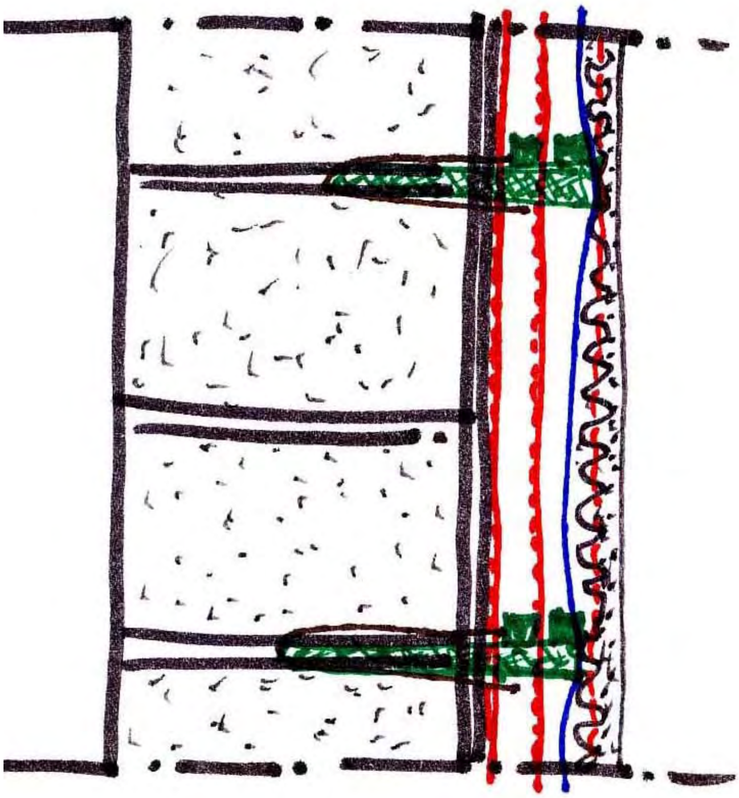
HUYS ADVIES

CALCULATION EXAMPLES OF THERMAL INSULATION

Technical Working Paper ~ Number 2



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(updated)

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Calculations made in: TJS = Tajikistan Somoni April 2011: Euro 1 = Somoni 6.60
PKR = Pakistan Rupees April 2011: Euro 1 = Rupee 120

NOTES

Changes from version August 2011

- Table with figures made into a separate document, “Technical Working Paper 3 ~ TABLES”.
- Method of calculating the heat storage has been added.

Changes from version September 2011

- The values of the thermal storage have been presented in Watt for easier understanding.
- The width/thickness of the cavities is indicated in the designs.
- Each cavity is calculated separately depending on the type of enclosing materials.
- Additional examples of insulation designs have been included and compared.

Changes from version February 2012

- Chapters on inside/outside roof insulation and thermal bridges have been added.

Picture on Cover Page

Sketch used during a training course for the calculation of a wall insulation, showing a cement block wall with two reflective foils, plastic foil and cement plaster on wire mesh. The quality of this insulation option can be improved by having another cavity space of 1.5 cm between the cement blocks and the first reflective foil.

The tables of insulation values (Technical Working Paper #3) for materials and cavities are important tools in the calculation of the different types of constructions, both old and new.
Only by comparing the old and new insulation value, can the house owner make an informed decision on the choice of improvement.

INTRODUCTION

The Technical Working Papers incorporate knowledge gained from more than 30 years experience in project development and implementation in several development countries. Much time has been dedicated to providing practical information on how to realise beneficial, low-cost solutions for the inhabitants of the mountain regions of the Himalayas.

Introducing technologies without adapting these to local circumstances in not always possible because of socio-economic circumstances. Existing, proven technical solutions have been modified taking into consideration local customs, skills and building materials; ease of transport; availability of materials in the local markets of the mountain regions and possibility of introducing new items; and the affordability by the village people.

Making the buildings more comfortable and reducing Internal Air Pollution (IAP) in traditional and new high altitude buildings are important aspects linked to thermal insulation. The document incorporates the best experiences in house improvements to improve the life of other people living in similar and often remote mountain regions.

> For low-income people, it is important to find appropriate solutions taking into consideration the local economy of the people and local entrepreneurs, as well as the available skills, tools, materials and other resources, to create affordable products for an improved living conditions and livelihood.

This Technical Working Paper #2 gives the basic method of calculating the thermal insulation value of a building construction element, such as a roof or wall. Without such a calculation, it will be difficult to <u>compare the old with the new insulation value</u> and make an informed decision about the planned insulation action. This paper is linked with Technical Working Paper #1 ~ BASICS and #3 ~ TABLES.

The working papers can eventually be used as the basis for <u>curriculum development</u>. Educating professionals in the calculation of thermal insulation values is important to enable making an informed assessment about choices and costs of thermal insulation.

This paper covers the general principles of thermal insulation and includes the following themes:

- Calculation of thermal insulation values.
- Calculation of the dew point inside constructions.
- Calculation of the heat capacity of constructions.

All technical advisers should be able to understand the implications of certain types of thermal insulation and the resulting insulation values as a relation to the material and installation costs. Key persons in the villages need to be able to provide the right information to their peers to avoid expenses having insufficient effect.

1. CALCULATION OF INSULATION VALUES

For the proper understanding between the different thermal insulation options, it is essential to relate the cost of the option with the insulation value of a new or improved construction. The cost needs to include the materials bought and supplied by the owner and the skilled and unskilled labour. In this way, the house owner can study whether he/she supplies some of the materials and/or unskilled labour, or contracts the entire house improvement from local entrepreneurs.

Fact sheets are important instruments. They should include a design and calculation chart divided into the existing construction and the new construction, and indicate what the additional costs are for the house owner. When retrofitting an existing building, some old, heavy roof layers and rubble-clay masoned walls will probably have to be removed; the cost of doing so should be included as well.

For typical ceiling, roof or wall insulations, basic price indications can be presented for 10 m^2 building sections. Based on these figures, the actual cost of the real-size constructions can be estimated.

1.1 Relating the Construction Cost to the Added Insulation Value

In many cases, the villagers only look at the cost of an insulation option. However, without relating the added insulation value to the actual cost, no realistic comparison can be made.

Comparing one insulation option of PKR 400/m^2 with an added insulation value of R_C = 1.4 m^2.K/W gives a cost/“insulation value” ratio of PKR : R_C = 400 : 1.4 = 286.
Another type of insulation option of PKR 480/m^2 with an added insulation value of 2.4 m^2.K/W gives a cost/“insulation value” ratio of PKR : R_C = 480 : 2.4 = 200, being a lower cost ratio per added insulation value and thus a more economical (better) investment.

By making a calculation table of the existing and new insulation option, the total cost can be analysed against the total expected insulation value. That value should be minimal the recommended insulation value for the given altitude. Including a drawing of the old and new situation would assist the house owner in visualizing the difference.

The following is a small excerpt of the complete building materials table from Technical Working Paper #3 ~ TABLES.

The specific weight is given in the second column and the $R_{Material}$ value of that material in the last column. The total insulation value of the construction can be calculated by adding all the R_C values and the specific transmission factors for inside and outside constructions.

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_M=m.K/W
6	**1**	**Air, low humidity**	**0.025**	**40**
85	**1100**	**Adobe blocks (dried clay soil)**	**0.48**	**2.08**
87	*1200*	*Sand-soil cement mixture (volumes 10:1), humid, moist*	*1.2*	*0.83*
88	**2000**	**Sand-cement block solid, low quality, dry**	**0.65**	**1.54**
97	**800**	**Gypsum board (paper two sides), “dry wall” panels**	**0.6**	**1.66**
102	**1900**	**Sand-cement plaster on walls (volumes 8:1), dry**	**1.3**	**0.77**
106	*1800*	*Non-dressed stone masonry, 10% cement mortar (8:1) gaps*	*1.5*	*0.66*

W = Watt, m = meter, K = Kelvin, R_M = 1/λ. Calculation of R_C = R_M x thickness in m, value in m^2.K/W
Bold are tested figures. *Cursive are estimates based on comparison.*

The material to air transmission values are also given in Technical Working Paper #3 as follows:

	Transmission Resistance	λ=W/m.K	R_C=m²$.K/W$
Smooth Surface	**Horizontal from room air to wall or window ← & →**	**inclusive**	**0.13**
	Downwards from room air to floor ↓↓↓	**inclusive**	**0.17**
	Upwards from room air to ceiling or roof ↑↑↑	**inclusive**	**0.10**
Smooth Surface	**Outside transmission resistance to wall, normal climate**	**inclusive**	**0.04**
Rough Surface	Outside transmission resistance to wall, very windy situation	inclusive	0.02
Under Shelter	Outside transmission resistance to the flat roof, low wind	inclusive	0.07

The first section of the existing construction (material A + B, etc.) can be filled out by multiplying the thickness of the material in meters by the R_M value. The light green boxes are added up and totalled in the dark green box. The cost of removing the old materials can be added in the right-hand section.

In the second section, the new construction material (C, D, etc.) is filled in with the same calculation; however, the inside and outside transmission values do not need to be added because these are already mentioned in the first section. The two dark green boxes are added up and totalled in the blue box.

The new material costs are listed in the right-hand side of the table. In the examples, all the values have been calculated for a 10 m² section, being a common surface size in houses. The costs are divided into material, skilled labour (hired craftsman or contractor) and unskilled labour. Finishing costs are also added to the second section, such as electrical wiring, plumbing, paint, transport and cleaning, which of course do not have thermal insulation values.

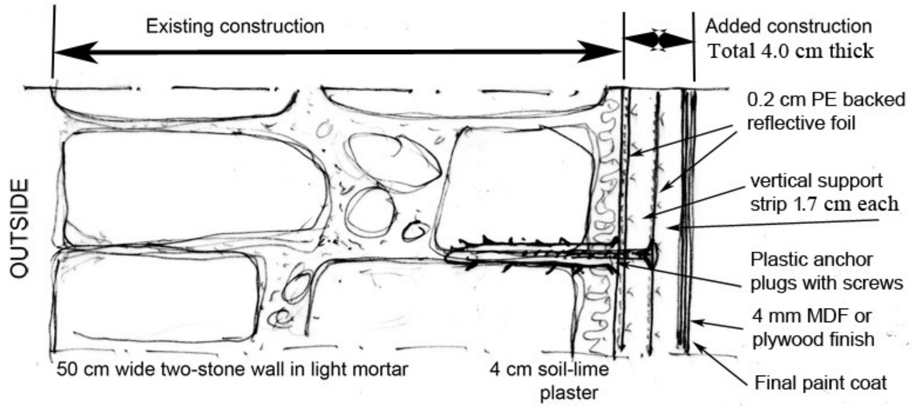
The total of each of the three columns are added up and the sum written in the yellow box.

Construction: Description of new insulation construction Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in €	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	=	=	0.04			
2	Material A						
3	Material B						
	Inside transmission factor	=	=	0.13			
	Subtotal Existing Construction R_C						
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in €	Skilled Labour Cost	Non-skilled Labour
10	Material C						
11	Material D						
12	Cavity						
13	Finishing Material E						
	Subtotal Newly Added Value R_C						
	Total Existing and New R_C Values				***Total Costs 10 m²***		
	Altitude Above Sea Level Building 1500 m	Recommended R_C Value		2.0	Ratio = Total Cost / R_C Total		

The ratio of the effectiveness of the new insulation value is calculated by dividing the amount in the yellow box by the blue box and placed in the pink box.

A sample drawing and calculation table is given on the following page.

Example 1a



RFPE = Reflective Foil with PE Backing
HRF = Highly Reflective Foil
GBM = General Building Material

Construction: Two-stone wall with soil plaster inside, one RFPE against wall and one RFPE in middle, plywood finish Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Two-stone wall in light mortar	0.5	0.66	0.33			
3	Soil lime plaster inside	0.04	1.1	0.044			
	Inside transmission factor	-	-	0.13			
Subtotal Existing Construction R_C				**0.544**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	First 0.2 cm RFPE one side	0.002	22	0.044	*600*	*20*	*10*
11	1.7 cm x 3 cm support strips every 50 cm, vertical cavity HRF-RFPE	0.017	**Blue**	0.63	*100*	*30*	*15*
12	1.7 cm x 6 cm wide support strips at joining sheets locations	x	x	x	*100*	*20*	*10*
13	Plastic anchor plugs with 10 cm long screws to fix support strips	x	x	x	*150*	*80*	*40*
14	Second 0.2 cm PE reflective foil	0.002	22	0.044	*600*	*10*	*05*
15	1 cm x 6 cm support strips at joints, vertical cavity HRF-GBM	0.017	**Pink**	0.57	*100*	*10*	*05*
16	Staples 6 mm long (25/m²)	x	x	x	*50*	*x*	*x*
17	4 mm plywood or MDF	0.04	7.1	0.284	*1200*	*60*	*30*
18	Painting white wash	x	x	x	*85*	*self*	*x*
19	Total transport costs to village	x	x	x	*400*	*100*	*x*
Subtotal Newly Added Value R_C				**1.572**	*3385*	*330*	*115*
Total Existing and New R_C Values				**2.116**	***Total Cost 10 m²***		*3830*
Altitude Above Sea Level Building 1500 m		Recommended R_C Value		2.0	Ratio = Total Cost / R_C Total		***1810***

The **Pink** and **Blue** refers to the lines of the same colour in the middle graph for vertical cavities on page 16 of HA Technical Working Paper #3 ~ TABLES.

Example 1b

When the above construction is made with an additional 1.7 cm cavity between the existing wall construction and the first reflective foil (RFPE), the insulation value as well as the cost will change.

RFPE = Reflective Foil with PE Backing
HRF = Highly Reflective Foil
GBM = General Building Material

Construction: Two-stone wall with soil plaster inside, three cavities and two RFPE in the middle, plywood finish				Thickness x R_M = R_C	Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	=	=	0.04			
2	Two-stone wall in light mortar	0.5	0.66	0.33			
3	Soil lime plaster inside	0.04	1.1	0.044			
	Inside transmission factor	=	=	0.13			
	Subtotal Existing Construction R_C			**0.544**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	1.7 cm x 3 cm support strips every 50 cm, vertical cavity GBM-RFPE	0.017	**Pink**	0.57	*100*	*30*	*15*
11	Plastic anchor plugs with 10 cm long screws to fix support strips	x	x	x	*150*	*80*	*40*
12	First 0.2 cm RFPE one side	0.002	22	0.044	*600*	*20*	*10*
13	1.7 cm x 3 cm support strips every 50 cm, vertical cavity HRF-RFPE	0.017	**Blue**	0.63	*100*	*30*	*15*
14	1.7 cm x 6 cm wide support strips at joining sheets locations	x	x	x	*100*	*20*	*10*
15	Second 0.2 cm PE reflective foil	0.002	22	0.044	*600*	*10*	*05*
16	1 cm x 6 cm support strips at joints, vertical cavity HRF-GBM	0.017	**Pink**	0.57	*100*	*10*	*05*
17	Staples 6 mm long (25/m²)	x	x	x	*50*	*x*	*x*
18	4 mm plywood or MDF	0.04	7.1	0.284	*1200*	*60*	*30*
19	Painting white wash	x	x	x	*85*	*self*	*x*
20	Total transport costs to village	x	x	x	*400*	*100*	*x*
	Subtotal Newly Added Value R_C			**2.142**	*3485*	*360*	*130*
	Total Existing and New R_C Values			**2.686**	***Total Cost 10 m²***		*3975*
	Altitude Above Sea Level Building 1500 m	Recommended R_C Value		2.0	Ratio = Total Cost / R_C Total		***1480***

The **Pink** and **Blue** refers to the lines of the same colour in the middle graph for vertical cavities on page 16 of HA Technical Working Paper #3 ~ TABLES.

Remarks: The additional cavity with reflective foil substantially increases the insulation value, but does not increase the cost very much. The effect is that the Cost/R_C ratio drops from 1810 to 1480. For high altitudes where additional thermal insulation would be required, this is a good option.

