, the cost also increases and therefore the ratio.
- If the straw-lime is well compacted, the insulation value will be reduced.
- Only recommended when existing soil layer is rather thin and does not have large load. In such a case, the soil layer in the roof will act as a heat storage. Heat storage in the ceiling is not very effective in warming up the room air below.

Thermal Insulation Example Roof #13 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the support structure.

Roof #13: New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling + 1 x RFPE. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036		replace		
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Plastic foil moisture barrier	0.0002	-	-		*100*	*100*	*50*
11	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
12	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
13	New plastic waterproofing	0.0002	-	-		*200*	*100*	*50*
14	Replace top layer	0.06	-	-		*200*	*100*	*50*
15	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
16	1 x Reflective foil RFPE	0.003	22	0.066		*600*	*100*	*50*
17	Cavity horiz. GBM-HRF	>0.015	**Pink**	0.45		-	-	-
18	Hardboard ceiling	0.004	6	0.024		*300*	*100*	*50*
	Subtotal Newly Added Value R_C			**3.14**		*1750*	*700*	*350*
	Total Existing and New R_C Values			**3.597**			***Total Cost 10 m^2***	***2800***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***778***

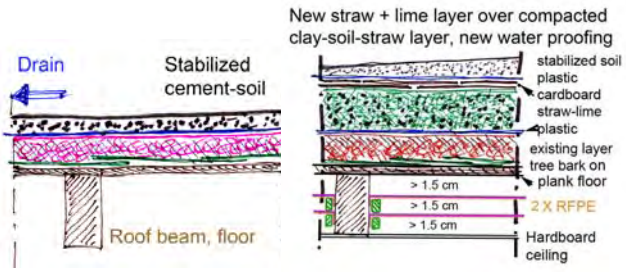
Insulation is suitable for altitudes up to 2600 m, according to recommendation.

Remarks:

- The insulation value increases as well as the cost, but the ratio remains about the same.
- If the straw-lime is well compacted, the insulation value will be reduced.

Thermal Insulation Example Roof #14 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the support structure.

Roof #14: New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling + 2 x RFPE. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036		replace		
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Plastic foil moisture barrier	0.0002	-	-		*100*	*100*	*50*
11	Straw + lime, dry	0.20	10	2.0		*250*	*100*	*50*
12	Cardboard cover	0.01	15	0.15		*100*	*100*	*50*
13	New plastic waterproofing	0.0002	-	-		*200*	*100*	*50*
14	Replace top layer	0.06	-	-		*200*	*100*	*50*
15	Cavity horiz. GBM-RFPE	>0.015	**2x Pink**	0.90		-	-	-
16	2 x Reflective foil RFPE	0.006	22	0.132		*1200*	*150*	*50*
17	Cavity horiz. HRF-RFPE	>0.015	**Blue**	0.47		-	-	-
18	Hardboard ceiling	0.004	6	0.024		*300*	*100*	*50*
	Subtotal Newly Added Value R_C			**3.676**		*2350*	*750*	*350*
	Total Existing and New R_C Values			**4.133**		***Total Cost 10 m^2***		***3450***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***835***

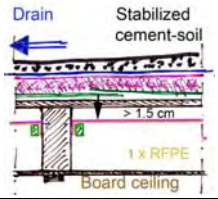
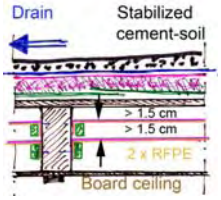
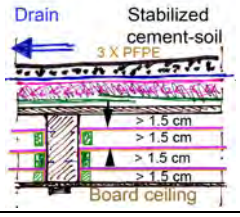
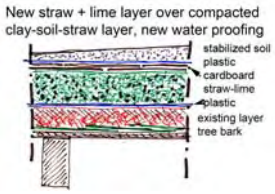
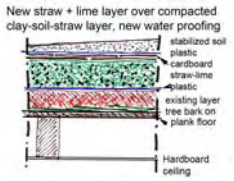
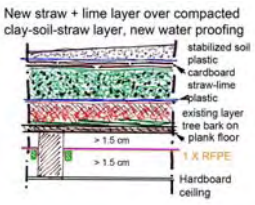
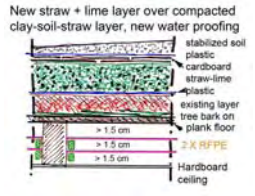
Insulation is suitable for altitudes up to 3600 m, according to recommendation.

Remarks:

- The insulation value and cost increases again, but the ratio remains about the same.
- If the straw-lime is well compacted, the insulation value will be reduced.

COMPARISON TABLE OF EXAMPLE ROOFS #8 – #14

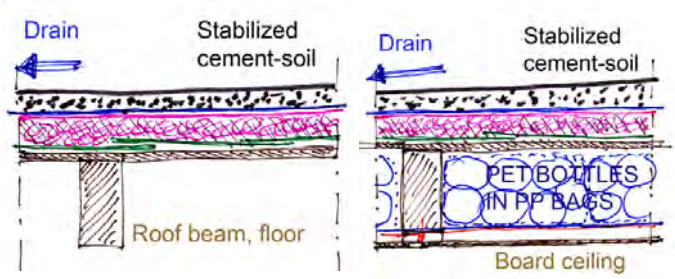
Roof designs with **additional insulation**.

#	Mini Picture of Construction Design	Description	Added R_C = m^2.K/W	Total Insulation Value	Total Cost of Added Insulation	Ratio = Total Cost / R_C Total
Roof # 8		Planks, tree bark, clay-soil straw mixture, waperproof plastic, stabilized cement-soil, 1 x RFPE, 2 x cavity, hardboard.	**1.06**	**1.52**	**1350**	**890**
Roof # 9		Planks, tree bark, clay-soil straw mixture, waperproof plastic, stabilized cement-soil, 2 x RFPE, 3 x cavity, hardboard.	**1.53**	**1.99**	**2050**	**1032**
Roof # 10		Planks, tree bark, clay-soil straw mixture, waperproof plastic, stabilized cement-soil, 3 x RFPE, 4 x cavity, hardboard.	**2.07**	**2.52**	**2800**	**1110**
Roof # 11		New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil.	**2.15**	**2.61**	**1600**	**614**
Roof # 12		New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling.	**2.33**	**2.79**	**2050**	**735**
Roof # 13		New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling + 1 x RFPE.	**3.14**	**3.60**	**2800**	**778**
Roof # 14		New plastic moisture barrier, straw layer + lime, cardboard and plastic waterproofing, cement stabilized soil, hardboard ceiling + 2 x RFPE.	**3.68**	**4.13**	**3450**	**835**

Compare the various designs with the insulation values and costs, suitable for a given altitude.

Thermal Insulation Example Roof #15 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof support structure.

Roof #15: Planks, tree bark, clay-soil straw mixture, waterproof plastic, stabilized cement-soil, PET bottles in bags, plastic, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	PET bottles double in bags	0.15	12	1.80		*450*	*100*	*50*
11	Plastic foil moisture barrier	0.0002	-	-		*100*	*50*	*20*
12	Fixing materials wire-mesh	-	-	-		*100*	*100*	*50*
13	Cavity horiz. GBM-GBM	>0.015	**Black**	0.16		-	-	-
14	Board MDF or plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**1.988**		*950*	*350*	*170*
Total Existing and New R_C Values				**2.445**		***Total Cost 10 m^2***		***1470***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***601***

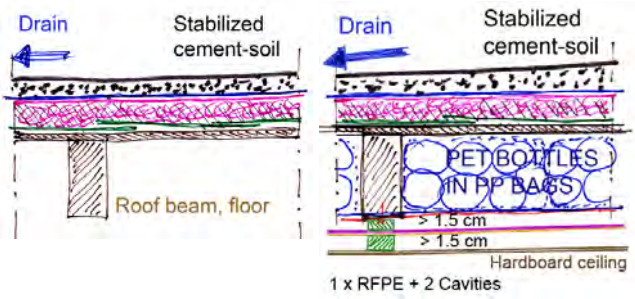
Insulation value is suitable for altitudes up to 1900 m, according to recommendation.