When in example 1a the first reflective foil is omitted, the calculation also changes.

Example 1c

When the above construction is made without the first reflective foil against the wall and starts with a 1.7 cm cavity between the existing wall construction and only one reflective foil (RFPE), the insulation value and the cost will reduce.

RFPE = Reflective Foil with PE Backing
HRF = Highly Reflective Foil
GBM = General Building Material

Construction: Two-stone wall with soil plaster inside, two cavities and one RFPE in the middle, plywood finish		Thickness x R_M = R_C			Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Two-stone wall in light mortar	0.5	0.66	0.33			
3	Soil lime plaster inside	0.04	1.1	0.044			
	Inside transmission factor	-	-	0.13			
	Subtotal Existing Construction R_C			**0.544**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	1.7 cm x 3 cm support strips every 50 cm, vertical cavity GBM-RFPE	0.017	**Pink**	0.57	*100*	*30*	*15*
11	Plastic anchor plugs with 10 cm long screws to fix support strips	x	x	x	*150*	*80*	*40*
12	One 0.2 cm RFPE one side	0.002	22	0.044	*600*	*20*	*10*
13	1 cm x 6 cm support strips at joints, vertical cavity HRF-GBM	0.017	**Pink**	0.57	*100*	*10*	*05*
14	Staples 6 mm long (25/m²)	x	x	x	*50*	*x*	*x*
15	4 mm plywood or MDF	0.04	7.1	0.284	*1200*	*60*	*30*
16	Painting white wash	x	x	x	*85*	*self*	*x*
17	Total transport costs to village	x	x	x	*400*	*100*	*x*
	Subtotal Newly Added Value R_C			**1.468**	*2685*	*300*	*100*
	Total Existing and New R_C Values			**2.012**	***Total Cost 10 m²***		*3085*
	Altitude Above Sea Level Building 1500 m	Recommended R_C Value		2.0	Ratio = Total Cost / R_C Total		***1533***

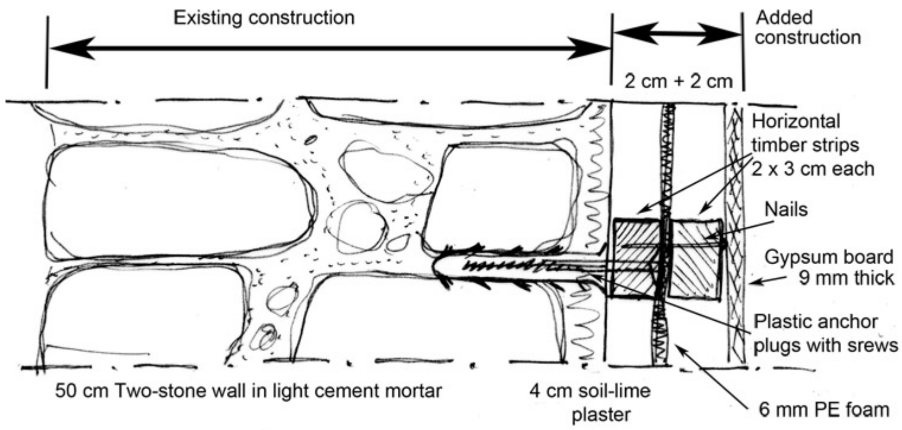
The **Pink** refers to the lines of the same colour in the middle graph for vertical cavities on page 16 of HA Technical Working Paper #3 ~ TABLES.

Remarks: The omission of the foil against the wall does not substantially reduce the insulation value, but does lower the cost (one expensive foil less). The effect is that the Cost/R_C ratio drops from 1810 (1a) to 1533. Because for a house at 1500 m altitude the R_C value of 2.0 is the proposed minimum, this is a more cost-efficient solution. For higher altitudes, this is insufficient.

Comparing the design and cost options with the insulation values gives a good indication which option is most cost-effective for the planned insulation value. However, the house owner should always strive to obtain the minimum recommended insulation value for the given altitude. The available amount of solar radiation in the winter has an influence on the minimum recommended insulation value.

Example 1d

If the house owner does not apply two reflective foils, but wants one 6 mm PE foam and 2 x 2 cm air layers behind gypsum panel boards, the calculation would be as follows:



Construction: Two-stone wall with soil plaster inside, insulated with two layers of air, PE foam and gypsum board finish Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Two-stone wall in light mortar	0.5	0.66	0.33			
3	Soil lime plaster inside	0.04	1.1	0.044			
	Inside transmission factor	-	-	0.13			
	Subtotal Existing Construction R_C			**0.544**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in PKR	Skilled Labour Cost	Non-skilled Labour
10	First air layer 2 cm vertical cavity GBM-GMB	0.02	**Black**	0.18	*x*	*x*	*x*
11	2 cm x 3 cm support strips every 50 cm horizontal (two times)	x	x	x	*400*	*60*	*30*
12	Plastic anchor plugs with 10 cm long screws to fix support strips	x	x	x	*150*	*80*	*40*
13	Nails to nail strips on each other	x	x	x	*50*	*x*	*x*
14	One 0.6 cm PE foam (damp proof)	0.006	22	0.132	*600*	*10*	*10*
15	Second air layer 2 cm, vertical cavity GMB-GBM	0.02	**Black**	0.18	*x*	*x*	*x*
16	Staples 6 mm long (5/m²)	x	x	x	*10*	*x*	*x*
17	9 mm gypsum carton board	0.009	1.66	0.015	*1000*	*60*	*100*
18	Closing joints with tape plaster	x	x	x	*200*	*100*	*x*
19	Painting white wash	x	x	x	*85*	*self*	*x*
20	Total transport costs to village	x	x	x	*400*	*100*	*x*
	Subtotal Newly Added Value R_C			**0.507**	*2895*	*410*	*180*
	Total Existing and New R_C Values			**1.051**		***Total Cost 10 m²***	*3485*
	Altitude Above Sea Level Building 1500 m	Recommended R_C Value		2.0	Ratio = Total Cost / R_C Total		***3316***

The insulation value of 1.05 is totally inadequate for the altitude.

Because the material cost is slightly lower and the insulation value is much lower, the Cost/R_C ratio is twice as high. Option 1d is therefore NOT a good option if one of the other options can be realised. Options 1b and 1c are the best depending on the requirements and the altitude.

	Description of Construction	R_C Value	Cost	Cost/R_C
1a	2 x 1.7 cm cavities with one RPFE on the side + one in the middle	2.116	3830	1810
1b	**3 x 1.7 cm cavities with two RFPE in the middle**	**2.686**	**3975**	**1480**
1c	**2 x 1.7 cm cavities with one RFPE in the middle**	**2.012**	**3085**	**1533**
1d	2 x 2.0 cm cavities with PE foam in the middle	1.051	3485	3316

The same sketch and table can be used to calculate and draw the temperature curve inside the wall. This temperature curve is important for determining where condensation may occur. In this case, the reflective foil (RFPE) and the PE foam are both insulators and moisture barriers.

It is possible to calculate the economic recovery cost of any insulation improvement, but that does not give the value of increased comfort or time saving. The house owner, based on his/her awareness of the effects of the possible thermal improvements and the available budget, needs to decide which improvement should be undertaken in which room.

1.2 Calculation of the Temperature Curve

The calculation and drawing of the temperature curve gives an indication about the risk of condensation inside the construction. The level of condensation depends on various factors, such as:

(a) **Level of humidity** inside the building. This depends on:
- ◊ The number of people and the amount of time they spend in the building or a particular room. Adults produce about one litre of water per night through breathing.
- ◊ The cooking and bathroom activities taking place in the room. An open cooking pot or wok on the stove evaporates one litre of water per hour.
- ◊ The amount of natural ventilation through doors and windows. This levels out the humidity between inside and outside. It also is one of the causes of heat loss.
- ◊ The presence of a fireplace with an ongoing fire. This consumes oxygen from the room and draws in fresh air from outside. When that air is warmed up, its humidity reduces.

(b) **Level of thermal insulation** of the construction. Condensation will appear on the coldest surface of the room. In most cases, being the glass windowpanes.

(c) **Porosity of the construction**. With a porous construction, such as adobe, there will be fast humidity transport from inside to the outside and less condensation.

(d) **Total temperature difference** between inside and outside. The amount of humidity the air can contain increases with high temperatures. When humid air cools off, it will condensate. These values are presented in the Mollier diagram.

1.3 Mollier

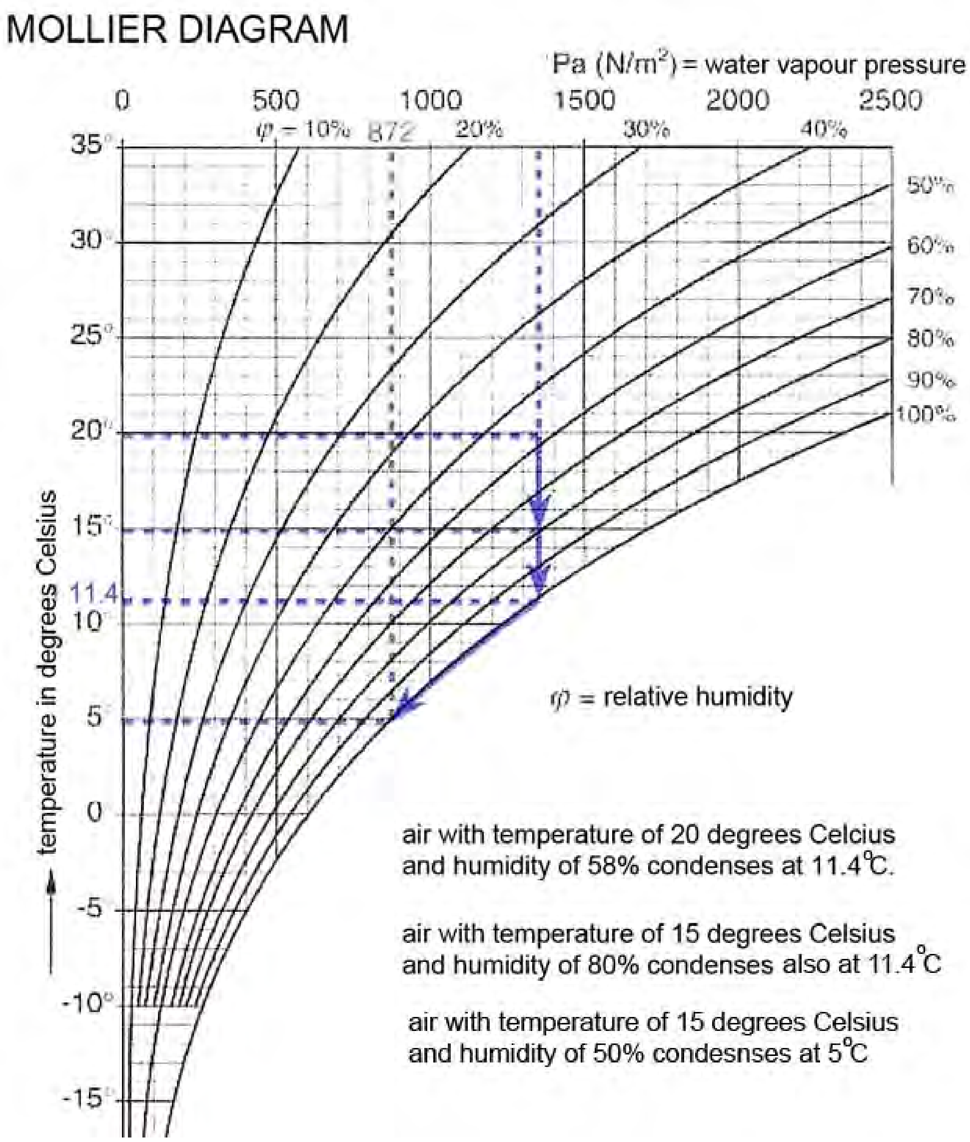
The Mollier diagram can be used to estimate the condensation point of humid air when the temperature of the air drops. Because water vapour pressure tends to equalize in nature, the higher humidity level of the warm side of the construction (inside the house) wants to move to the cold side of the construction.

In order to use the Mollier diagram, the temperature inside each layer of the construction needs to be calculated and a temperature line drawn.

Condensation inside a construction can be avoided by using plastic or metalized foil to seal the warm side of the exterior wall construction. That way the humidity from the inside air cannot enter into the construction. Such a foil seal should be precise and without gaps; otherwise behind the gap condensation will occur. Adjoining plastic foils need to overlap and be stapled or taped together. For reflective foils, aluminium coated tapes are available in the market.

The application of damp proofing from the inside is especially important in roof constructions. Humidity inside the roof can affect the strength of timber beam constructions.

- Ventilating with inside (warm, humid) air will worsen and increase the condensation.
- Ventilating above the damp proofing with cold outside air can reduce the humidity but will eliminate the insulation above the ventilated zone.



In mountain areas, the outside air humidity drops to low levels during the winter. When dry air enters a house, it will become even more drier when warmed up. In other words, the humidity level will drop to very low levels. That is why many people put a water kettle on top of the stove, to bring air humidity back into the room. A comfortable air quality has 30-50% humidity.

During the night, people breathe out about one litre of vaporized water. The air humidity will rise substantially with several people, while the room temperature will drop during the night. This may cause condensation inside the structure (roof or walls).

Kerosene or gas space heaters also produce large amounts of water vapour as exhaust gasses. With the use of such heating equipment, additional ventilation is required to remove the exhaust gasses.

1.4 Calculation of the Dew Point

To calculate the condensation point, the same table can be used with an additional column for the temperatures per construction layer; the point temperature difference (T_P).

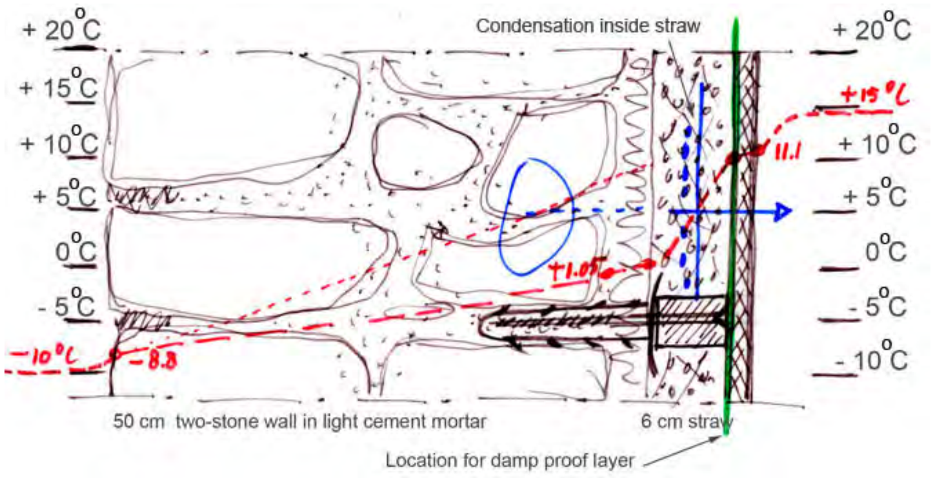
$$T_P = \frac{\text{Insulation value } R_C \text{ of total construction before the measuring point}}{\text{The total insulation value } R_C \text{ of total construction}} \times (\triangle T = \text{inside - outside})$$

T_{P1}	=	0.040/0.837	x	25°C	=	**1.19°C**	difference	**-10°C**	**plus**	**1.19°C**	=	**- 8.80°C**
T_{P2}	=	0.370/0.837	x	25°C	=	**11.05°C**	difference	**-10°C**	**plus**	**11.05°C**	=	**+1.05°C**
T_{P3}	=	0.392/0.837	x	25°C	=	**11.07°C**	difference	**-10°C**	**plus**	**11.07°C**	=	**+1.07°C**
T_{P4}	=	0.692/0.837	x	25°C	=	**20.67°C**	difference	**-10°C**	**plus**	**20.67°C**	=	**+10.67°C**
T_{P5}	=	0.707/0.837	x	25°C	=	**21.12°C**	difference	**-10°C**	**plus**	**21.12°C**	=	**+11.12°C**
T_{P5}	=	0.837/0.837	x	25°C	=	**25.00°C**	difference	**-10°C**	**plus**	**25.00°C**	=	**+15.00°C**

Construction: Two-stone wall with 2 cm soil plaster, 6 cm straw insulation and gypsum board finish on the inside

#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Cumulative R_C	Temp
0	Outside temperature					-10.00°C
1	Outside transmission factor	-	-	0.040	0.040	-8.80°C
2	Two-stone wall in light mortar	0.5	0.66	0.330	0.370	+1.05°C
3	Soil lime plaster inside 2 cm	0.02	1.1	0.022	0.392	+1.07°C
4	One layer straw 6 cm	0.06	5.0	0.300	0.692	+10.67°C
5	9 mm gypsum carton board	0.009	1.66	0.015	0.707	+11.12°C
6	Inside transmission factor	-	-	0.130	0.837	+15.00°C
7	Inside room temperature					+15.00°C
	Total Values R_C and $\triangle T$			**0.837**	0.837	**25.00°C**

See Mollier Diagram: With an inside air temperature of +15°C and a humidity level of 50%, the condensation of the humidity will be at +5°C, thus inside the straw layer. This humidity will reduce the insulation factor and then cause rot in the straw. The green line should therefore be fixed as a moisture barrier, such as 0.15 mm thick plastic foil, PE foam, EPS or a metalized reflective foil.



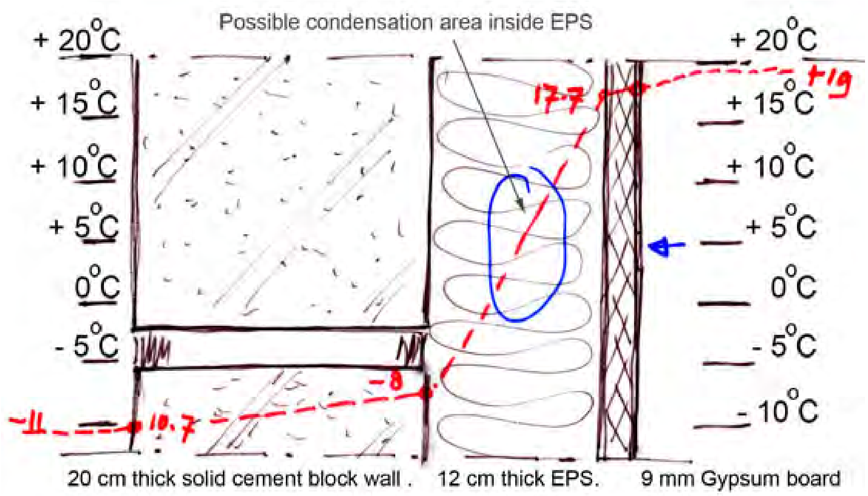
If the inside straw insulation did not exist, condensation would have occurred inside the two-stone wall in the blue circled zone. If condensation inside the stone wall freezes, it will break the cement mortar binding.

The following example shows a solid cement block wall with Expanded Polystyrene (EPS) insulation on the inside, covered with gypsum board.

T_{P1}	=	0.040/3.493	x	30°C	=	**0.34°C**	difference:	**-11°C**	**plus**	**0.34°C**	=	**- 10.7°C**
T_{P2}	=	0.348/3.493	x	30°C	=	**2.99°C**	difference:	**-11°C**	**plus**	**2.99°C**	=	**- 8.0°C**
T_{P3}	=	3.348/3.493	x	30°C	=	**28.75°C**	difference:	**-11°C**	**plus**	**28.75°C**	=	**+17.7°C**
T_{P4}	=	3.363/3.493	x	30°C	=	**28.88°C**	difference:	**-11°C**	**plus**	**20.67°C**	=	**+17.9°C**
T_{P5}	=	3.349/3.493	x	30°C	=	**30.00°C**	difference:	**-11°C**	**plus**	**30.00°C**	=	**+19.0°C**

Construction: Two-stone wall with 2 cm soil plaster, 6 cm straw insulation and gypsum board finish on the inside						
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Cumulative R_C	Temp
0	Outside temperature					-11.00°C
1	Outside transmission factor	-	-	0.040	0.040	-10.7°C
2	Cement block wall in mortar	0.2	1.54	0.308	0.348	-8.0°C
3	One layer EPS 12 cm	0.12	25.0	3.00	0.348	+17.7°C
4	9 mm gypsum carton board	0.009	1.66	0.015	3.363	+17.9°C
5	Inside transmission factor	-	-	0.130	3.349	+19.0°C
6	Inside room temperature					+19.0°C
	Total Values R_C and $\triangle$T			**3.493**	3.349	**30.00°C**

See Mollier Diagram: With an inside air temperature of +19°C and a humidity level of only 40%, the condensation of the humidity will also be at +5°C, thus inside the EPS layer. The difference with straw, however, is that EPS does not transmit humidity and it is not affected by moisture. In this case, the joints between the EPS panels should be precisely closed; otherwise humidity will pass through the joints and condensation will leak down along the stone wall or be sucked into the cement blocks and freeze.



As many constructions are similar per region (the old situation as well as the possible new situations), a folder can be produced containing standard solutions, temperature and humidity curves, and cost calculations of the various constructions. This way, the technical advisors can rapidly determine (and explain) the characteristics of each design to the house owner.

To assist in making similar charts, the example format in Annexe I can be used.

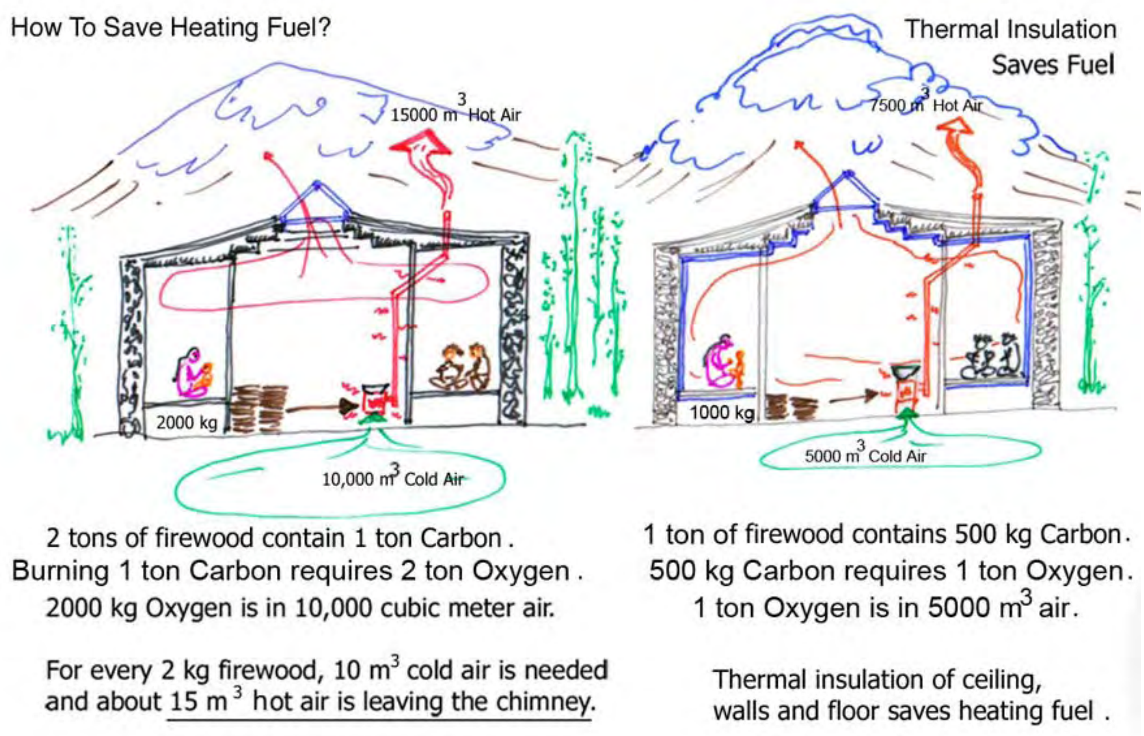
1.5 Effect of Ventilation

Heat loss from a building is caused by five basic factors:

(1) Conduction through the construction material. When a material contains a lot of locked up air, such as wool or Expanded Polystyrene (EPS), the insulation value is high (~ 20%).
(2) Convection of air circulating around the materials. The air picks up heat from warm surfaces and releases the heat against colder surfaces (~ 15%).
(3) Radiation (infrared) from a warm surface to a colder environment (~ 65%).
(4) Humidity exchange passing through building materials. In frost areas, this is little.
(5) Ventilation.

Air has a low heat storage capacity. That is why it is possible to ventilate a warm room for short periods in the winter without much heat loss. The fresh air is rapidly warmed up by the warm walls, floor and ceiling of the room, especially when these are made from stone material. Building materials have about the same heat storage capacity as air by weight, but much more by volume.

Firewood and coal heating stoves require large quantities of oxygen (fresh air) for the burning process. For burning 2 kg dry firewood, about 10 m^3 of fresh air is needed.[1]



This large quantity of fresh air is coming from outside as long as the stove burns. The chimney evacuates very hot air, thus adding to the need for heating. Therefore, if a fuel-consuming stove is used, doors and windows must not be hermetically sealed. For the above reason, it is double effective to insulate first before modifying the stove. With better insulation, the stove is less required.

[1] The amount of oxygen in the air is about 20% only (1/5th). The air pressure reduces at higher altitudes, also meaning less oxygen particles. At 2000 m, the air pressure is 80 kPa, as compared to about 100 kPa at sea level. In other words, 20% less oxygen is available at 2000 m (2400 m = 76 kPa; 3000 m = 70 kPa).

1.6 <u>Need for Trickle Ventilation</u>

Apart from supplying oxygen for the burning process of a space-heating stove, ventilation is necessary for expelling carbon dioxide (exhaled air) and supplying fresh air (with oxygen) in a room. Constant <u>trickle ventilation</u> is therefore important for living rooms and especially in bedrooms. For rooms without a fuel-burning device, a <u>minimum permanent trickle ventilation opening of 12 cm^2 (2 sq.in.) pp is advised</u>. For a bedroom where six people sleep, this means at least a 72 cm^2 (12 sq.in.) opening for fresh air ventilation. This area must be divided into two zones, one low position (below the window level or under the door) and a high position (above the door or window).

Double windows need either a locking system to allow trickle ventilation, a small window or a specially designed ventilation slot for permanent trickle ventilation. All these ventilation openings can be closed when the house is unoccupied. The following three photos show a double glass window in a timber frame having a closing handle that allows trickle ventilation (middle position). The small window can also be opened completely for increased ventilation. It is recommended to ventilate the house fully for short periods on a regular basis.

Window Closed

Trickle Ventilation

Window Open

Houses using fuel-burning space-heating stove in the (bed) room, such as firewood, charcoal, kerosene or gas stoves, need a large amount of <u>additional ventilation</u> to remove the (poisonous) burning gasses and the humidity from the room and refresh the air.

Such stoves should not be used during sleeping hours.

The photo shows the large amount of condensation (window is the coldest area in the room) from a non-chimney gas bottle or kerosene space heater.

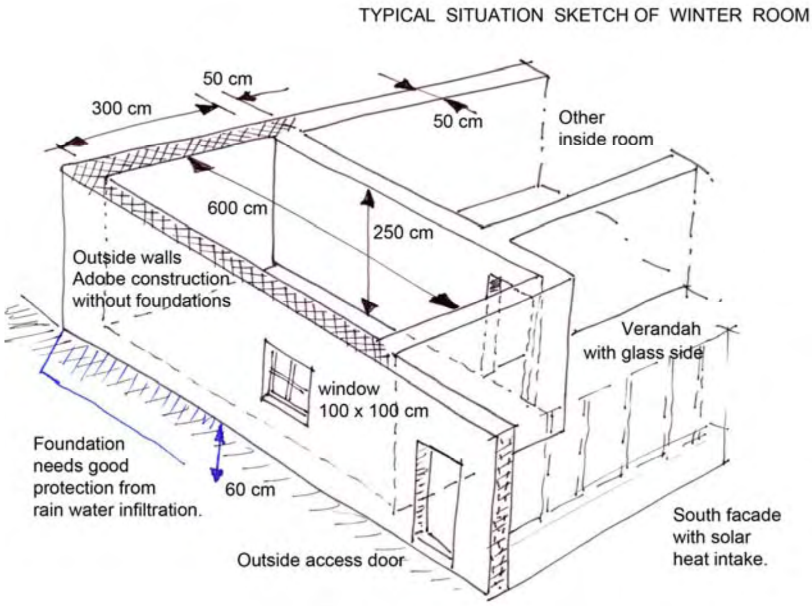
If this humidity penetrates into the walls, the insulation value will reduce, causing more heat loss.

2. COMPARISON OF CALCULATED VALUES

The farmhouse sketch below has a large veranda with one inside room of 3 m x 6 m. The current insulation values of the outside walls, ceiling, window and floor have been calculated and presented in the table below.

Tajikistan
Altitude 1500 m

Hand-packed adobe wall structure without foundation



Recommended for Altitude 1500 m		Current R_C = m^2.K/W	Surface Divided by R_C = Energy Loss in Watt / ºC / Hour	Proposed R_C = m^2.K/W	Total Cost Estimate	10 m^2 Ratio = Cost / New R_C
Building Element	Inside Dimensions	x	Larger Surface = Larger Heat Loss	Minimum 2.0	x	x
Ceiling	3 m x 6 m = 18 m^2	1.59	11.3			
Floor on Soil	3 m x 6 m = 18 m^2	0.245	73 (½ = 36.5)			
Outside Walls	(3+3+6+1 m) x 2.4 = 31.2 m^2	1.17	27			
Window	1.7 m^2	0.15	11.3			
Door	2 m^2	0.2	10			
Total	To insulate 69 m^2	x	>>>>>>>>>>>>			

Note: The ground temperature under the house during the winter is much higher than the outside temperature. The heat loss per hour will be about half in comparison with walls or roof with the same R_C.

The total amount of heat loss through a construction is a relation between the:

- Total surface (m^2)
- Total temperature difference between inside and outside (△T)
- Thermal insulation value (R_C)

As can be seen from the above table, the insulation values (R_C) of the existing situation show large variations. The ceiling is already reasonably insulated; the floor the least insulated. The thick adobe wall has 30% less insulation <u>value</u> than the ceiling, but is almost five times better insulating than the floor. The △T of the floor, however, is usually only half that of the walls or ceiling.

These figures confirm that the family sleeping on the floor is very uncomfortable and cold, caused by the mattress having contact with the floor. The sleeping area on the floor can be further improved with 1 cm PE foam (R_C = 0.01 x 22 = 0.22 m^2.K/W). Although the added insulation value is small, the added comfort is large and subsequently the heating demand and firewood consumption will be sharply reduced.

The total heat loss to the floor (73) is six and a half times that of the ceiling (11.3). However, because the floor has direct contact with the ground and the ground under the house is half the temperature of the outside air (in winter), the actual heat loss is 73 : 2 = 36.5 or more than three times the ceiling. Hence, the floor is priority ONE.

The heat loss from the existing window (11.3) is not very large because the surface is small. By adding two roll curtains, the insulation value will increase to R_C = 0.35 m^2.K/W and the heat loss will be half.

The outside walls have in total 145% more heat loss (27) than that of the ceiling (11.3) and should be the second area of insulation after the floor.

Although in many situations the ceiling is the first area of attention (because heat rises), this is not the case in this farmhouse. Especially when people sleep on the floor, thermal insulation of the floor, (particularly the sleeping area) is priority ONE. Reducing heat loss from the walls is priority number TWO. The lowest insulation value (biggest heat leak) always needs to be improved first. Reducing heat loss from the windows and door is priority number THREE. However, because the window is usually kept closed in the winter, sufficient ventilation through the door should be assured.