Remarks:

- The support strips for the board need to be 2.5 cm thick; otherwise, the wire-mesh will sag.
- The cost of the used PET bottles in plastic bags can differ greatly per region.
- If the PET bottles are not tightly packed or not inside plastic bags, the insulation value will be lower (R_M = 10 m^2.K/W).
- Plastic moisture barrier under the bags is necessary to ensure good sealing because small openings will remain between the bags.

Thermal Insulation Example Roof #16 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof support structure.

Roof #16: Planks, tree bark, clay-soil straw mixture, waterproof plastic, stabilized cement-soil, PET bottles, plastic, 1 x RFPE, 2 x cavity, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilised cement-soil, wet	0.06	0.6	0.036				
3	Plastic foil 0.2 mm	0.0002	-	-				
4	Straw clay-soil layer, dry	0.08	1.67	0.134				
5	Tree bark	0.005	7	0.035				
6	Timber plank ceiling	0.02	5.6	0.112				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.457**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	PET bottles double in bags	0.15	12	1.80		*450*	*100*	*50*
11	Plastic foil moisture barrier	0.0002	-	-		*100*	*50*	*20*
12	Fixing materials wire-mesh	-	-	-		*100*	*100*	*50*
13	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
14	1 x RFPE with timber strips	0.003	22	0.066		*600*	*100*	*50*
15	Cavity horiz. GBM-RFPE	>0.015	**Pink**	0.45		-	-	-
16	Board MDF or plywood	0.004	7	0.028		*300*	*100*	*50*
Subtotal Newly Added Value R_C				**2.794**		*1550*	*450*	*220*
Total Existing and New R_C Values				**3.251**		***Total Cost 10 m^2***		***2220***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***683***

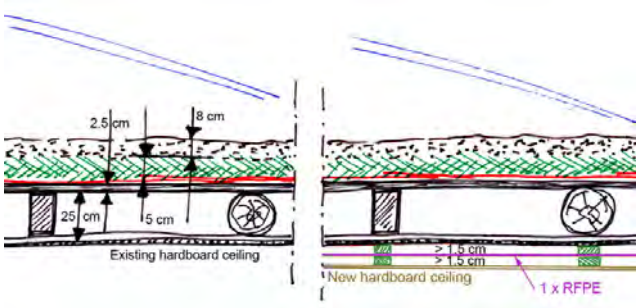
Insulation value is suitable for altitudes up to 2700 m, according to recommendation.

Remarks:

- The first support strip for the RFPE needs to be 2.5 cm thick; otherwise, the wire-mesh will sag.
- If the PET bottles are not tightly packed or not inside plastic bags, the insulation value will be lower (R_M = 10 m^2.K/W).
- Plastic moisture barrier under the bags is necessary to ensure good sealing because between the bags openings will remain.

Thermal Insulation Example Roof #17 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof support system.

Roof #17: Under open GI sheet roof + 1 x RFPE under existing ceiling, new hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Dry clay-soil cover of straw	0.08	1.40	0.112				
3	Compressed straw, dry	0.05	10.0	0.50				
4	Asphalt paper	0.005	8.3	0.04				
5	Plank flooring	0.025	5.00	0.125				
6	Cavity horiz. GBM-GBM	0.16	**Black**	0.16				
7	Hardboard ceiling	0.004	5.00	0.02				
8	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**1.127**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	1 x RFPE + timber strips	0.003	22	0.066		*600*	*100*	*50*
11	2 x Cavity GBM-RFPE	>0.015	**2x Pink**	0.90		-	-	-
12	Fixing strips 3/4" x 1.5"	-	-	-		*50*	*100*	*50*
13	Hardboard ceiling	0.004	6	0.024		*300*	*200*	*100*
Subtotal Newly Added Value R_C				**0.99**		*950*	*400*	*200*
Total Existing and New R_C Values				**2.117**		***Total Cost 10 m^2***		***1550***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***732***

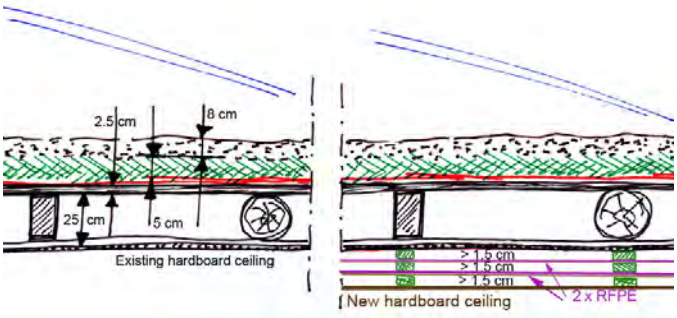
Insulation value is suitable for altitudes up to 1600 m, according to recommendation.

Remarks:

- Comparing this solution with filling in the space in the ceiling with straw-lime (in bags), the straw insulation is far more effective and has a lower cost when access to straw is available.
- Under the full GI roof cover, the outside thermal insulation is dry and transmission increased.
- The space under the roof can still be used as storage area.
- The reflective foil works at the same time as a moisture barrier.
- Finishing of joints between hardboard sheets or painting not included.

Thermal Insulation Example Roof #18 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Roof #18: Under open GI sheet roof + 2 x RFPE under existing ceiling, new hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Dry clay-soil cover of straw	0.08	1.40	0.112				
3	Compressed straw, dry	0.05	10.0	0.50				
4	Asphalt paper	0.005	8.3	0.04				
5	Plank flooring	0.025	5.00	0.125				
6	Cavity horiz. GBM-GBM	0.16	**Black**	0.16				
7	Hardboard ceiling	0.004	5.00	0.02				
8	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**1.127**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	1 x RFPE + timber strips	0.003	22	0.066		*600*	*100*	*50*
11	2 x Cavity GBM-RFPE	>0.015	**2x Pink**	0.90		-	-	-
12	1 x RFPE + timber strips	0.003	22	0.066		*600*	*100*	*50*
13	1 x Cavity HRF-RFPE	>0.015	**Blue**	0.47		-	-	-
14	Fixing strips 3/4" x 1.5"	-	-	-		*50*	*100*	*50*
15	Hardboard ceiling	0.004	6	0.024		*300*	*200*	*100*
Subtotal Newly Added Value R_C				**1.526**		*1550*	*500*	*250*
Total Existing and New R_C Values				**2.653**		***Total Cost 10 m^2***		***2300***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***867***

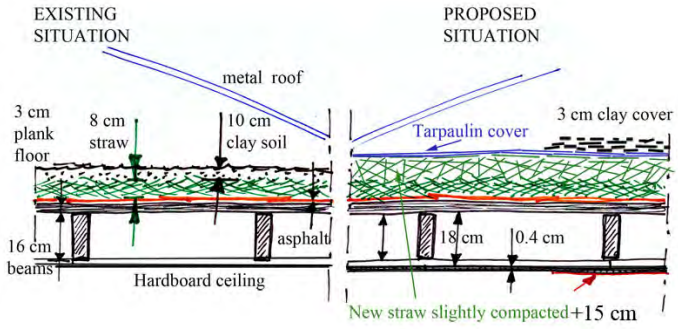
Insulation value is suitable for altitudes up to 2100 m, according to recommendation.

Remarks:

- With a better insulation value, the cost ratio is about the same. This depends on the cost of the foil.
- When the GI sheet is fully closed and an attic is created, the additional insulation value of that enclosed space can be estimated at R_C = 0.2 m^2.K/W.

Thermal Insulation Example Roof #19 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include the support structure of the roof.