The two non-insulated inside walls play an important role in the overall room climate because the thick adobe walls absorb and release humidity and function as a heat storage (buffer).

Improvement Options

The ceiling insulation can be enhanced by an additional layer of straw-lime mixture on top of the existing straw. Because no new ceiling is required, the cost would be rather low, assuming the house owner supplies the straw himself. In this case, straw insulation is the most cost-efficient solution.

Floor insulation is essential when sleeping on the floor and can be accomplished with local materials such as straw-soil mixture and a thick grass mat. The straw needs to stay dry and therefore packed in plastic. Alternatively, EPS sheets can be used. EPS is not affected by moisture, is easy to transport and can be self-applied.

The foundation needs additional protection against water infiltration from the outside. The gutter and/or water storage tank is an added expenditure, but an important pre-condition for insulating the house and keeping it dry. The cost of applying asphalt sheeting or thick plastic foil (0.2 mm, black) will be substantially reduced if the house owner digs the trenches himself.

The walls definitely require insulation before adding insulation to the ceiling. Because insulating the walls on the inside with 16 cm straw will reduce the room space considerably, the much thinner reflective foil is recommended. A large part of the cost is the gypsum board. This cost factor can be reduced by using medium density hardboard (3.5 mm to 4 mm) having about the same purchase cost, but with lower transport cost and easier application.

The house owner must be informed of all the technical options with their insulation values and implied costs. The head of household will be the one making the final decision and it should be a well-informed decision based on facts.

3. CALCULATION OF HEAT STORAGE

To calculate the heat storage capacity of construction elements inside the house, the mass of the materials and the specific heat storage capacity of that mass have to be known. Specific heat is the amount of heat it takes to increase a known mass by a known temperature. For instance, it takes 1 calorie to raise the temperature of 1 gram of water (1 cm^3) 1 degree Celsius. Thus, the specific heat of water is 1 Calorie/cm^3 x °C.

In the metric system, the heat or energy is measured in Joules. The specific heat of water is 4190 J/kg.°C or 4.19 kJ/kg.K (kiloJoule per kg x Kelvin). This is the same as 1.16 W/kg.K.

To better understand the total energy amount, Joules can be converted to Watthour to get the total amount of Watt stored in the material. 3600 Joule = 3.6 kJ = 1 Watthour or 1 W.

The table in Technical Working Paper #3 ~ TABLES gives the W/kg.K value in the last column for some of the materials. From the table, it can be seen that the "specific heat storage capacity" of water is about four to five times as high as nearly all the other materials. The heat storage capacity of air is about the same as other building materials per kg.

Stone, concrete, adobe and sand have a high mass. Because the total heat storage capacity of a material is calculated by multiplying the "specific heat storage capacity" with the mass, these heavy materials are good heat storage materials. Air has a low mass of about 1 kg/m^3.

The calculation for the energy in thermal mass: $Q = m \times c \times \Delta T$

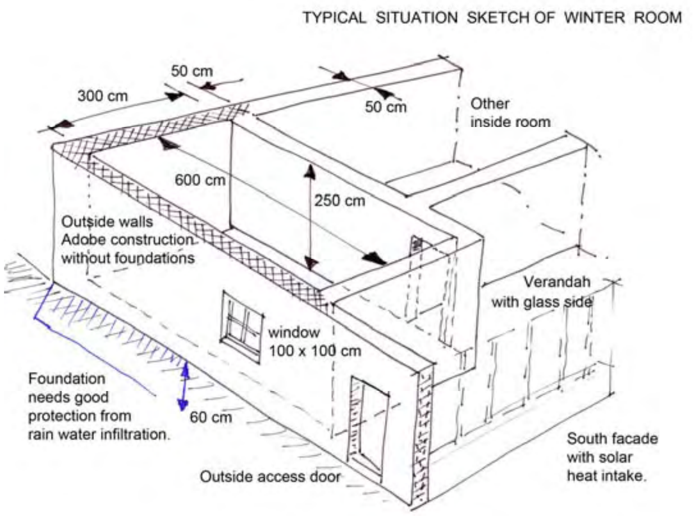
- **Q** is the **energy** required to raise the temperature of an object, in kilo Joules (kJ)
- **m** is the **mass** of the object, in kilograms (kg)
- **c** is the "specific heat storage capacity" of the material, in kilo Joules per kg mass x K (kJ/kg.K) or W/kg.K
- **ΔT** is the increase in temperature (°C or K)

Example Calculation 1

When calculating the heat storage capacity of the two inside walls of the house presented, the result is: (6 m + 3 m – 1 m door) x 2.5 m x 0.5 m = 10 m^3. The material is adobe soil blocks or rammed earth with about 0.8 kJ/kg.K. = 0.222 W/kg.K

The mass of non-compressed adobe blocks or rammed earth is 1100 kg/m^3 or for this inside wall 11,000 kg.

To heat up this massive wall from 0°C to 15°C with ΔT = 15 K gives:
Q = 11,000 kg x 0.222 W/kg.K. x 15 K = 36,630 Watt or 36.6 kW.



Dry firewood has an energetic value of about 4.5 kWh/kg. When a space-heating stove has an energy efficiency of 20%, every kg of dry firewood will produce 0.2 x 4.5 kW/kg = 0.9 kWh.

If only the wall temperature needs to be increased by 15°C, than 36.6/0.9 = 40.5 kg firewood will be needed. However, when the stove initially operates, it first needs to heat the air around it, which in turn then heats all the surfaces in the room.

Example Calculation 2

When calculating the heat storage capacity of only the air inside this room, the volume of air is: 6 m x 3 m x 2.5 m = 45 m^3. The material air weighs about 1 kg/m^3 or total 45 kg. The air inside has to be warmed in order to transfer its heat adequately to the surrounding walls. The temperature difference from -5°C to + 25°C = ΔT = 30 K.

Q = 45 x 0.197 x 30 = 266 Watt or 0.27 kW. This demonstrates that the heat storage capacity of air is very low and briefly ventilating a room has little effect on the overall room temperature when there is sufficient heat storage mass in the walls.

Dry firewood has an energetic value of approximately 4.5 kWh/kg. When a space-heating stove has an energy efficiency of 20%, every kg of dry firewood will produce 0.9 kWh. If only the air temperature needs to be increased by 30°C, 0.27/0.9 = 0.3 kg firewood will be needed.

Example Calculation 3

The amount of heat required to warm up the outside walls depends on their structure and mass. With traditional non-insulated adobe walls, the amount of firewood for heating the two outside walls in the winter will be about four times (= 160 kg firewood) the amount required to warm the inside adobe walls. This is because the outside temperature is much lower (ΔT = 30 K) and the heat will be immediately lost on the outside due to the cooling effect of the cold outside air. In addition, the ceiling and floor will require heating.

When thermal insulation is applied using lightweight reflective foils on the inside of the exterior walls and ceiling, and there is a timber floor, the heat requirement can be calculated as follows:

Wall surface = 11 m^2, ceiling surface = 18 m^2, together 29 m^2. The floor = 18 m^2.
The material of the foil and air cavities is negligible, but the 9 mm gypsum board wall finish weighs 29 m^2 x 0.009 m x 800 kg/m^3 = 209 kg. The timber framing may be 100 kg, total 300 kg. The weight of the timber plank floor without the support beams is 18 m^2 x 0.03 m x 700 kg/m^3 = 378 kg. If there are some carpets, the total weight to be heated would be about 1000 kg.

The temperature difference ΔT of the boards is the same as for the inside wall: 0°C + 15°C = 15 K.

Q = 1000 kg x 0.222 W/kg.K x 15 K = 3330 Watt or 3.3 kW.
Dry firewood has an energetic value of approximately 4.5 kWh/kg. When a space-heating stove has an energy efficiency of 20%, every kg of dry firewood will produce 0.9 kWh. If only the inside wall and the ceiling finishing need to be increased by 15°C, 3.3/0.9 = 3.7 kg firewood will be needed.

This shows that the heat storage capacity of the inside reflective foil thermal insulation and finishing is very low and results in the room quickly heating up. This also indicates a disadvantage of the reflective foil insulation: when the finishing on the inside is lightweight, the heat storage capacity is very low. In that case, ventilating briefly a room does strongly affect the overall room temperature when there are no inside walls with sufficient heat storage capacity, but the room will also heat up quickly again.

Observation: Applying reflective foils for inside thermal insulation of heated rooms in cold climate zones is very energy effective. The heat storage capacity of these foils and the lightweight finishing (board, planks), however, is very low.

Recommendation: With the use of reflective foils for thermal insulation, heat storage capacity can be created by the inside finishing (plasterwork), cavity walls and other internal walls of the building.

4. PRACTICAL EXAMPLES

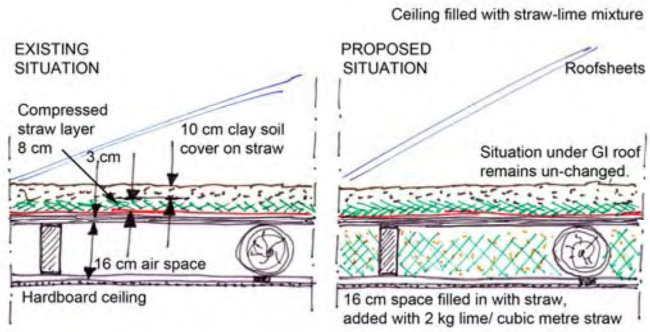
The following case study is based on the farmhouse pictured on page 21 (and sketch, page 14), a common village house design often found in mountain areas.

4.1 Ceiling *Current Insulation Value R_C = 1.59 m^2.K/W*

The ceiling construction is closed with board, straw layer and covered with soil. The flat ceiling is under a reasonably good corrugated asbestos cement roof construction and closed at the gable ends.

Ceiling Insulation Option A
Value of R_C = 3.35 m^2.K/W

Fill cavity of traditional ceiling with 16 cm straw-lime, plastic foil, re-use old ceiling material



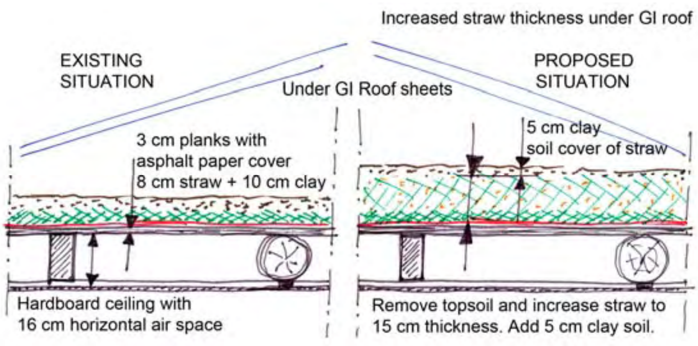
Ceiling Insulation Option A: Remove (painted) board ceiling, add 16 cm straw-lime mix inside cavity, plastic foil, replace board ceiling — Thickness x R_M = R_C					Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor (roof)	-	-	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	Cardboard boxes	0.01	15.0	0.15			
5	Plank flooring	0.03	5.00	0.15			
6	Horizontal cavity	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			**1.59**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	Straw 16 cm thick, transport	0.16	12	1.92	*10*	*15*	*10*
- 6	Reduction of lost air space	-	-	-0.16	-	-	-
11	Mixing lime @ 2kg per cubic meter For 10 m^2 = 4 kg	x	x	x	*8*	*4*	*2*
12	Plastic moisture barrier	0.0001	-	-	*5*	-	-
13	Removing and replacing ceiling (materials are nails)	x	x	x	*10*	*20*	*10*
14	New cover strips from timber for joints between sheets and cornice	x	x	x	*10*	*10*	*5*
15	New ceiling paint white wash	x	x	x	*20*	*10*	*5*
	Subtotal Newly Added Value R_C			**1.76**	*63*	*59*	*32*
	Total Existing and New R_C Values			**3.35**		***Total Cost 10 m^2***	*154*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***46***

If the house owner wants a straighter and flatter ceiling, he can opt for a finishing of gypsum board. The cost will be higher, due to the difficulty to transport the gypsum board in large sections. Labour for fixing, closing joints and painting may increase costs as well.

The main complaint of the house owner was the cold floor during the winter. This is especially felt because the family sleeps on the floor on rather thin mattresses. In this case, the primary focal area for thermal insulation should be the floor and the window, not the ceiling. Secondarily, the two outside walls should be considered.

Ceiling Insulation Option B
Value of $R_C = 2.36\ m^2.K/W$

The soil cover is an unwanted load of 4 m^3, having a mass of almost 8 tonnes. Removing this load will increase the earthquake safety of the room and building.

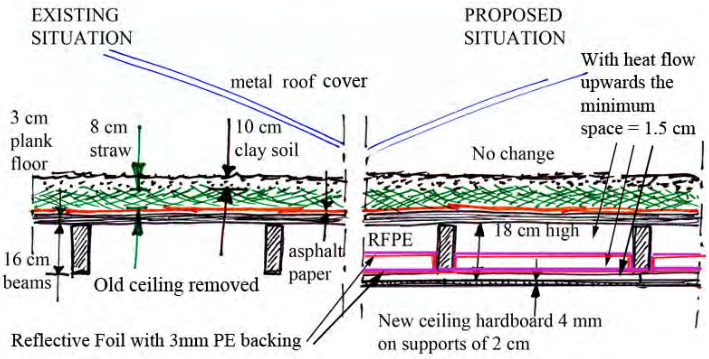


Ceiling Insulation Option B: Remove clay soil, addition of straw-lime up to 15 cm and replacing 5 cm soil protection Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor (roof)	-	-	0.07			
2	Dry clay soil cover of straw	0.10	1.40	0.14	remove	x	self
3	Compressed straw, dry	0.08	10.0	0.80			
4	Asphalt	0.01	15.0	0.15			
5	Plank flooring	0.03	5.00	0.15			
6	Horizontal cavity	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			**1.59**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	Straw 15 cm thick	0.07	12	0.84	*10*	*15*	*10*
11	Mixing lime @ 2kg per cubic meter For 10 m² = 4 kg	x	x	x	*8*	*5*	*5*
12	Removing of half the soil = removing half insulation value (2)	-0.05	1.40	- 0.07	*0*	*20*	*10*
13	New ceiling paint white wash	x	x	x	*20*	*10*	*5*
	Subtotal Newly Added Value R_C			**0.77**	*38*	*50*	*30*
	Total Existing and New R_C Values			**2.36**		***Total Cost 10 m²***	*118*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***50***

In comparing the two options, the cost of Option A is slightly higher because the ceiling needs to be opened up. Option B is only possible when the asphalt is a good moisture barrier. Increasing the thickness of the straw with Option B can increase the insulation value to equal Option A.

Ceiling Insulation Option C
Value of $R_C = 2.95$ m^2.K/W

Traditional ceiling/roof under a metal roof



Ceiling Insulation Option C: Remove hardboard ceiling, apply 2 x RFPE, new hardboard ceiling, paint				Thickness x R_M = R_C	Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor (roof)	-	-	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	Cardboard boxes	0.01	15.0	0.15			
5	Plank flooring	0.03	5.00	0.15			
6	Horizontal cavity	0.16	**Black**	0.16			
7	Hardboard ceiling	0.004	5.00	0.02	remove	x	self
8	Inside transmission factor	-	-	0.10			
	Subtotal Existing Construction R_C			**1.59**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
-6	Horizontal cavity	0.16	**Black**	-0.16			
10	2 x RFPE half way the beams and under the beams before strips	0.006	22	0.132	*120*	*40*	*20*
11	Horizontal top cavity: GBM-HRF	>0.017	**Pink**	0.45	-	-	-
12	Staples to fix the foil	-	-	-	*20*	-	-
13	Cavity between 2 foils RFPE-HRF	>0.017	**Blue**	0.47			
14	Horizontal cavity between new ceiling and foil: GBM-RFPE	>0.017	**Pink**	0.45	-	-	--
15	Timber strips for fixing hardboard	0.02	x	-	*30*	*20*	*10*
16	Hardboard ceiling	0.004	5.00	0.02	*100*	*20*	*10*
17	Painting of hardboard ceiling	-	-	-	*100*	*30*	*15*
	Subtotal Newly Added Value R_C			**1.362**	*370*	*110*	*55*
	Total Existing and New R_C Values			**2.952**		***Total Cost 10 m^2***	*535*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***181***

Option C is more expensive, but a large part of the expenses is in replacing the old ceiling. The horizontal air cavities with reflective foils have an optimum height of 1.7 cm for up-going heat flow. When most of the dry soil load is removed from the upper part, the insulation value will only drop by $R_C = 0.10$ m^2.K/W, while the lesser weight will make the building more earthquake safe.

Ceiling Insulation Option D
Value of $R_C = 3.49\ m^2.K/W$

With one extra foil – total 3 foils and 4 cavities of >0.017 m

Because adequate height is available between the ceiling beams, a third reflective foil can be placed, increasing the total insulation value by another $R_C = 0.47\ m^2.K/W$, bringing it to $3.49\ m^2.K/W$. This will be suitable for very high altitudes. This has almost the same cost/R_C efficiency as option C.

Comparison of the Four Ceiling Insulation Designs

	Description of Ceiling Construction	R_C Value	Cost	Cost/R_C
A	**Fill in 16 cm straw + plastic inside the ceiling**	**3.35**	**154**	**46**
B	Reconstruct top layer with more straw insulation	2.36	118	50
C	3 x >1.7 cm cavities with two RFPE	2.95	535	181
D	4 x >1.7 cm cavities with three RFPE	3.49	625	179

The different options should be studied with the house owner taking into consideration own contributions, re-use of materials and the desired insulation value for the given altitude.

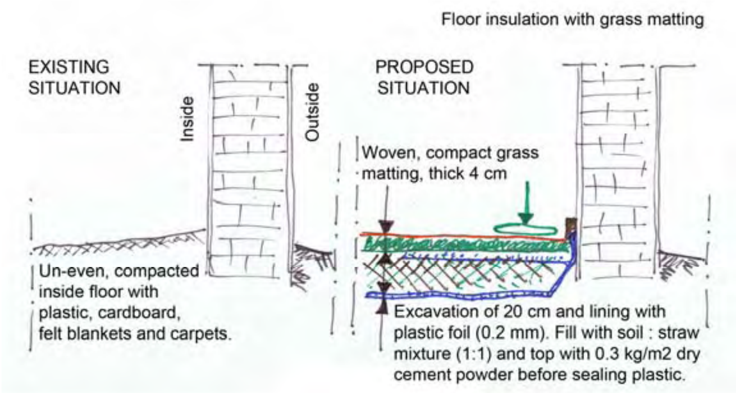
In this example for a house at 2000 m altitude (recommended $R_C = 2.5$), Option B gives insufficient insulation. Because the straw is low cost, Option A is by far the best solution. The cost will increase with a new board ceiling and paint.

House entrance on low side with porch. The recommendation is to make a vestibule for the two doors opening to the porch area. The porch should close against the ceiling.

High road side requires roof gutter and rainwater evacuation.

4.2 Floor *Current Insulation Value $R_C = 0.245\ m^2.K/W$*

Floor Insulation Option A
Value of R_C= 1.16 m^2.K/W



Considering the house owner's request for low-cost options, a simple floor insulation is proposed. To stop moisture rising from the underground, the adobe soil floor should be excavated for 20 cm, lined with plastic foil (recycled 0.2 mm) and filled in with a dry straw-soil mixture (1:1). The mixture should be topped with dry cement powder before being sealed with the plastic foil. A 4 cm woven grass mat should be placed on top of the plastic and PE foam under the sleeping mattresses.

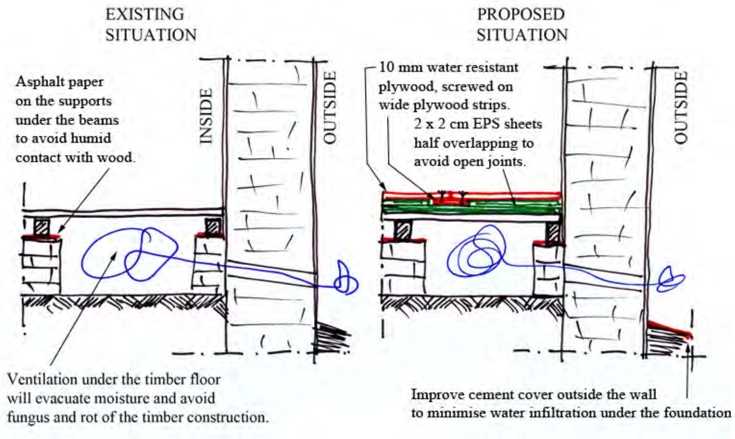
Floor Insulation Option A: Excavating soil, plastic foil, refill with 20 cm straw-soil in plastic bag, grass mat, PE foam				Thickness x R_M = R_C	Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	x			
2	Carton sheets, flattened	0.005	5.00	0.025		Replace	
3	Carpets, thin	0.005	10.0	0.05		Replace	
4	Inside transmission factor	-	-	0.17			
	Subtotal Existing Construction R_C			**0.245**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	Excavation of 20 cm soil	x	x	x			*self*
11	Plastic foil sheeting, 0.2 mm thick, 30 m^2 including overlap per 10 m^2	x	x	x	*100*	*10*	*5*
12	Straw and soil mixture, dry 2 m^3	0.20	3.00	0.60	*20*	*10*	*5*
13	Cement powder dust as topping and moisture binding, 3 kg	x	x	x	*30*	*5*	*0*
14	Woven grass mat per 10 m^2	0.04	5	0.20	*60*	*10*	*5*
15	PE foam mattress	0.005	22	0.11			
	Subtotal Newly Added Value R_C			**0.91**	*210*	*35*	*15*
	Total Existing and New R_C Values			**1.16**	***Total Cost 10 m^2***		*260*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		1.25	Ratio = Total Cost / R_C Total		***224***

The insulation is almost adequate for 2000 m altitude according to recommended R_C value because floors require half the value of walls and roofs. However, because the family sleeps on the floor, the insulation value should be increased and therefore at least 10 mm Polyethylene foam (PE) under the carpet is needed. This will increase the calculated insulation value by another R_C = 0.005 x 22 = 0.11 m^2.K/W.

Floor Insulation Option B
Value of R_C = 1.45 m^2.K/W

Elevated floor design
EPS + multiplex
over floor and ventilated cavity

Floor suitable for clinics (beds) and schools (desks) needing to have floors with a hard surface and easy to clean with water.



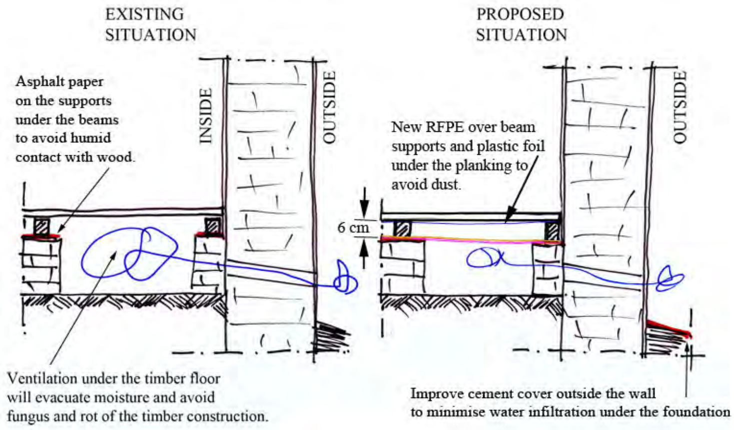
Floor Insulation Option B: Covering elevated plank floor with 3 cm + 1 cm EPS, 1 cm multiplex, paint Thickness x R_M = R_C					Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	x	Repair outside gutters		
2	Crawl space, light ventilation	x	x	0.10			
3	Plank floor	0.03	5.0	0.15	Repairs needed in places		
4	Inside transmission factor	-	-	0.17			
	Subtotal Existing Construction R_C			**0.42**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	EPS 3 cm first layer, full	0.03	25	0.75	*65*	*10*	*10*
11	EPS 1 cm second layer overlap, with spacing for joints in multiplex	0.01	25	0.25	*25*	*10*	*10*
12	Plywood floor, screwed on strips	0.01	3.0	0.03	*500*	*50*	*15*
13	Fixing materials, glue and screws	x	x	x	*50*	*10*	-
14	Polyurethane paint + cleaning	x	x	x	*125*	*20*	*10*
15	Plinth and door adjustments	x	x	x	*50*	*20*	*10*
	Subtotal Newly Added Value R_C			**1.03**	*815*	*120*	*55*
	Total Existing and New R_C Values			**1.45**	***Total Cost 10 m^2***		*990*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***683***
	Recommended R_C Value with Ventilation under the Floor			1.875			

The above design with EPS and waterproof plywood is durable, and it does not require lifting the existing floor or modifying the supporting beams or planking. Because the space under the floor is ventilated, half the recommended thermal insulation value for the altitude is too little and <u>¾ of the recommended value should be considered</u> (¾ x 2.5 = 1.875). If the supporting beams are weak, affected by moisture and rotted, and the floorboards need replacement, another design is possible using reflective foils.

Floor Insulation Option C
Value of R_C = 2.49 m^2.K/W

Elevated floor design
Plastic + RFPE
over ventilated cavity

Floor suitable for schools (desks) needing to have floors with a hard surface.



Floor Insulation Option C: Remove plank floor, place one RFPE over supports, plastic under planks		Thickness x R_M = R_C			Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	x	Repair outside gutters		
2	Crawl space, light ventilation	x	x	0.10			
3	Plank floor	0.03	5.0	0.15	Remove self		
4	Inside transmission factor	-	-	0.17			
	Subtotal Existing Construction R_C			**0.42**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	RFPE + 3 mm over supports	0.003	22	0.066	*60*	*10*	*5*
11	Replacement floor joists, horizontal cavity GBM-HRF	0.06	**Blue**	2.0	-	-	-
12	Plastic protection under planks	0.001	-	-	*10*	*10*	*5*
13	Plank floor replacement-repair	-	x	x	*50*	*20*	*10*
14	Polyurethane paint	x	x	x	*125*	*20*	*10*
	Subtotal Newly Added Value R_C			**2.066**	*245*	*60*	*30*
	Total Existing and New R_C Values			**2.486**	***Total Cost 10 m^2***		*335*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***135***
	Recommended R_C Value with Ventilation under the Floor			1.875			

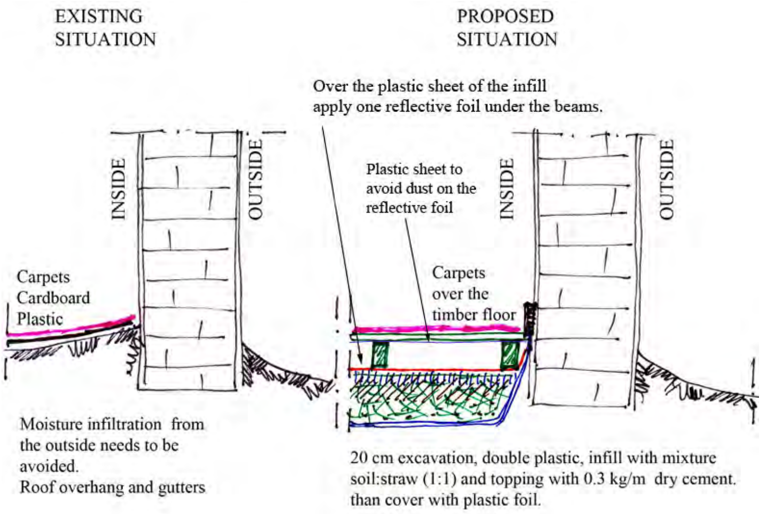
This third option is very effective because of the high thermal insulation values of the reflective foil under the floor, applicable with a downward heat flow. With downward heat flow, the insulation value increases with the distance to the reflective foil.

In the above design, it is important that the reflective foil under the floor remains intact and doesn't become dirty from dust falling through the planks. A thick quality (0.2 mm) plastic foil or a PP tarpaulin stretched under the plank floor will protect the reflective foil.

Because the area under the foil is slightly ventilated, ¾ of the recommended minimum value for thermal insulation for the particular altitude area is recommended.

Floor Insulation Option D
Value of $R_C = 2.54\ m^2.K/W$

Straw + plastic + 1 x RFPE over infill and under timber floor beam



Floor Insulation Option D: Excavating soil, refill with 20 cm straw-soil in plastic bag; RFPE plus timber floor — Thickness x R_M = R_C					Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	x			
2	Carton sheets, flattened	0.005	5.00	0.025			
3	Carpets, thin	0.005	10.0	0.05			
4	Inside transmission factor	-	-	0.17			
	Subtotal Existing Construction R_C			**0.245**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
-2	Remove carton sheets	0.005	5.00	-0.025			*self*
10	Excavation of 20 cm soil	x	x	x			*self*
11	Plastic foil sheeting, 0.2 mm thick, 30 m^2 including overlap per 10 m^2	x	x	x	*100*	*10*	*5*
12	Straw and soil mixture, dry 2 m^3	0.20	3.00	0.60	*20*	*10*	*5*
13	Cement powder dust as topping and moisture binding, 3 kg	x	x	x	*30*	*5*	*0*
14	RFPE foil on plastic bag	0.003	22	0.066	*60*	*5*	-
15	Timber supports 6 cm high, horizontal cavity HRF-GBM	0.06	**Blue**	1.50	*50*	*20*	*10*
16	Plastic sheet over timbers	0.002	-	-	*10*	*10*	*5*
17	New plank floor over plastic sheet	0.03	5.0	0.15	*50*	*20*	*10*
	Subtotal Newly Added Value R_C			**2.291**	*320*	*80*	*35*
	Total Existing and New R_C Values			**2.536**		***Total Cost 10 m^2***	*435*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		1.25	Ratio = Total Cost / Rc Total		***172***

This floor has a very high insulation value being twice the recommended value for floors at the given altitude. This floor will be comfortable to sit (pre-school) or sleep on.

The cost of the floor depends largely on the materials that can be supplied by the house owner and the amount of self-help labour. Important in this design is that the reflective foil under the plank floor remains clean. The good quality plastic sheet under the planking will assure this.

Floor Insulation Option E
Value of R_C = 1.94 m^2.K/W

Without the excavation and straw pack, levelling soil, 1 x RFPE, timber floor similar to Option D

Comparison of the Four Floor Insulation Options

	Description of Floor Construction	R_C Value	Cost	Cost/R_C
A	Excavated, straw-soil, plastic, grass, PE foam	1.16	260	224
B	Elevated floor, ventilated, 4 cm EPS, plywood cover	1.45	990	683
C	**Elevated floor, ventilated, plastic, 1 RFPE**	**2.49**	**335**	**135**
D	**Excavated, straw-soil, 1 x RFPE, timber floor**	**2.54**	**435**	**172**
E	**Levelling soil, 1 x RFPE, timber floor**	**1.94**	**2.85**	**147**

The floor designs are rather different and the choice will depend partly on the technical requirements of the floor. Option B can be substantially improved with a reflective foil under the floor similar to Option C. Options A and B are adequate for lower altitudes (up to 1500 m) since the required minimum insulation value for the floor is half the recommended insulation value for the walls and roofs.

4.3 Outside Door

Insulating the door to the outside entrance area or vestibule is important, but sealing the winter room with a high-quality new door is out of the question if the door is the main ventilation opening for the space-heating stove. In the house pictured on page 21, it would be more effective to make a small vestibule (1.5 m x 1.5 m and connecting this to the 3 m high ceiling) enclosing the current two outside doors (blue). This way a buffer is created, so cold air does not immediately enter the living rooms and the two rooms are connected internally without the need to go outside. The vestibule should have only one outside door with a spring closure. The room door can be further improved by hanging a heavy curtain on the inside to reduce draft. If there is a window in the new vestibule, it should be double glass. The vestibule construction will be relatively expensive.