Roof #19: Under open GI sheet roof, cleaning and adding to traditional basis, straw + lime over plastic foil. Thickness x R_M = R_C				New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Dry clay-soil cover of straw	0.10	1.40	0.14		remove		
3	Compressed straw, dry	0.08	10.0	0.80				
4	Asphalt paper	0.005	8.3	0.04				
5	Plank flooring	0.03	5.00	0.15				
6	Cavity horiz. GBM-GBM	0.16	**Black**	0.16				
7	Hardboard ceiling	0.004	5.00	0.02				
8	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**1.48**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-2	Dry clay-soil cover of straw	0.10	1.40	-0.14				
10	Straw, lightly compacted	0.15	10	1.5		*100*	*100*	*50*
11	Mixing lime @ 2kg per m^3	-	-	-		*50*	-	*50*
12	Tarpaulin over straw	0.0002	-	-		*100*	*50*	-
13	Replacement of clay	0.04	1.20	0.048		-	*200*	*100*
Subtotal Newly Added Value R_C				**1.408**		*250*	*350*	*200*
Total Existing and New R_C Values				**2.888**		***Total Cost 10 m^2***		***800***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***277***

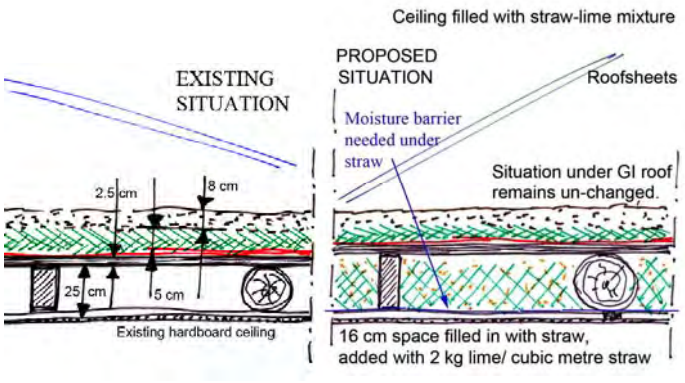
Insulation value is suitable for altitudes up to 2300 m, according to recommendation.

Remarks:

- If the quality of the asphalt paper cover over the planks is uncertain, a new plastic foil needs to be placed over the plank floor to ensure a moisture barrier.
- If the moisture barrier is not good, condensation can occur inside the straw and affect the quality of the insulation. Calculation of condensation point is recommended here.
- The tarpaulin is necessary; otherwise, the clay-soil will fall down into the straw.
- The cover is not firm enough for storage of heavy loads; the straw will compact more.

Thermal Insulation Example Roof #20 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the support structure of the roof.

Roof #20: Under open GI sheet, filling in of traditional timber ceiling with 16 cm straw + lime over new plastic foil. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Dry clay-soil cover of straw	0.10	1.40	0.14				
3	Compressed straw, dry	0.08	10.0	0.80				
4	Asphalt paper	0.005	8.3	0.04				
5	Plank flooring	0.03	5.00	0.15				
6	Cavity horiz. GBM-GBM	0.16	**Black**	0.16				
7	Hardboard ceiling	0.004	5.00	0.02				
8	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**1.48**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-6	Cavity horiz. GBM-GBM	0.16	**Black**	-0.16		-	-	-
10	Straw, loose	0.20	12	2.40		*100*	*100*	*50*
11	Mixing lime @ 2kg per m^3	-	-	-		*50*	-	*50*
12	Removing/replacing ceiling	-	-	-		*300*	*200*	*100*
13	Plastic moisture barrier	0.0002	-	-		*100*	*100*	*50*
14	New cover strips board	-	-	-		*250*	*100*	*50*
Subtotal Newly Added Value R_C				**2.24**		*800*	*500*	*300*
Total Existing and New R_C Values				**3.72**		***Total Cost 10 m^2***		***1600***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***430***

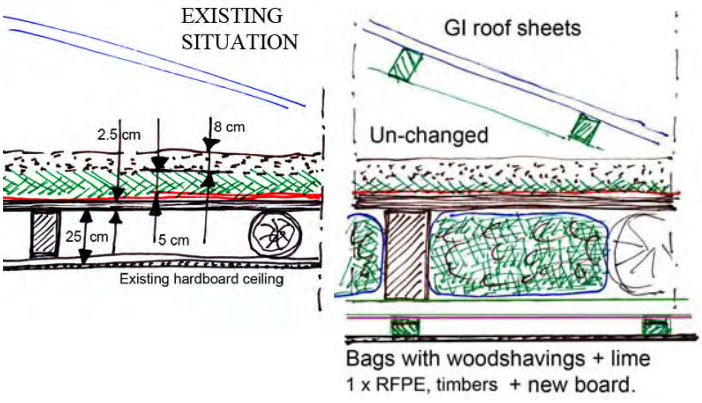
Insulation value is suitable for altitudes up to 3200 m, according to recommendation.

Remarks:

- Under the open GI cover, the outside thermal insulation is dry and transmission higher.
- The space under the roof can still be used as storage area.

Thermal Insulation Example Roof #21 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include roof support structure.

Roof #21: Under open GI sheet, filling in of traditional timber ceiling with 16 cm straw + lime over new 1 x RFPE and ceiling. Thickness x R_M = R_C				New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Dry clay-soil cover of straw	0.10	1.40	0.14				
3	Compressed straw, dry	0.08	10.0	0.80				
4	Asphalt paper	0.005	8.3	0.04				
5	Plank flooring	0.03	5.00	0.15				
6	Cavity horiz. GBM-GBM	0.16	**Black**	0.16				
7	Hardboard ceiling	0.004	5.00	0.02				
8	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**1.48**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-6	Cavity horiz. GBM-GBM	0.16	**Black**	-0.16		-	-	-
10	Straw, loose in plastic bags	0.20	12	2.40		*100*	*100*	*50*
11	Mixing lime @ 2kg per m^3	-	-	-		*50*	-	*50*
12	Replace supports ceiling	0.02	**Pink**	0.45		*100*	*100*	*50*
13	RFPE, moisture barrier	0.003	22	0.066		*600*	*100*	*50*
14	Cavity horizontal	>0.015	**Pink**	0.45		-	-	-
15	New cover strips + board	-	-	-		*400*	*200*	*100*
Subtotal Newly Added Value R_C				**3.206**		*1250*	*500*	*300*
Total Existing and New R_C Values				**4.686**		***Total Cost 10 m^2***		***2050***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***437***

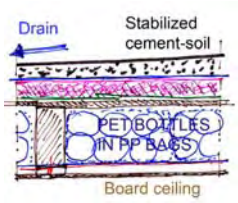
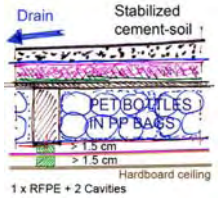
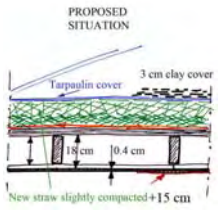
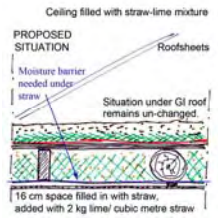
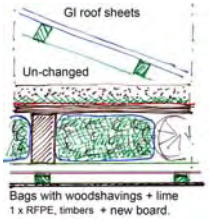
Insulation value is suitable for altitudes up to 4100 m, according to recommendation.

Remarks:

- Under the open GI cover, the outside thermal insulation is dry and transmission higher.
- The space under the roof can still be used as storage area.
- The reflective foil works at the same time as a moisture barrier.

COMPARISON TABLE OF EXAMPLE ROOFS #15 – #21

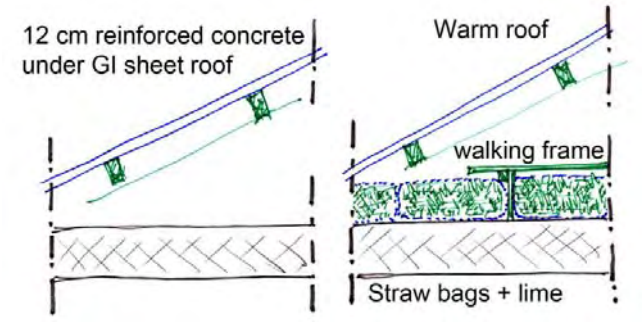
Roof designs with **additional insulation**.