Example of outside porch, door spring and curtain behind door.

4.4 Window

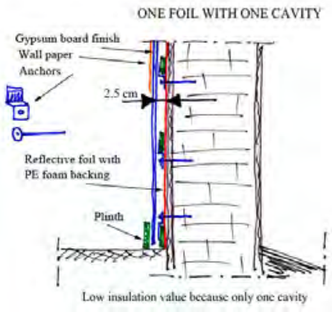
An additional window frame (photo page 21) should be placed on the inside of the existing window frame, thus creating a double glass window with a new R_C = 0.4 m^2.K/W. With the addition of two roll curtains (a fully transparent day curtain and a decorative night curtain), the total would be about R_C = 0.6 m^2.K/W.

4.5 Walls *Current Insulation Value R_C = 1.17 m^2.K/W*

Given the small space for the six family members sleeping in the room, the wall insulation (33 m^2) should be kept thin by using a single reflective foil. The internal wall adjoining the next room (10 m^2) does not need to be insulated.

Wall Insulation Option A
Value of R_C = 1.92 m^2.K/W

1 x RFPE foil against the wall + gypsum board finishing



Wall Insulation Option A: 1 x RFPE against wall, 1 x cavity, gypsum board finish		Thickness x R_M = R_C			Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Adobe wall, hand packed	0.5	2.00	1.00			
3	Inside transmission factor	-	-	0.13			
	Subtotal Existing Construction R_C			**1.17**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	Reflective foil with 3 mm PE back	0.003	22	0.066	*60*	*10*	*x*
11	Vertical cavity HRF-GBM	0.025	**Blue**	0.675	-	-	-
12	Timber strips 1 x 3 cm per 10 m^2	x	x	x	*10*	*10*	*5*
13	Fixing materials per 10 m^2	x	x	x	*10*	*10*	*5*
14	Gypsum-carton board 8 mm	0.008	1.66	0.013	*150*	*20*	*10*
15	Covering joints with web-sealant	x	x	x	*10*	*10*	*5*
16	Painting two coats of white wash	x	x	x	*20*	*x*	*20*
	Subtotal Newly Added Value R_C			**0.754**	*260*	*60*	*45*
	Total Existing and New R_C Values			**1.924**		***Total Cost 10 m^2***	*365*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***190***

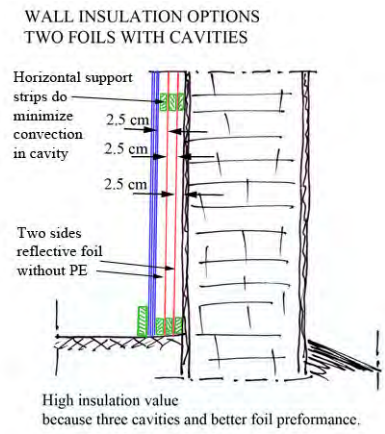
The above R_C value is insufficient for 2000 m altitude. The insulation value of the wall will be substantially improved if the reflective foil is placed free from the wall. The most cost-effective distance for vertical cavities in combination with reflective foils is 2.5 cm. This will require additional timber work and fixing materials. To avoid convection in between the foils, the vertical cavities should be interrupted with horizontal supports. The construction cost of the reflective foils and cavities will be reduced with the use of efficient stapling and nailing tools.

Wall Insulation Option B *Option A Modified*
Value of R_C = 2.57 m^2.K/W

Option B is to create a 2.5 cm cavity between the wall and the first RFPE of Option A. This will add an R_C value of 0.65 of vertical cavity 2.5 cm (GBM-RFPE, **Pink**) and a cost of TJS 40, bringing the new ratio to Cost/R_C = 405/2.574 = 157, which is a considerable improvement over the 190 ratio of Option A.

Wall Insulation Option C
Value of $R_C = 3.23\ m^2.K/W$

2 x HRF + 3 x cavity +
gypsum board finishing



Wall Insulation Option C: 2 x HRF, 3 x cavity, gypsum board finish Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Adobe wall, hand packed	0.5	2.00	1.00			
3	Inside transmission factor	-	-	0.13			
	Subtotal Existing Construction R_C			**1.17**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	2.5 cm x 3 cm support strips every 50 cm, vertical GBM -HRF	0.025	**Blue**	0.67	*20*	*10*	*10*
11	Plastic anchor plugs with 10 cm long screws to fix support strips	x	x	x	*20*	*20*	*10*
12	2.5 cm x 3 cm support strips every 50 cm, vertical HRF-HRF	0.025	Orange	0.71	*20*	*10*	*5*
13	2.5 cm x 6 cm wide support strips at joining sheets locations	x	x	x	*20*	*10*	*5*
14	First HRF	0.0001	x	x	*60*	*10*	*x*
15	2.5 cm x 3 cm support strips c.o.c 50 cm, vertical HRF-GBM	0.025	**Blue**	0.67	*20*	*10*	*5*
16	Second HRF	0.0001	x	x	*60*	*10*	*x*
17	Nails/staples	x	x	x	*100*	*x*	*x*
18	Fixing materials per 10 m²	x	x	x	*40*	*20*	*10*
19	Gypsum-carton board 8 mm	0.008	1.66	0.013	*150*	*20*	*10*
20	Covering joints with web-sealant	x	x	x	*10*	*10*	*5*
21	Painting two coats of white wash	x	x	x	*20*	*x*	*10*
	Subtotal Newly Added Value R_C			**2.063**	*540*	*130*	*70*
	Total Existing and New R_C Values			**3.233**		***Total Cost 10 m²***	*740*
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		***229***

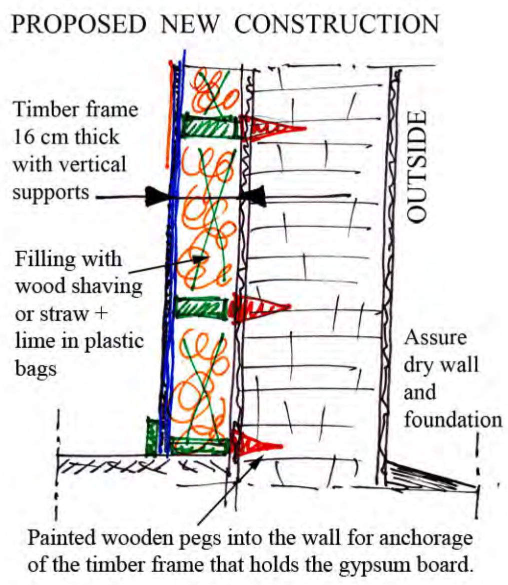
This insulation value is suitable for altitudes up to 2700 m.

Wall Insulation Option D
Value of $R_C = 3.183\ m^2.K/W$

Without reflective foil, but with 16 cm straw or wood shavings

Filling plastic bags with wood shavings or straw makes the filing of the wall construction easy. To protect the straw and wood shavings from insects, a handful of dry lime is added to each bag before closing. The bags are not filled tightly so they can be shaped to fill the corners of the timber support structure.

In this design, the timber support structure requires a lot of timber and needs to be well fixed to the wall.



Wall Insulation Option D: Pegs with 16 cm timber support frame, bags with straw + lime dust, gypsum board — Thickness x R_M = R_C					Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-	0.04			
2	Solid adobe wall	0.5	2.00	1.00			
3	Inside transmission factor	-	-	0.13			
	Subtotal Existing Construction R_C			**1.17**			
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Material in TJS	Skilled Labour Cost	Non-skilled Labour
10	Wooden pegs hammered	-	-	-	*20*	*10*	*5*
11	Timber lattice and planks	0.16	-	-	*160*	*20*	*10*
12	Filling, loose straw-lime	0.16	12.5	2.0	*10*	*10*	*5*
13	Mixing lime @ 2kg/m³, bags	-	-	-	*10*	-	*5*
14	Plastic moisture barrier	0.002	-	-	*10*	*10*	*5*
15	Fixing materials per 10 m²	-	-	-	*10*	*10*	*5*
16	Gypsum-carton board 8 m	0.008	1.66	0.013	*60*	*10*	*5*
	Subtotal Newly Added Value R_C			**2.013**	280	70	40
	Total Existing and New R_C Values			**3.183**	***Total Cost 10 m²***		**390**
	Altitude Above Sea Level Building 2000 m	Recommended R_C Value		2.5	Ratio = Total Cost / R_C Total		**123**

This insulation value is suitable for altitudes up to 2600 m.

Remarks:
- This design is low-cost when the house owner supplies the insulation material free of cost.
- The plastic moisture barrier is required to avoid (humid) air to pass in between the plastic bags with straw and the timber frame and cause condensation.
- The pegs need to be well protected with paint against possible moisture in the wall.
- The total insulation value of this wall is rather good, but it requires a thickness of 17 cm, which is taken away from the room width. This may cause a problem for small rooms.

Comparison of the Four Wall Insulation Options

	Description of Wall Constructions	R_C Value	Cost	Cost/R_C
A	One RFPE against wall, 1 x cavity 2.5 cm, board	1.92	365	190
B	**One RFPE, 2 x cavity 2.5 cm, board**	**2.57**	**405**	**157**
C	Two RFPE, 3 x cavity 2.5 cm, board	3.23	740	229
D	**Pegs, 16 cm frame with bags straw + lime, plastic, board**	**3.18**	**390**	**123**

By comparing the four options, Option B with only one RFPE in the middle of two cavities is the most cost-efficient design, giving a high thermal insulation value. It is also the thinnest design. If more insulation is required because of a very high altitude, a combination can be made with sheep wool or straw bags. The cost of the space and the support structure, however, needs to be considered. In the above designs, the cost of finishing the inside surface is not included.

In the case study house, the walls definitely required insulation before adding insulation to the ceiling. Because insulating the walls with a thick layer of straw will reduce the room space too much, the much thinner single reflective foil is recommended.

When comparing the various designs, it is recommended to apply the RFPE or HRF always with a cavity on both sides of the reflective foil for optimum insulation results.

4.6 Comparison Table

Comparison table of the above selected insulation improvement options.
The total cost estimate is the 10 m^2 x the actual surface in m^2/10.

Recommended for Altitude 1500 m		Current R_C = m^2.K/W	Surface Divided by R_C = Energy Loss in Watt / ºC / Hour	Proposed R_C = m^2.K/W	Total Cost Estimate	10 m^2 Ratio = Cost / New R_C
Building Element	Inside Dimensions	x	Larger Surface = Larger Heat Loss	Minimum 2.5	x	x
Ceiling A	3 m x 6 m = 18 m^2	1.59	11.3	+ 16 cm straw new top 3.35	TJS 277	46
Floor E	3 m x 6 m = 18 m^2	0.245	73	+ 20 cm straw-soil + RFPE + timber 1.94	TJS 513	147
Walls B	(3+3+6+1 m) x 2.4 = 31.2 m^2	1.17	27	+ 1 RFPE, 2 x cavity, gypsum 2.57	TJS 1264	157
Outside Window	1.7 m^2	0.15	11.3	Double glass 0.4	TJS 250 1.7 m^2	3676
Outside Door	2 m^2	0.2	Constructed floor vestibule 3 m^2	0.2 + 0.2 + 0.2 + 0.17 = 0.77 for 8m^2	TJS 2000	3246
Total	Insulated 69 m^2	x	>>>>>>>>>>>>	Tajikistan Somoni	**4304**	

Cost Analysis
Because it is proposed to fill the ceiling with a straw-lime mixture and replace the old ceiling, the cost is rather low (1.8 m^2 x 154 = TJS 277 for Option A). This is based on the house owner supplying the low-cost straw, an activity that can only be done in the autumn after harvest.

Floor insulation is essential and can mainly be done with local materials (1.8 m^2 x 260 = TJS 468 for Option D). Cement dust is applied to the top layer inside the plastic to absorb any remaining humidity. Making this bag thicker by adding more straw-soil will increase the insulation value. Adding more straw to the mix (for example 2:1 (straw : soil in volume) will also increase the insulation value, but the package will be less firm. A lower cost, however, is without the straw bags infill (Option E).

Changing the door with a vestibule or porch is costly but will substantially reduce draft, improve insulation and comfort. Constructing the new outside vestibule will be by far the largest cost factor with TJS 2000 or more for about 8 m^2 timber panelling work and a double glazed window/door.

The additional window (1.2 x 1.7 m^2 = TJS 250) is a substantial cost factor as compared to the other cost elements, but a very important element in reducing heat loss and improving comfort. Always the largest heat loss factor needs to be reduced first (close the largest heat leak first).

The permanent double glass window should be additionally insulated with a transparent roll curtain for the winter and an extra blinding roll curtain for the night = + R_C 0.2 together.

Window with both a transparent roll curtain and a decorated roll curtain, providing two additional insulating air layers when closed.

5. INSIDE OR OUTSIDE ROOF INSULATION

There are substantial differences between inside and outside thermal insulation of the roof. These differences are listed in the tables below.

Outside Roof Insulation. The coloured boxes are critical issues.

	Advantages		Disadvantages
1	No modifications are required inside the house. This can be important when the ceiling is nice.	1	The outside cover needs to be weatherproof against rain, snow and strong winds. New gutters or gargoyles are required.
2	The outside flat roof surface can be improved and made stronger for walking upon and/or more useable for storage.	2	The upper surface of a new flat roof needs to be strong enough for walking. Maintenance of the surface or snow removal must be possible.
3	The entire existing support structure of the roof will be thermally insulated. The possibility of condensation on roof beams is minimized.	3	The total construction surface is larger than with inside insulation. The roof beams on the outside wall and the top of the wall also need to be insulated.
4	The existing roof structure can remain in place, while the existing insulation can be totally renewed.	4	When the existing roof is not opened up for inspection, rotten or bad constructions can reduce the durability of the construction.
5	The existing roof insulation reduces the need for extra additional insulation material.	5	Old thermal insulation material can be of poor quality. It is more practical to insulate the roof with good new insulation.
6	A leaking roof can be made waterproof at the same time when applying the new insulation.	6	Old thermal insulation can be heavy, which needs to be removed.
7	The old waterproofing of the roof functions as a moisture barrier.	7	Outside cement and plaster work need to be realised during the summer period.

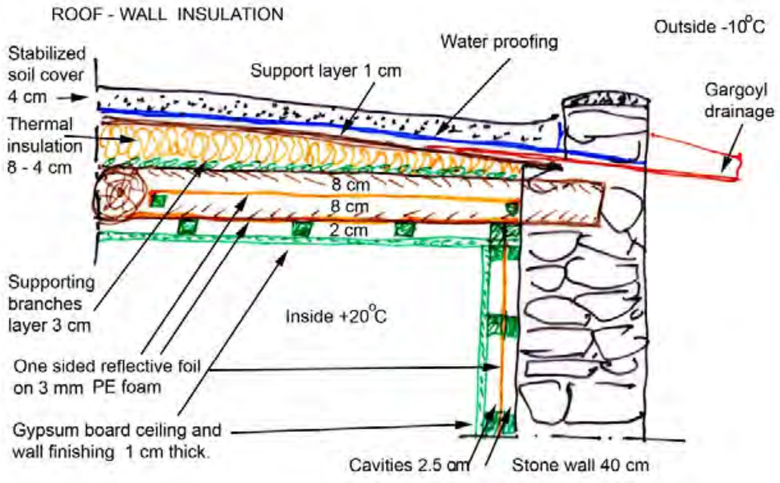
Inside Roof Insulation. The coloured boxes are critical issues.