#	Mini Picture of Construction Design	Description	Added R_C = m^2.K/W	Total Insulation Value	Total Cost of Added Insulation	Ratio = Total Cost / R_C Total
Roof # 15		Planks, tree bark, clay-soil straw mixture, waperproof plastic, stabilized cement-soil, PET bottles in bags, plastic, hardboard.	**1.99**	**2.45**	**1470**	**601**
Roof # 16		Planks, tree bark, clay-soil straw mixture, waperproof plastic, stabilized cement-soil, PET bottles, plastic, 1 x RFPE, 2 x cavity, hardboard.	**2.79**	**3.25**	**2220**	**683**
Roof # 17		Under open GI sheet roof + 1 x RFPE under existing ceiling, new hardboard.	**0.99**	**2.12**	**1550**	**732**
Roof # 18		Under open GI sheet roof + 2 x RFPE under existing ceiling, new hardboard.	**1.53**	**2.65**	**2300**	**867**
Roof # 19		Under open GI sheet roof, cleaning and adding to traditional basis, straw + lime over plastic foil.	**1.41**	**2.89**	**800**	**277**
Roof # 20		Under open GI sheet, filling in of traditional timber ceiling with 16 cm straw + lime over new plastic foil.	**2.24**	**3.72**	**1600**	**430**
Roof # 21		Under open GI sheet, filling in of traditional timber ceiling with 16 cm straw + lime over new 1 x RFPE and ceiling.	**3.21**	**4.69**	**2050**	**437**

Compare the various designs with the insulation values and costs, suitable for a given altitude.

Thermal Insulation Example Roof #22 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include roof support structure.

Roof #22: Under open GI sheet, bags with straw + lime, walking frame. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Reinforced concrete roof	0.12	0.6	0.72				
3	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.89**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Plastic bags with wood shavings or loose straw	0.20	12.5	2.5		*400*	*100*	*50*
11	Walking platform	-	-	-		*500*	*200*	*100*
	Subtotal Newly Added Value R_C			**2.50**		*900*	*300*	*150*
	Total Existing and New R_C Values			**3.39**		***Total Cost 10 m^2***		***1350***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***398***

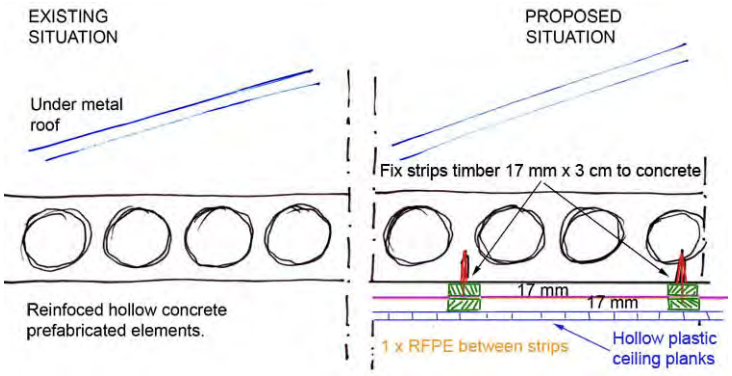
Insulation value is suitable for altitudes up to 2600 m, according to recommendation.

Remarks:

- The heavy concrete works as a very large heat storage area and stabilizes the room temperature. On the other hand, the ceiling in this building will absorb a large amount of heat before it reaches room temperature.
- When the concrete roof is supported on the outside walls, the warmth from the concrete will flow into these walls and outside. This will cause a cold zone in the concrete near the wall and may be the location where condensation will form.
- Under the open GI cover, the outside thermal insulation needs to remain dry on the sides.
- When the GI sheet roof is fully closed and an attic is created, the additional insulation value of that enclosed space can be estimated at R_C = 0.2 m^2.K/W.
- The space under the roof can still be used as storage area with the platform.
- If the straw or wood shavings are compressed, the insulation value will be lower. For that reason, a timber floor is needed for the walking area.
- The plastic bags should never be exposed to the sun because the UV light destroys the plastic.

Thermal Insulation Example Roof #23 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof supporting structure.

Roof #23: Under GI sheet, hollow concrete, 1 x RFPE, 2 x cavity on strips under existing ceiling, new plastic panel. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Hollow prefab concrete	0.15	0.86	0.13				
3	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.30**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing plugs into ceiling	-	-	-		*100*	*200*	*50*
11	Wooden supports 2 x 3 cm cavity GBM-RFPE	>0.017	**Pink**	0.45		*150*	*100*	*50*
12	1 x RFPE	0.003	22	0.066		*600*	*100*	*50*
13	Wooden supports 2 x 3 cm cavity GBM-RFPE	>0.017	**Pink**	0.45		*150*	*100*	*50*
14	Fixing materials ceiling	-	-	-		*100*	-	-
15	Wooden strips 1.7 x 3 cm	-	-	-		*150*	*100*	*50*
16	PVC 8 mm hollow panels	0.008	20	0.16		*800*	*200*	*100*
Subtotal Newly Added Value R_C				**1.126**		*2050*	*800*	*350*
Total Existing and New R_C Values				**1.426**		***Total Cost 10 m^2***		***3200***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***2244***

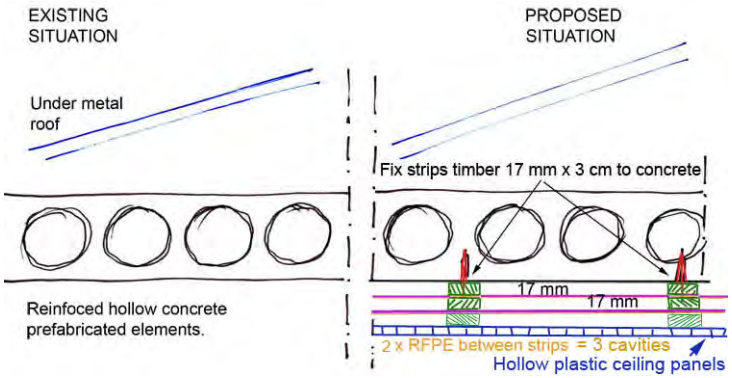
Insulation value is still inadequate for 1500 m altitude.

Remarks:

- Adding a thick straw layer on the outside will improve the insulation.
- The concrete will be cold where supported on the outside walls due to heat leakage.
- Under the full GI roof cover, the outside thermal insulation is dry and transmission higher.
- The space under the roof can still be used as storage area or insulation added.
- The single reflective foil works as a moisture barrier.
- The plastic panel is at the same time a finishing; painting is not required.

Thermal Insulation Example Roof #24 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof supporting structure.

Roof #24: Under GI sheet, hollow concrete, 2 x RFPE, 3 x cavity on strips under existing ceiling, new plastic panel. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.07				
2	Hollow prefab concrete	0.15	0.86	0.13				
3	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.30**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing plugs into ceiling	-	-	-		*100*	*200*	*50*
11	Wooden supports 2 x 3 cm cavity GBM-RFPE	>0.017	**Pink**	0.45		*150*	*100*	*50*
12	1 x RFPE	0.003	22	0.066		*600*	*100*	*50*
13	Wooden supports 2 x 3 cm cavity HRF-RFPE	>0.017	**Blue**	0.46		*150*	*100*	*50*
14	1 x RFPE	0.003	22	0.066		*600*	*100*	*50*
15	Wooden strips 2 x 3 cm cavity GBM-HRF	-	**Pink**	0.45		*150*	*100*	*50*
16	1 x RFPE	0.003	22	0.066		*600*	*100*	*50*
17	Fixing materials ceiling	-	-	-		*100*	-	-
18	PVC 8 mm hollow panels	0.008	20	0.16		*800*	*200*	*100*
Subtotal Newly Added Value R_C				**1.718**		*3250*	*1000*	*450*
Total Existing and New R_C Values				**2.018**		***Total Cost 10 m^2***		***4700***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***2329***

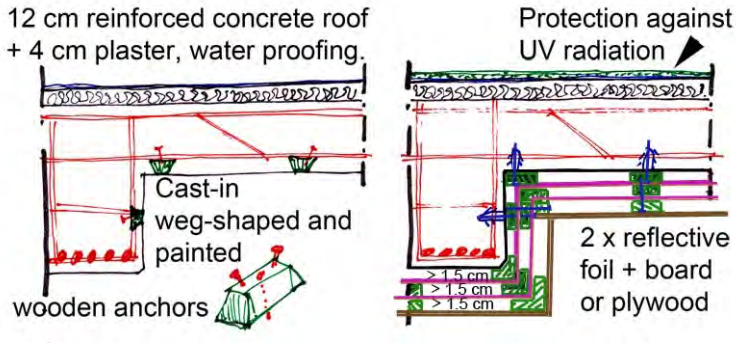
Insulation value is just inadequate for 1500 m altitude, according to recommendation.
For higher latitudes outside insulation is necessary.

Remarks:

- Under the full GI roof cover, the outside thermal insulation is dry and transmission higher.
- The space under the roof can still be used as storage area or insulation added.
- The plastic panel is at the same time a finishing; painting is not required.

Thermal Insulation Example Roof #25 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #25: Reinforced concrete with beam, 2 x RFPE on strips, 3 x cavity, board or plywood. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Asphalt paper, bitumen	0.004	8.3	0.033				
3	Cement floor cover, dry	0.04	1.0	0.04				
4	Reinforced concrete	0.12	0.6	0.072				
5	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.285**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*100*	*300*	*100*
11	Wooden supports 2 x 3 m cavity GBM-RFPE	>0.015	**Pink**	0.45		*150*	*100*	*50*
12	First RFPE	0.003	22	0.066		*600*	*100*	*50*
13	Wooden supports 2 x 3 m cavity HRF-RFPE	>0.015	**Blue**	0.46		*150*	*100*	*50*
14	Second RFPE	0.003	22	0.066		*600*	*100*	*50*
15	Wooden strips 2 x 3 cm	>0.015	**Pink**	0.45		*150*	*100*	*50*
16	Fixing materials ceiling	-	-	-		*100*	-	-
17	Board or plywood	0.004	7	0.028		*300*	*200*	*100*
18	Reflective gravel protection	0.01	0.5	0.005		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**1.525**		*2350*	*1100*	*500*
Total Existing and New R_C Values				**1.81**		***Total Cost 10 m^2***		***3950***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***2182***

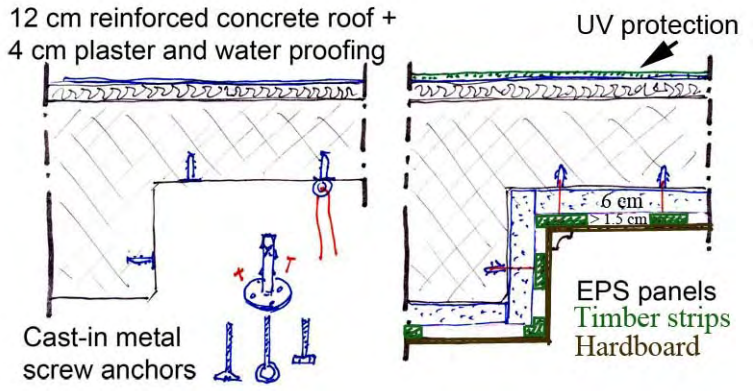
Insulation value is not yet sufficient for 1500 m altitude. Additional insulation on top is required.

Remarks:

- For new constructions, wedge-shaped hardwood anchors are to be cast in the concrete.
- Quality of fitting of the ceiling anchors depends largely on the equipment used.
- Beams also need to be insulated because they will otherwise act as large heat loss areas.

Thermal Insulation Example Roof #26 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #26: Reinforced concrete, 6 cm EPS panels, cavity strips, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Asphalt paper, bitumen	0.004	8.3	0.033				
3	Cement floor cover, dry	0.04	1.0	0.04				
4	Reinforced concrete	0.12	0.6	0.072				
5	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.285**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*100*	*300*	*100*
11	EPS panels	0.06	25	1.50		*300*	*100*	*50*
12	Wooden supports 2 x 3 cm	>0.015	**Black**	0.16		*150*	*100*	*50*
13	Fixing materials ceiling	-	-	-		*100*	-	-
14	Hardboard or plywood	0.004	7	0.028		*300*	*200*	*100*
15	Reflective gravel protection	0.01	0.5	0.005		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**1.693**		*1150*	*800*	*350*
Total Existing and New R_C Values				**1.978**		***Total Cost 10 m^2***		***2300***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***1163***

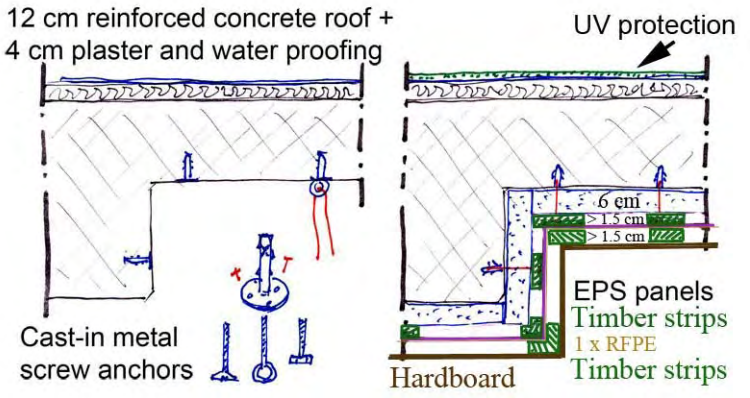
Insulation value is just sufficient for 1500 m altitude, according to recommendation.

Remarks:

- For new constructions, screw tube anchors are to be cast in the concrete.
- Quality of fitting of the ceiling anchors depends largely on the equipment used.
- Beams also need to be insulated because otherwise they will act as large heat loss areas.
- Asphalt paper or bitumen coating on the roof needs good solar protection (UV radiation).
- Increasing the thickness of the EPS panels will increase the insulation value.

Thermal Insulation Example Roof #27 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #27: Reinforced concrete, 6 cm EPS panels, cavity, 1 x RFPE, cavity strips, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Asphalt paper, bitumen	0.004	8.3	0.033				
3	Cement floor cover, dry	0.04	1.0	0.04				
4	Reinforced concrete	0.12	0.6	0.072				
5	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.285**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*100*	*300*	*100*
11	EPS panels	0.06	25	1.50		*300*	*100*	*50*
12	Wooden supports 2 x 3 cm GBM-RFPE	>0.015	**Pink**	0.45		*150*	*100*	*50*
13	1 x RFPE	0.003	22	0.066		*600*	*100*	*50*
14	Wooden supports 2 x 3 cm	>0.015	**Pink**	0.45		*150*	*100*	*50*
15	Fixing materials ceiling	-	-	-		*100*	-	-
16	Hardboard or plywood	0.004	7	0.028		*300*	*200*	*100*
17	Reflective gravel protection	0.01	0.5	0.005		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**2.499**		*1900*	*1000*	*450*
Total Existing and New R_C Values				**2.784**		***Total Cost 10 m^2***		***3350***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***1203***

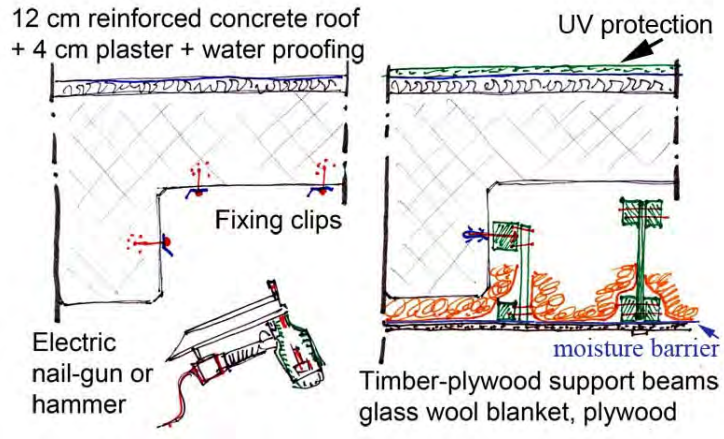
Insulation value is sufficient for 2200 m altitude, according to recommendation.