	Advantages		Disadvantages
1	No modifications are needed outside the house. This can be important when the existing roof is of good quality.	1	The inside ceiling construction needs to be modified. In some cases, the free height of the room will be lowered.
2	The inside ceiling can be restructured and better decorated to look nicer.	2	The headings of the roof support beams or trusses remain on the cold outside wall and can be affected by condensation.
3	The total construction surface is smaller than with outside insulation. As a result, the construction cost can be lower.	3	When the existing roof is not opened up for inspection, rotten or bad constructions can reduce the durability of the construction.
4	The moisture barrier needs to be on the warm side of the roof and well sealing. Inside application is cheaper than outside.	4	When the existing roof leaks a little, the moisture inside the roof will not evaporate and cause reduction of insulation or rot.
5	The heat storage of the inside insulation is low, thus the room will warm up quickly.	5	Old thermal insulation material can be of poor quality. It is more practical to insulate the roof as a whole with good insulation.
6	The inside insulation does not have to support the weight of people walking on it and can be very light, such as reflective foil.	6	Old outside thermal insulation can be heavy, which is disadvantageous in terms of earthquake resistance.
7	Eventual inside cement or plaster work can be realised during the winter.	7	The rooms below cannot be used during the renovation period.
8		8	The timber roof support structure needs to remain dry under all weather conditions. This can mean additional insulation for the support in the outside walls.

Because of Point 2-Inside Roof Insulation-Disadvantages, additional insulation or reconstruction work may be needed. Generally speaking, total reconstruction (including tie-beam, earthquake diaphragm and thermal insulation on the outside of the support construction) is recommended.

Example Calculations of Temperatures in the Beam Support Areas

Three calculations need to be made, one for the wall and two for the roof. Because the thickness of the roof insulation differs, the critical area near the wall is also calculated.



The temperature is calculated for each construction layer.

Inside air temperature is 20°C.
Inside wall temperature is 18°C.

Outside air temperature is -10°C.
Outside wall temperature is -9.4°C.

The above sketch design gives the following values:

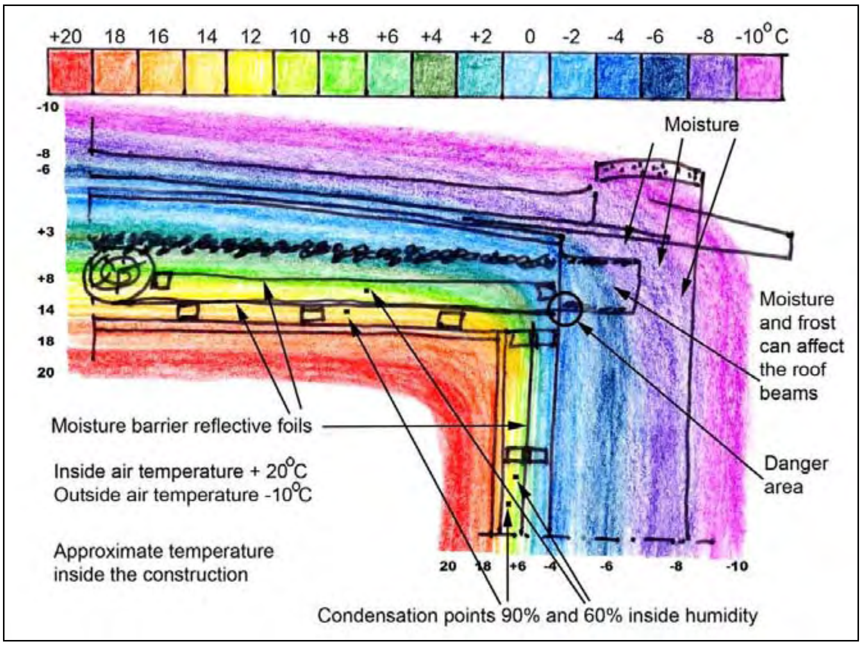
Wall: Stone wall (40 cm), 2 x cavity (2.5 cm), PE foam with reflective foil, 1 cm gypsum board. Thickness x R_M = R_C						The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference = Rc / TRc x △T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.040	-9.36	0.64		
2	Stone wall	0.40	0.83	0.332	-4.08	5.28		
3	Cavity GBM-RFPE	0.025	PINK	0.650	6.25	10.33	At 12°C	At 15°C
4	Cavity GBM-HRF	0.025	BLUE	0.675	16.98	10.73		
5	Gypsum board	0.01	6	0.060	17.93	0.954		
6	Inside transmission factor	-	-	0.130		2.067		
			Value Total R_C	**1.887**	-20ºC	△T=30ºC		

Roof Centre : Stabilized soil (4 cm), carton (1 cm), straw (4 cm), branches (3 cm), 2 x cavity reflective foil (8 cm), 1 x cavity (2 cm), 1 cm gypsum board. Thickness x R_M = R_C						The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x △T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-9.57	0.43		
2	Stabilized soil cover	0.40	0.83	0.33	-5.98	3.59		
3	Hardboard layer	0.01	5	0.05	-5.44	0.54		
4	Straw layer	0.08	10	0.80	3.25	8.69		
5	Cavity GBM-RFPE	0.08	PINK	0.45	8.14	4.89	At 12°C	
6	Cavity RFPE-HRF	0.08	Orange	0.47	13.25	5.11		At 15°C
7	Cavity HRF-GBM	0.02	BLUE	0.46	18.25	5.00		
8	Gypsum board	0.01	6	0.06	18.90	0.65		
9	Inside transmission factor	-	-	0.10		1.10		
			Value Total R_C	**2.76**	-20ºC	△T=30ºC		

The Insulation of traditional roofs is usually thinner at the sides (by the walls). Therefore, a second calculation needs to be made to show the difference.

Roof Side Near Wall: Stabilized soil (4 cm), carton (1 cm), straw (4 cm), branches (3 cm), 2 x cavity reflective foil (8 cm), 1 x cavity (2 cm), 1 cm gypsum board. Thickness x R_M = R_C						The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x △T	Condensation with 60% Jumidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-9.49	0.51		
2	Stabilized soil cover	0.40	0.83	0.33	-5.30	4.19		
3	Hardboard layer	0.01	5	0.05	-4.66	0.64		
4	Straw layer	0.04	10	0.40	0.42	5.08		
5	Cavity GBM-RFPE	0.08	PINK	0.45	6.14	5.72		
6	Cavity RFPE-HRF	0.08	Orange	0.47	12.12	5.98	At 12°C	At 15°C
7	Cavity HRF-GBM	0.02	BLUE	0.46	17.97	5.85		
8	Gypsum board	0.01	6	0.06	18.73	0.76		
9	Inside transmission factor	-	-	0.10		1.27		
Value Total R_C				**2.36**	-20ºC	△T=30ºC		

The above temperature values are entered into the construction sketch using the rainbow colours.



The temperatures are given with a 2°C interval and show the condensation points with 90% (bathroom) and 60% (living room) humidity level inside the house.

In the ceiling construction, the temperature curves inside the construction are lower near the corner. The condensation point for 90% humidity is below (before) the first moisture barrier of the ceiling. In this case, water drops can form and fall onto the board or gypsum ceiling.

When the room humidity is only 60%, the condensation point is above (behind) the first moisture barrier of the ceiling. When this moisture barrier is well sealed, no condensation will occur.

The entire wall construction is below the freezing point.

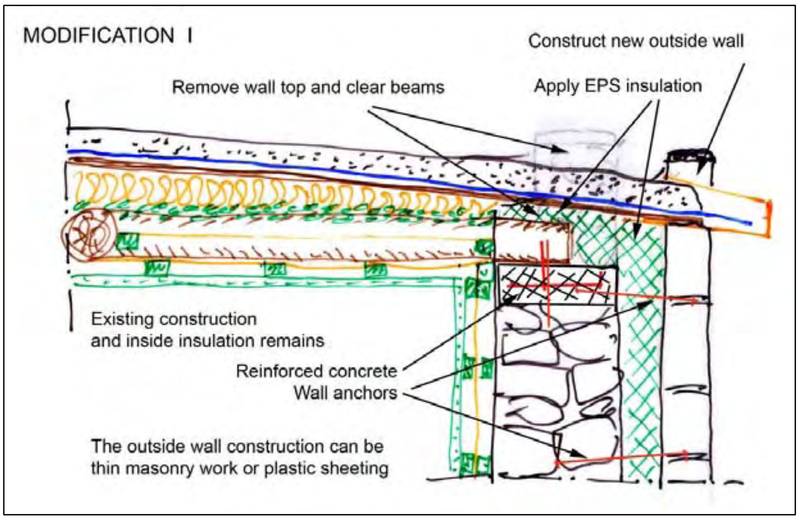
In the above case, water drops can form on the vertical plastic foil and drip down along the plastic to the ground. This will cause wet spots at the base of the wall board or gypsum panels. The only way to avoid this is to apply a second moisture barrier directly behind the board or increase the overall insulation value of the wall behind the moisture barrier.

Because the wooden roof support structure is supported in the cold wall, it can become moist or wet by hydroscopic action. When the upper wall is not totally sealed or when the side wall can absorb humidity, it will become moist. The frost will negatively affect the beams. The combination with the moisture may cause the beams to rot.

The condensation points for both the 90% and 60% humidity need to be well before the first moisture barrier.

The above situation can be avoided basically by two different measurements:

I. Creation of an outside insulating layer that fully envelops the beam structure and the existing wall, and keeps it dry during all seasons. The roof is extended.



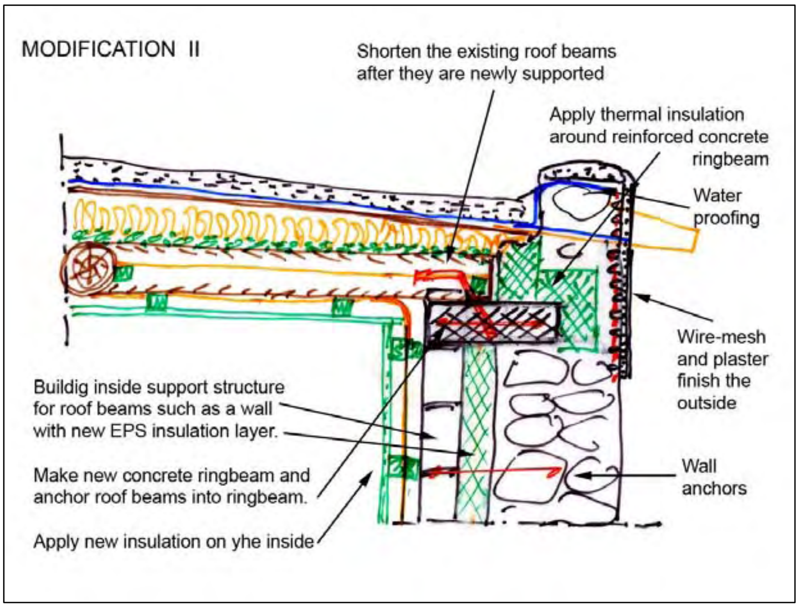
Allows the option of making a flat reinforced concrete tie- beam and attach the roof beams to this tie- beam.

This is necessary in all earthquake areas.

The new outside wall can be made of different materials.

The condensation point is now on the cold side of the humidity barrier.

II. The construction of an inside cavity wall with thermal insulation and supporting the shorter roof beams on the inside wall, inside the insulating layer.



Some room area will be lost when making the inside support structure over new insulation.

When the new insulation is much better than the old insulation, a new inside wall can be plastered. This will increase the thermal storage capacity of the wall as compared with a thin thermal insulation on the inside.

The condensation point is now on the cold side of the humidity barrier.

6. HEAT LEAKAGE AREAS (THERMAL BRIDGES)

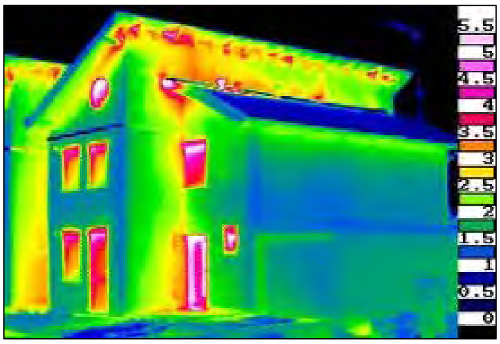
When insulating the outside shell of a building, the technical details of the construction must be known in order to determine possible heat leakage areas (thermal bridges). Warm air passes through such locations faster than the surrounding materials. Cold is the absence of heat. It is not the cold air coming inside, but rather the heat flowing outside.

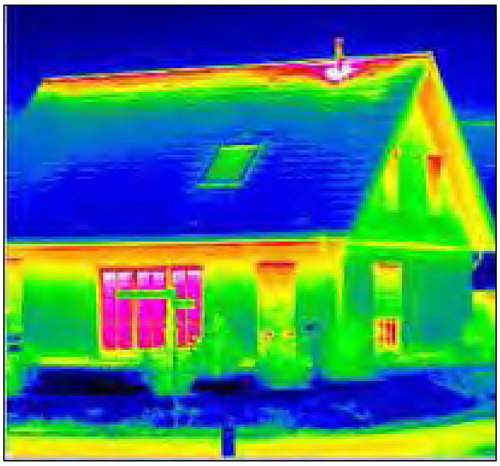
Door and window openings are obvious heat leakage areas as these are usually less insulated than the walls. Other heat leakage areas can be:

1. The solid construction of an inside cross or shear wall with the outside supporting wall.
2. The connection of a concrete floor or roof that is supported on the cold outside wall.
3. The construction of a reinforced concrete or steel frame balcony from which the supports are connected to the inside wall.
4. Reinforced concrete or steel profile lintels over doors and windows.
5. Reinforced concrete or steel profile columns inside the wall construction.
6. Reinforced concrete or steel profile beams or columns supporting the roof and supported on the outside walls.

Reinforced concrete constructions or steel profiles that are connected to both the outside and inside of the shell construction have a low insulation value compared with other building materials and a very low insulation value compared to insulation materials.

Heat leakage areas (thermal bridges) can be made visible with an Infra Red camera placed outside during the winter when the house is heated.[2] Reducing heat leakage areas will reduce heat loss and save energy. The pictures below are only indicative. The colour range shows to what extent heat is lost to the outside.





In the first photo, the highest temperature (light pink) is seen at the windows. Yellow and green are the middle ranges. The entire house is heated, but more heat loss occurs in the inside corner of the walls.

Blue is a lower temperature, therefore less heat leakage. The inclined roof is well insulated because the colour is dark blue.

The insulation under the higher roof line is poor, shown by the red colour. Here the cavity wall insulation apparently has settled down, creating a heat leak.

In the second photo, the low insulation value of the large window on the ground floor can be seen.

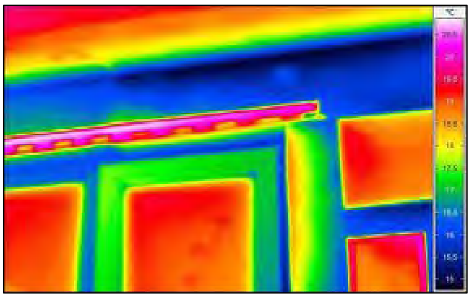
The warmth in the building rises and heats the first floor construction (ceiling of the ground floor). Because the first floor construction is supported against/on the outside wall, that area shows a high heat loss to the outside.

The inclined roof construction is insulated, but the area around the chimney and roof ridge is a heat leak, shown by the red colour.

[2] IR photography should be done perpendicular to the measured surface, without sun or wind (early morning), and with a temperature just above freezing point. The background temperature and material emissivity must be correctly entered.