Remarks:

- Beams also need to be insulated because otherwise they will act as large heat loss areas.
- Asphalt paper or bitumen coating on the roof needs good solar protection (UV radiation).

Thermal Insulation Example Roof #28 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #28: Reinforced concrete, timber support frames, 8 cm glass wool blanket, moisture barrier, hardboard. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Asphalt paper, bitumen	0.004	8.3	0.033				
3	Cement floor cover, dry	0.04	1.0	0.04				
4	Reinforced concrete	0.12	0.6	0.072				
5	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.285**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*200*	*200*	*100*
11	Timber beams, cavity GBM	>0.20	**Black**	0.16		*1000*	*300*	*100*
12	Fixing materials ceiling	-	-	-		*100*	-	-
13	Glass wool blanket	0.08	25	2.0		*300*	*100*	*50*
14	Board or plywood	0.004	7	0.028		*300*	*200*	*100*
15	Reflective gravel protection	0.01	0.5	0.005		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**2.193**		*2100*	*900*	*400*
Total Existing and New R_C Values				**2.478**		***Total Cost 10 m^2***		***3400***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***1372***

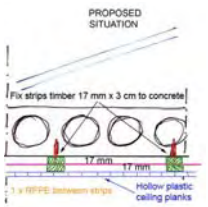
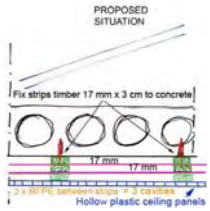
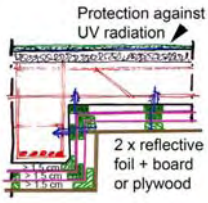
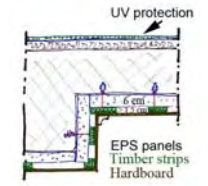
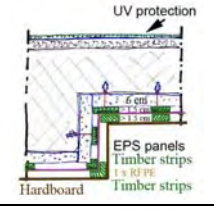
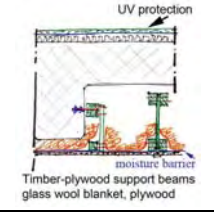
Insulation value sufficient for 1900 m altitude, according to recommendation.

Remarks:

- Using a concrete nail gun to fix the anchors will speed up the work.
- Beams need to be well supported in side walls, but carry little weight.
- Asphalt paper or bitumen coating on the roof needs good solar protection (UV radiation).
- Increasing the thickness of the glass wool will increase the insulation value.

COMPARISON TABLE OF EXAMPLE ROOFS #22 – #28

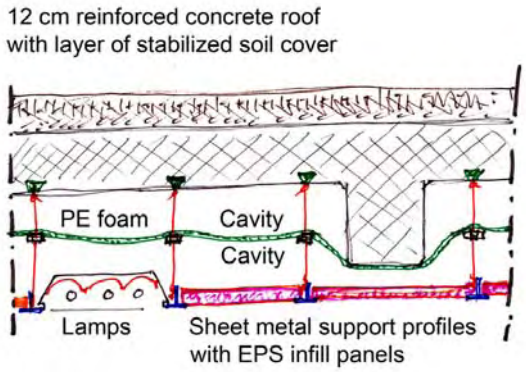
Roof designs with **additional insulation**.

#	Mini Picture of Construction Design	Description	Added R_C = m^2.K/W	Total Insulation Value	Total Cost of Added Insulation	Ratio = Total Cost / R_C Total
Roof # 22		Under open GI sheet, bags with straw + lime, walking frame.	**2.50**	**3.39**	**1350**	**398**
Roof # 23		Under GI sheet, hollow concrete, 1 x RFPE, 2 x cavity on strips under ceiling, new plastic panel.	**1.13**	**1.43**	**3200**	**2244**
Roof # 24		Under GI sheet, hollow concrete, 2 x RFPE, 3 x cavity on strips under existing ceiling, new plastic panel.	**1.72**	**2.02**	**4700**	**2329**
Roof # 25		Reinforced concrete with beam, 2 x RFPE on strips, 3 x cavity, board or plywood.	**1.53**	**1.81**	**3950**	**2182**
Roof # 26		Reinforced concrete, 6 cm EPS panels, cavity strips, hardboard.	**1.69**	**1.98**	**2300**	**1163**
Roof # 27		Reinforced concrete, 6 cm EPS panels, cavity, 1x RFPE, cavity strips, hardboard.	**2.50**	**2.78**	**3350**	**1203**
Roof # 28		Reinforced concrete, timber support frames, 8 cm glass wool blanket, moisture barrier, hardboard.	**2.19**	**2.48**	**3400**	**1372**

Compare the various designs with the insulation values and costs, suitable for a given altitude.

Thermal Insulation Example Roof #29 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #29: Reinforced concrete, 2 x cavity GBM, suspended ceiling of EPS panels with lamps. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilized soil cover, wet	0.08	0.8	0.064				
3	Reinforced concrete	0.12	0.6	0.072				
4	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.276**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*200*	*200*	*100*
11	Wooden supports beam	-	-	-		*100*	*100*	*50*
12	Cavity horizontal GBM	0.1	**Black**	0.16		-	-	-
13	PE + fixing materials	0.007	22	0.176		*200*	*100*	*50*
14	Cavity horizontal GBM	0.1	**Black**	0.16		-	-	-
15	Metal support frame	-	-	-0.05		*500*	*200*	*100*
16	H-EPS ceiling panels	0.04	20	0.80		*500*	*200*	*100*
17	Metal lamp fittings	-	-	-0.10		-	-	-
	Subtotal Newly Added Value R_C			**1.146**		*1500*	*800*	*400*
	Total Existing and New R_C Values			**1.422**			***Total Cost 10 m^2***	***2700***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***1899***

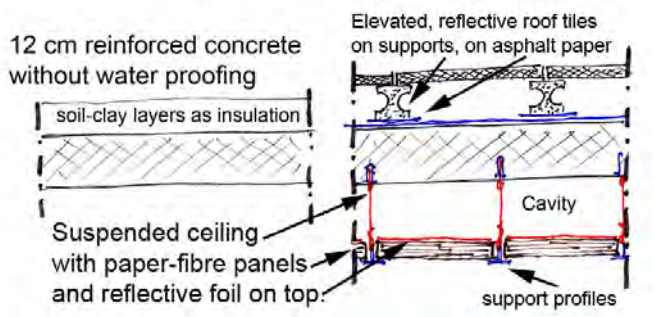
Insulation value is sufficient for altitudes up to 900 m only, according to recommendation.

Remarks:

- Stabilized soil layer on roof reduces heat gain of the concrete by the summer sun.
- Increased roof weight by thick soil layers is not advised in earthquake areas.
- The sheet metal support strips in the ceiling panels will reduce the insulation value.
- Light fittings cause openings in the ceiling insulation and reduction of the cavity value.
- A reflective foil on top of the PE foam will greatly reduce heat gain of the room in summer.

Thermal Insulation Example Roof #30 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #30: Reinforced concrete, 1 x cavity, suspended ceiling of 4 cm paper fibre panels, RFPE. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilized soil cover, wet	0.08	0.8	0.064				
3	Reinforced concrete	0.12	0.6	0.072				
4	Inside transmission factor	-	-	0.10				
	Subtotal Existing Construction R_C			**0.276**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Fixing anchors in concrete	-	-	-		*200*	*200*	*100*
11	Metal support frame	-	-	-0.05		*500*	*200*	*100*
12	Cavity GBM-RFPE	0.2	**Pink**	0.45		-	-	-
13	Paper fibre ceiling panels	0.05	12	0.60		*500*	*200*	*100*
14	RFPE on top panels	0.003	22	0.066		*600*	*100*	*50*
15	PE + fixing materials	0.007	22	0.154		*200*	*100*	*50*
16	Asphalt bitumen	0.004	8.3	0.033		*200*	*100*	*50*
17	Concrete support, tiles	-	-	-		*800*	*200*	*100*
	Subtotal Newly Added Value R_C			**1.253**		*3000*	*1100*	*550*
	Total Existing and New R_C Values			**1.529**		***Total Cost 10 m^2***		***4650***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***3041***

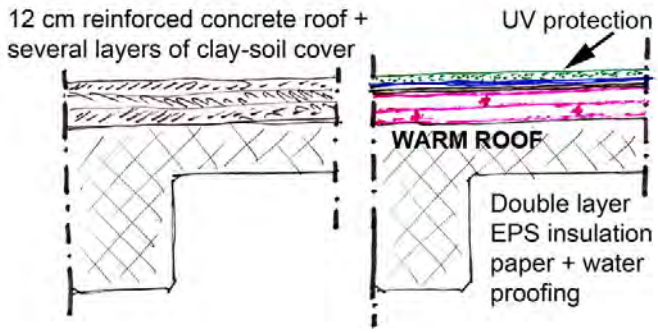
Insulation value is sufficient for altitudes up to 1000 m only, according to recommendation.

Remarks:

- Stabilized soil layer removed and replaced with elevated and ventilated tile floor.
- The ventilated floor strongly reduces the heat load on the concrete during the summer.
- The ventilated tile floor protects the asphalt paper from direct solar (UV) radiation.
- The reflective foil on top of the suspended sheets will substantially reduce heat gain of the room in the summer provided it remains clean without dust.
- Raising the RFPE 2 cm above the suspended panels will increase R_C = 0.45 m^2.K/W by which the roof design becomes adequate for 1500 m altitude.

Thermal Insulation Example Roof #31 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof construction itself.

Roof #31: Reinforced concrete, H-EPS (10 cm), cover, asphalt bitumen seal, UV protection gravel. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Stabilized soil cover, wet	0.12	0.8	0.096		remove		
3	Reinforced concrete	0.12	0.6	0.072				
4	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.308**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-2	Remove soil layers	-	-	-0.096		-	-	*self*
10	High density EPS	0.10	22	2.2		*600*	*200*	*100*
11	Paper layer	0.0002	-	-		*100*	*50*	*50*
12	Asphalt bitumen seal	0.004	8.3	0.033		*200*	*100*	*50*
13	UV protective gravel	0.01	0.5	0.005		*200*	*100*	*50*
Subtotal Newly Added Value R_C				**2.142**		*1100*	*450*	*250*
Total Existing and New R_C Values				**2.45**		***Total Cost 10 m^2***		***1800***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***735***

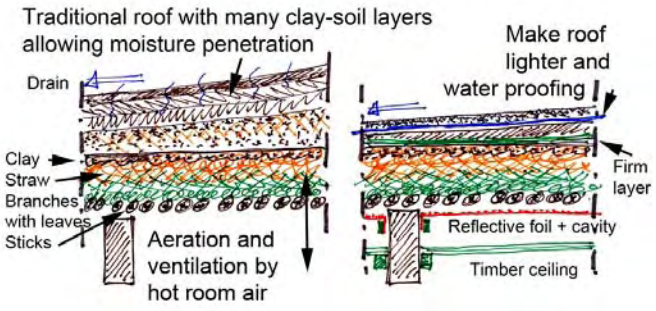
Insulation value is sufficient for altitudes up to 1900 m, according to recommendation.

Remarks:

- For reinforced concrete roofs, outside insulation is quickly applied and therefore cost-efficient.
- Stabilized soil layer removed will lighten the roof (earthquake area).
- The (white) gravel layer protects the asphalt from direct solar (UV) radiation.
- When the roof is protected from heating up by the sun, it avoids cracks along the walls.
- The concrete roof serves as a large heat storage for the inside air.
- The zone where the concrete roof is laid on the cold outside walls causes large heat leaks and will create condensation along the walls, unless the concrete is fully insulated all sides.

Thermal Insulation Example Roof #32 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C= 0.1 m^2.K/W.

Roof insulation applied on the inside.

Cost calculation does not include the roof support structure.

Roof #32: Sticks, branches with leaves, straw, straw-clay, clay-soil layers, cavity, RFPE, cavity, plank ceiling. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Several wet clay-soil layers	0.30	0.77	0.231		remove and dry self		
3	Straw-clay layer, moist	0.05	1.1	0.055		remove and dry self		
4	Straw layer, little moist	0.15	5	0.75		remove and dry self		
5	Branches with leaves	0.1	8.3	0.83				
6	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**2.006**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
-2	Remove clay-soil layers	-	-	-0.231		-	-	-
-3	Straw-clay layer, moist	-0.05	1.1	-0.055				
-4	Straw layer, little moist	-0.15	5	-0.75				
4	New dry straw	0.15	10	1.50		-	-	*self*
10	Plastic foil 0.2 mm	0.0002	-	-		*100*	*20*	*10*
11	Stabilised cement-soil, wet	0.04	0.6	0.024		*100*	*100*	*50*
12	Equalizing-slope, dry	0.04	1.0	0.04		*100*	*100*	*50*
13	Cavity GBM-RFPE	>0.17	Pink	0.45		-	-	-
14	Reflective foil, 3 mm PE	0.003	22	0.066		*600*	*40*	*20*
15	Cavity GBM-HRF	> 0.17	Blue	0.46		-	-	-
16	Timber ceiling	0.02	5.6	0.112		*150*	*100*	*50*
Subtotal Newly Added Value R_C				**1.616**		*1050*	*360*	*180*
Total Existing and New R_C Values				**3.622**		***Total Cost 10 m^2***		***1590***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***439***

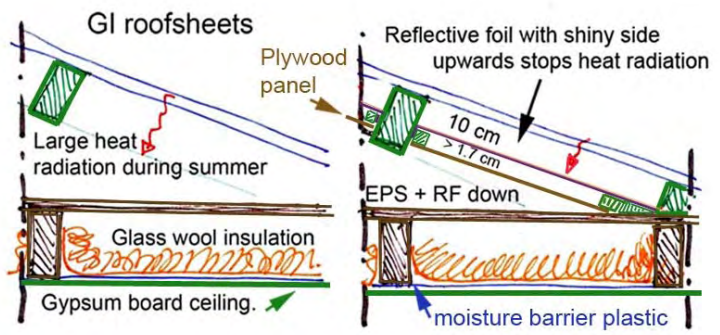
Insulation value is sufficient for altitudes up to 3100 m, according to recommendation.

Remarks:

- Making the roof lighter is essential in an earthquake area.
- The roof should be waterproof and draining well to the outside of the roof and support wall.

Thermal Insulation Example Roof #33 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied under sheets.

Cost calculation does not include roof support structure.