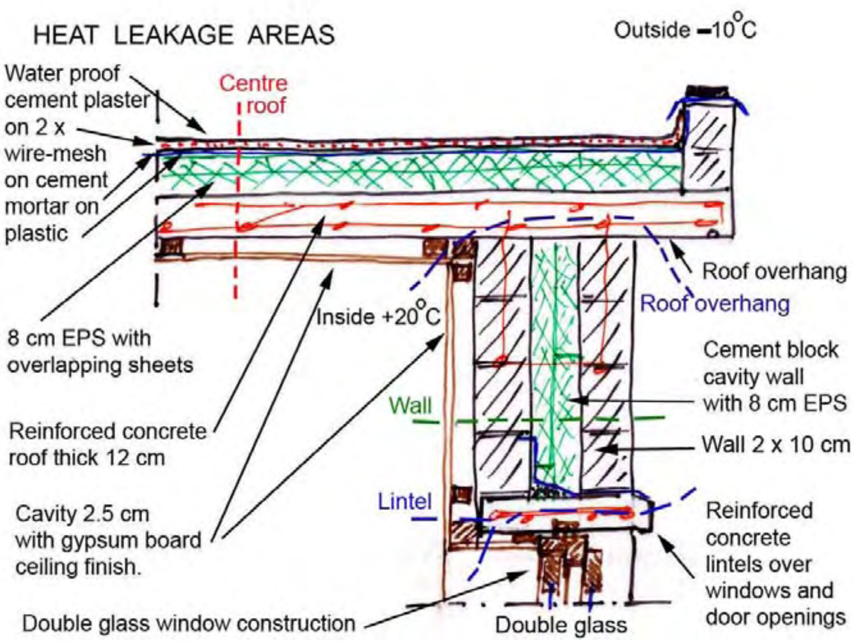
The wall (blue) and window frame (blue) with window construction shows the glass frame (green) being better insulated than the glass surface (red-orange).

Above the window, the supporting concrete or steel lintel construction is not insulated and the heat loss in this area is very large (pink). In this case, condensation can occur on the lintel above the window.



The same can be calculated before the construction is made. By calculating the possible heat loss areas, it can be avoided that condensation occurs inside the house. Condensation inside the construction may cause structural damage and reduce further the insulation value, while cold inner surfaces can be the cause of mould growing on the walls, ceilings and floors.

To illustrate the different temperature flows inside a construction, the following example has been analysed and calculation tables made for the various sections over the wall and roof.



Roof Centre (Red Line): Wire-mesh cement plaster (2 cm), EPS (8 cm), reinforced concrete (12 cm), cavity (2.5 cm), gypsum board (1 cm). Thickness x R_M = R_C					New Value	The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x $\triangle$T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-9.51	0.49		
2	Ferro-cement (wet)	0.02	0.6	0.012	-9.36	0.15	At 12°C	
3	EPS medium density	0.08	25	2.00	15.23	24.59		At 15°C
4	Reinforced concrete (dry)	0.12	0.6	0.072	16.11	0.88		
5	Cavity GBM-GBM	0.025	**Black**	0.16	18.08	1.96		
6	Gypsum board	0.01	6	0.06	18.81	0.74		
7	Inside transmission factor	-	-	0.10		1.23		
Value Total R_C				**2.44**	-20ºC	$\triangle$T=30ºC		

Heat flow Λ = 0.41 W/m^2.K = 12.3 W/m^2 for 30°K.

Roof Overhang (Blue Line): Reinforced concrete (trajectory 35 cm), timber (2.5 cm), Gypsum board (1 cm).			Thickness x R_M = R_C		New Value	The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x △T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-7.76	2.24		
2	Reinforced concrete (dry)	0.35	0.6	0.21	4.01	11.77		
3	Timber	0.025	5	0.125	11.02	7.01	At 12°C	
4	Gypsum board	0.01	6	0.06	14.38	3.36		At 15°C
5	Inside transmission factor	-	-	0.10		5.61		
			Value Total R_C	**0.535**	-20ºC	△T=30ºC		

Heat flow Λ = 1.87 W/m^2.K = 56 W/m^2 for 30°K.

Wall (Green Line): Cement blocks (10 cm), EPS (8 cm) cement blocks (10 cm), cavity (2.5 cm), gypsum board (1 cm).			Thickness x R_M = R_C		New Value	The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x △T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-9.53	0.47		
2	Cement block wall (moist)	0.10	0.6	0.06	-8.82	0.71	At 12°C	
3	EPS	0.08	25	2.00	14.80	23.62		At 15°C
4	Cement block wall (dry)	0.10	0.7	0.07	15.63	0.83		
5	Cavity GBM-GBM	0.025	Black	0.18	17.76	2.13		
6	Gypsum board	0.01	6	0.06	18.47	0.71		
7	Inside transmission factor	-	-	0.13		1.54		
			Value Total R_C	**2.54**	-20ºC	△T=30ºC		

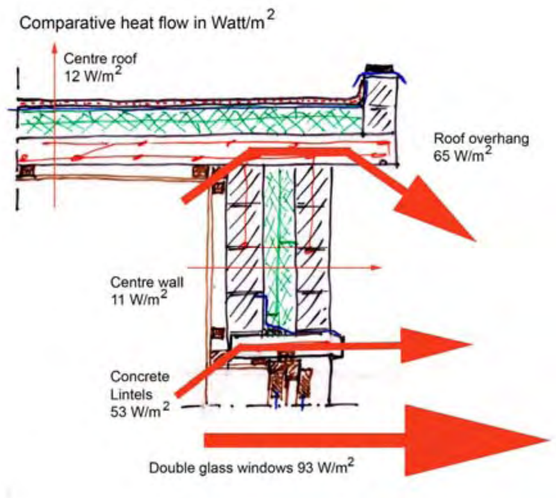
Heat flow Λ = 0.39 W/m^2.K = 11.8 W/m^2 for 30°K.

Lintel Window (Blue Line): Reinforced concrete (trajectory 30 cm), timber (2.5 cm), gypsum board (1 cm).			Thickness x R_M = R_C		New Value	The humidity condensation point is determined with the Mollier diagram.		
#	Description of the Existing Construction Layers	Thick Meter	R_M	R_C	Temp from -10ºC	Temperature Difference= Rc / TRc x △T	Condensation with 60% Humidity	With 90% Humidity
1	Outside transmission factor	-	-	0.04	-7.86	2.14		
2	Reinforced concrete (dry)	0.30	0.6	0.18	1.87	9.64		
3	Cavity GBM-GBM	0.025	Black	0.18	11.42	9.64	At 12°C	
4	Gypsum board	0.01	6	0.06	14.63	3.21		At 15°C
5	Inside transmission factor	-	-	0.10		5.36		
			Value Total R_C	**0.56**	-20ºC	△T=30ºC		

Heat flow Λ = 1.79 W/m^2.K = 53.7 W/m^2 for 30°K.

Double glass window R_C = 0.32 m^2.K/W with heat flow 3.125 W/m^2.K = 93W/m^2 for 30°K.

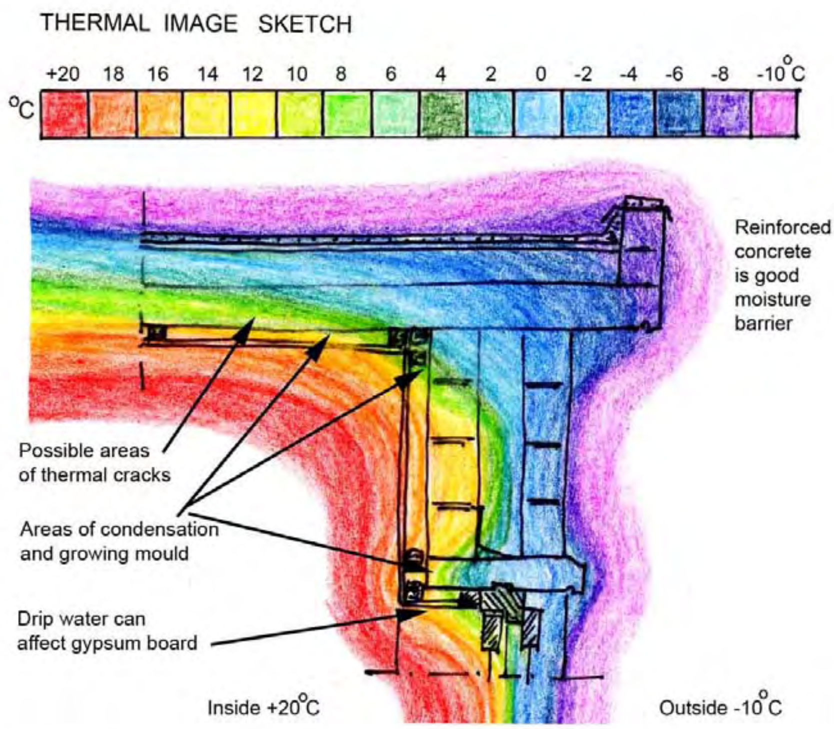
The following sketches give an impression of the comparative heat flow for each of these sections and the rainbow thermal image.



The calculations above show that the largest heat loss in Watt per m^2 is through the window. The lintels above the doors and windows have about half the heat loss per m^2 surface than the windows, but also their surface is much smaller than that of the window.

The roof overhang area, however, is over the entire length of the roof with the largest heat leakage in the corner.

Condensation of the inside humidity will occur foremost on the glass window, as well as near the lintels and the wall-roof corner. Given this large surface, it is important to design the thermal insulation of the roof-wall connection differently.



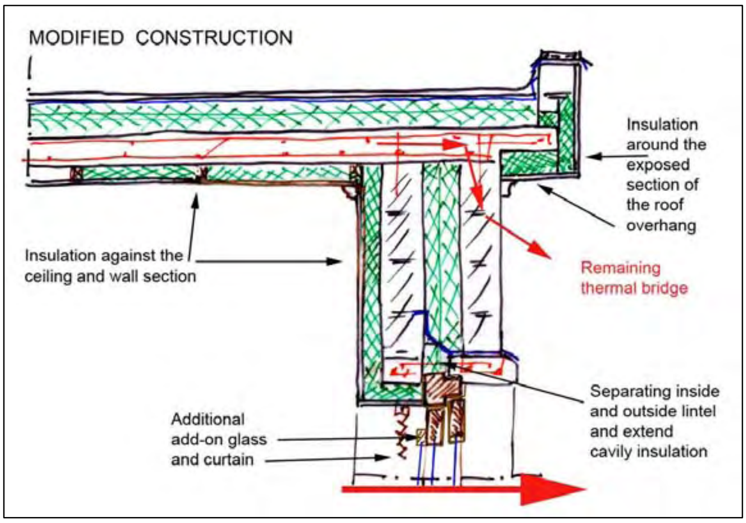
Both glass windows need easy drainage for the condensation water to go outside

The approximate effect of the inside-outside connecting reinforced concrete roof construction is made visible in the above sketch. Because the central concrete section of the roof structure will be +10°C (warm) and the outside rim of the roof -6°C (cold), thermal cracks can occur over the wall support.

Without high efficiency insulation glass with Argon/Krypton and heat reflective coatings, a third glass window and roll curtains can improve the insulation value of the window area.

The thermal bridge is caused by the non-insulating concrete roof overhang and the connection between the concrete and the outside support wall. Insulation is needed over an extended length of the ceiling and the inside upper wall to insulated both the concrete and inside block wall. When the R_C of the 8 cm EPS = 2 m^2.K/W, and the R_M of concrete is 0.6 m^2.K/W, the maximum length of the thermal bridge is 2/0.6 = 3.3 m. This length can be reduced by insulating the outside overhang of the roof. A similar situation applies to the inside wall supporting the roof.

In the sketch right, the window lintel has been divided into two elements and the cavity insulation is continued downwards. In addition, the inside wall insulation has been improved.



The roof design has added insulation on the outside overhang, as well as on the inside against the roof and the wall. Although this will minimise condensation problems, a thermal bridge with the outside wall section under the roof overhang still remains. This outside wall stays cold and has full contact with the inside reinforced concrete floor.

The desired roof insulation value is R_C = 2.44 m^2.K/W.
The insulation of the thermal roof bridge is R_C = 0.53 m^2.K/W, a difference of R_C = 1.91 m^2.K/W.
The insulation added to the ceiling and inside wall is 4 cm EPS = R_C = 1.00 m^2.K/W.
With the concrete R_C = 0.6 m^2.K/W, the insulation should extend 1.7 m from the outside wall or about 1.4 m from the inside wall surface.

The remaining insulation to reach the same insulation level of the central roof area or the wall construction is R_C = 0.9 m^2.K/W. This would mean 8 cm EPS against the ceiling for 1.5 m from the wall support and a further 1.5 meter of 4 cm EPS, in total about 3 m.

The above calculation shows that although the concrete roof is well insulated on the outside, the thermal bridge at the supports requires application of another insulation layer below the ceiling, between 2 m and 3 m wide; practically under the entire roof. The most effective way to reduce such a thermal bridge is full insulation on the outside and on the outside supporting wall. This can be less expensive than adding a full layer of insulation to the whole ceiling.

A better solution is if the inside supporting construction, including the roof, is thermally not connected to the (cold) outside construction.

Many existing buildings with reinforced concrete roofs cannot easily be modified and inside thermal insulation is then the most economical or practical option. It must be ensured that any timber construction elements are not affected by moisture from condensation.

Resume

- With IR photography, a reasonable indication can be obtained of the potential heat leakage areas (thermal bridges) during the winter situation.
- With an IR measuring instrument, the same information can be obtained from either the inside of the building or from the outside, measuring many points under the same conditions.
- Knowing the construction details and making the temperature calculation for a winter situation gives a good indication of the thermal bridge areas.
- Insulating thermal bridges from the outside can avoid condensation on the inside and thermal cracks in reinforced concrete constructions.
- Insulating on the inside should be done with humidity blocking constructions located on the warm side to avoid condensation. Joints in critical areas need to be taped.

7. FIRST THERMAL INSULATION, THEN SPACE HEATERS

Although this paper deals with the calculation of thermal insulation value, it is important to repeat the information that better insulation should be realised before improving the stove.

When the house is too cold in the winter, it is very tempting to improve the stove with a heat exchanger that provides 25% more heat. However, the additional heat will be immediately lost to the outside when the building is not additionally insulated. The effect is that the people are only temporarily a little warmer during the period the new stove is burning.

People formerly cold in the winter and now having a new more efficient space-heating stove with a heat exchanger will tend to increase the inside temperature of the room. With increasing the room temperature, the ΔT between the inside and outside temperatures will also increase and with that the speed of heat loss. At the moment the new stove is no longer burning, the temperature will immediately drop again to the low temperature because the additionally generated heat is not retained in the room.

The overall effect is that the new stove/heat exchanger in the old (non-insulated) room will consume only slightly less firewood (not the 25%) and the long-term comfort will hardly increase. Although the stove/heat exchanger efficiency may be 25% better than the old stove, the actual firewood saving will be no more than 10%.

When the room is insulated, the stove/heat exchanger will produce 25% more heat for the same amount of firewood. In this case, the stove/heat exchanger will warm the room faster and the actual firewood saving will be far more than the 25% because less air from outside will be needed to keep the stove burning.

Use of the heat exchanger (left) and bread-baking oven (right, placed on an ICS, with cover).

The heat exchanger works more efficiently if the oven door is open and the extra cover is removed.

Baking round breads (25 cm diameter) has the best results in heat exchanger models having an additional cover to retain the heat while baking. After completing the bread baking, the two insulating halves of the cover can be removed and stored.

Because thin metal space heating stoves have a limited lifetime, the house owner will need to buy a new stove regularly. When doing so, a more firewood-efficient stove with heat exchanger should be purchased, but it does not eliminate the need for better house insulation which will be functional during the lifetime of the building and saves on firewood or other fuel.

ANNEXE I THERMAL INSULATION FORM

for Old and New Construction

Place for sketch with numbers of each layer.

Make one sheet for every type of construction.

Construction:				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 ºC	Material in …….	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission factor	-	-					
2								
3								
4								
5								
6	Inside transmission factor	-	-					
	Subtotal Existing Construction R_C							
#	Description of Each New Layer or New Activity to Install Insulation	Thick Meter	R_M	R_C	Temp ºC	Material In……	Skilled Labour Cost	Non-skilled Labour
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
	Subtotal Newly Added Value R_C							
	Total Existing and New R_C Values					***Total Cost 10 m^2***		
	Altitude Above Sea Level Building _______ m	Recommended R_C Value		2.0 - 2.5 3.0 - 3.5 4.0 - 4.5	△T	Ratio = Total Cost / R_C Total		

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