Roof #33: Under closed GI roof, 1 x RFPE with plywood added. Different summer-winter values. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Metal roof, closed	0.0003	0.02	0.000				
3	Cavity of enclosed attic	>0.5	**Black**	0.16				
4	Plank flooring	0.025	5.00	0.125				
5	Cavity, horizontal GBM	0.12	**Black**	0.16				
6	Glass wool blanket, loose	0.06	25	1.5				
7	Plastic moisture barrier	0.003	-	-				
8	Gypsum board ceiling	0.008	1.6	0.013				
9	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**2.098**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	RFPE outside under metal	0.003	22	0.066		*600*	*100*	*50*
11	2 x Cavity GBM-RFPE	>0.15	**Pink**	0.9		-	-	-
12	Plywood sheets 2 x 2 strips	0.04	5	0.2		*400*	*100*	*50*
Subtotal Newly Added Value R_C				**1.166**		*1000*	*200*	*100*
Total Existing and New R_C Values				**3.264**		***Total Cost 10 m^2***		***1300***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**ΔT**	Ratio = Total Cost / R_C Total		***398***

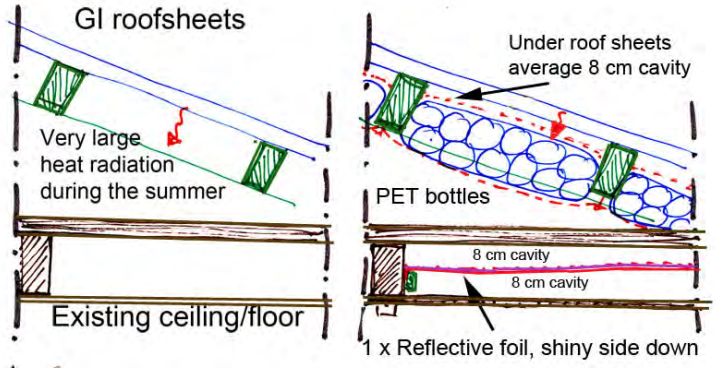
Insulation value is sufficient for altitudes up to 2700 m, according to recommendation.

Remarks:

- The fully enclosed attic area under the non-insulated GI roof cover will become very hot during the summer period due to very high temperature of the GI sheets.
- The outside reflective foil with cavities of 10 cm + 2 cm will strongly reduce the heat load towards the inside during the summer period. For horizontal spaces, the difference would be an additional R_C = 2.8 + 0.7 – 0.9 = 2.6 m^2.K/W. However, because the space is inclined, the actual added insulation value for the summer will be about R_C = 2.0 m^2.K/W.

Thermal Insulation Example Roof #34 Old and New Construction

Recommended Minimum Average R_C Value for Roofs = {0.5 + (altitude m/1000 m)} m^2.K/W



For each hour less than 5 hrs sun, the insulation value needs to be increased with R_C = 0.1 m^2.K/W.

Roof insulation applied on the outside.

Cost calculation does not include roof support structure.

Roof #34: Under closed GI roof, bags with PET bottles, wire-mesh, inside roof 1 x RFPE. Different summer-winter values. Thickness x R_M = R_C					New Value	Surface Unit of Estimation = **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04				
2	Metal roof, closed	0.003	0.02	0.000				
3	Cavity of enclosed attic	>0.5	**Black**	0.17				
4	Plank flooring	0.025	5.00	0.125				
5	Cavity ceiling GBM	>0.015	**Black**	0.16				
6	Hardboard ceiling	0.004	7	0.028				
7	Inside transmission factor	-	-	0.10				
Subtotal Existing Construction R_C				**0.623**				
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp °C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	Cavity under roof GBM	>0.015	**Black**	0.16		*300*	*100*	*50*
11	Bags with PET bottles	0.10	12	1.20		*250*	*100*	*50*
12	Wire-mesh support bags	-	-	-		*50*	*100*	*50*
13	Cavity horiz. GBM-RFPE	0.08	**Pink**	0.45		-	-	-
14	RFPE shiny side down	0.003	22	0.066		*600*	*100*	*50*
15	Cavity horiz. GBM-RFPE	0.08	**Pink**	0.45		-	-	-
Subtotal Newly Added Value R_C				**2.326**		*1200*	*400*	*200*
Total Existing and New R_C Values				**2.949**		***Total Cost 10 m^2***		***1800***
Altitude Above Sea Level _____m		Recommended R_C value		2.0--2.5 3.0--3.5 4.0--4.5	**△T**	Ratio = Total Cost / R_C Total		***610***

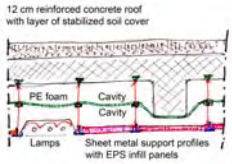
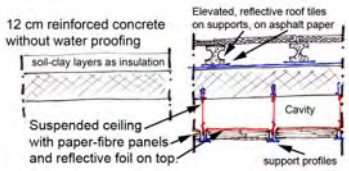
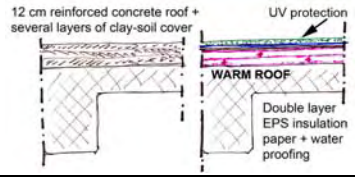
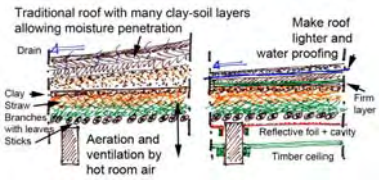
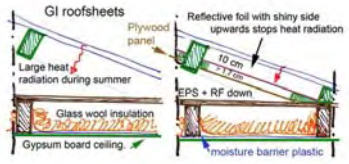
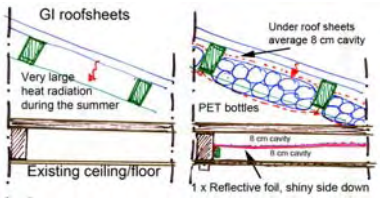
Insulation value is sufficient for altitudes up to 2400 m, according to recommendation.

Remarks:

- The outside bags with PET bottles will also strongly reduce the heat load towards the inside during the summer period. For horizontal spaces, the difference is an additional R_C = 2.5 m^2.K/W. However, because the space is inclined, the actual added insulation value for the summer will be about R_C = 2.0 m^2.K/W.
- In addition, the foil inside the middle of the floor will add another 2 x 2.5 – 0.45 m^2.K/W = 4.5 m^2.K/W as additional insulation for the summer period only.

COMPARISON TABLE OF EXAMPLE ROOFS #29 – #34

Roof designs with **additional insulation**.

#	Mini Picture of Construction	Description	Added R_C = m^2.K/W	Total Insulation Value	Total Cost of Added Insulation	Ratio = Total Cost / R_C Total
Roof # 29		Reinforced concrete, 2 x cavity GBM, suspended ceiling of EPS panels with lamps.	**1.15**	**1.42**	**2700**	**1899**
Roof # 30		Reinforced concrete, 1 x cavity, suspended ceiling of 4 cm paper fibre panels, RFPE.	**1.25**	**1.53**	**4650**	**3041**
Roof # 31		Reinforced concrete, H-EPS (10 cm), cover, asphalt bitumen seal, UV protection gravel.	**2.14**	**2.45**	**1800**	**735**
Roof # 32		Sticks, branches with leaves, straw, straw-clay, clay-soil layers, cavity, RFPE, cavity, plank ceiling.	**1.62**	**3.62**	**1590**	**439**
Roof # 33		Under closed GI roof, 1 x RFPE with plywood added. Different summer-winter values.	**1.17**	**3.26**	**1300**	**398**
Roof # 34		Under closed GI roof, bags with PET bottles, wire-mesh, inside roof 1 x RFPE. Different summer-winter values.	**2.33**	**2.95**	**1800**	**610**

Empty PET Bottles – The use of empty PET bottles in sealed plastic bags (R_M = 12 m^2.K/W) or in agricultural PP fibre bags (R_M = 11 m^2.K/W) is an economical thermal insulation method. It is very light and because it is mainly collected as household waste materials for recycling, it can be obtained at low cost. Its cost packed in bags should be compared with EPS as it has about half the thermal insulation value.

The re-use of PET bottles in cavity walls and as ceiling or roof insulation will stimulate local waste collection and economy. At the same time, it will reduce non-biodegradable waste, thus cleaning up the environment in mountain villages.

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