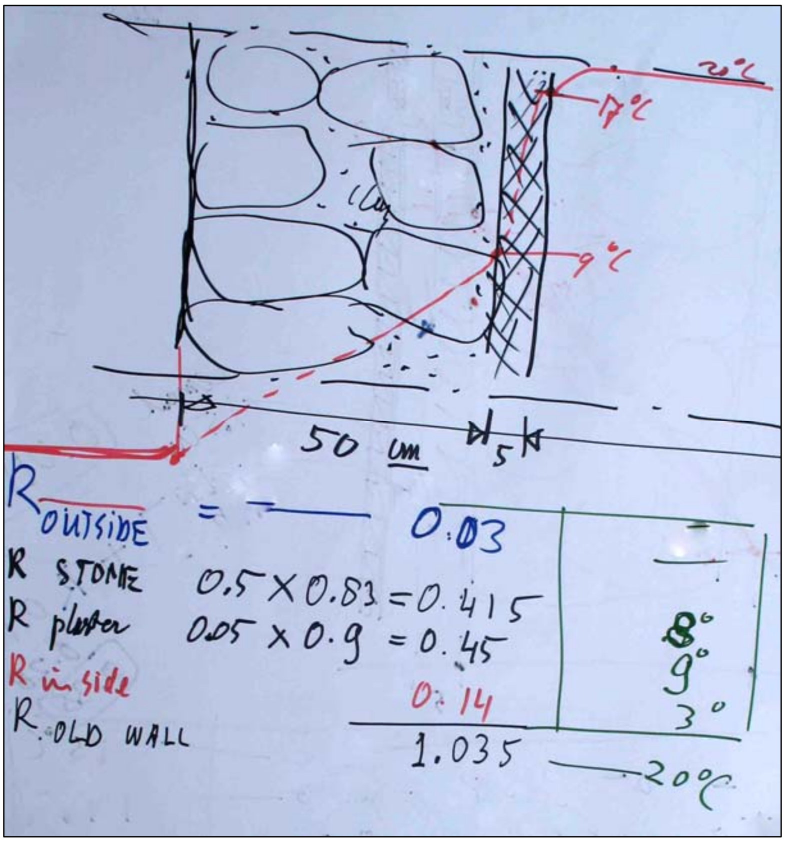
HUYS ADVIES

CALCULATION OF THERMAL INSULATION

Technical Working Paper ~ Number 2



Report by:
Sjoerd Nienhuys
Renewable Energy Advisor
www.nienhuys.info

August 2011
(updated)

TABLE OF CONTENTS

INTRODUCTION 1

1. CALCULATION OF INSULATION VALUES 2

1.1 Relating the Construction Cost to the Added Insulation Value 2
1.2 Calculation of the Temperature Curve 6
1.3 Mollier 6
1.4 Calculation of the Dew Point 8
1.5 Effect of Ventilation 10
1.6 Need for Trickle Ventilation 11

2. COMPARISON OF CALCULATED VALUES 12

ANNEXE I MATERIAL CHARACTERISTICS 14

ANNEXE II THERMAL INSULATION FORM 20

ANNEXE III PRACTICAL EXAMPLES 21

NOTES:

Changes from Version March 2011:
- Chapter 2 – Comparison of Calculated Values
- Clarification of air layer insulation in Annexe I
- Adjustment of reflective foils in table Annexe I
- Clarification: ground floor insulation is minimal half of ceiling/roof insulation value

Changes from Version May 2011
- Paragraphs 1.5 and 1.6 have been added
- Annexe II with an example of a technical advice

Photo on Cover Page

Part of flip chart used during training course with a calculation of a wall with simple insulation.
The supply of the overview table of insulation values (Annexe) is an important tool 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 in 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 compare the old with the new insulation value and make an informed decision about the planned insulation action. This paper is linked with Technical Working Paper #1 ~ BASICS.

This document also provides the minimum recommended thermal insulation values for buildings in high altitudes of the Himalayan region. These values are still lower than the thermal insulation values of comparable regions in Europe, according to the newest European Insulation Standards.[1] On the other hand, these values are considerably higher than current building practice in the higher altitude mountain areas. Applying these values will substantially increase comfort and lower heating expenses for the lifetime of the building.

The objective is to develop the working papers so they can eventually be used as the basis or reference for curriculum development. 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.
- Table of thermal insulation values of different materials and air cavities.

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 methods for thermal efficiency of buildings in Europe are more complex than simple calculation of the thermal insulation values of building components and include equipment as well as customer behaviour.

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 or unskilled labour or buys/contracts the entire house improvement.

Fact sheets are an important instrument. 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. With retrofitting of an existing building, most likely some old, heavy roof layers and rubble-clay masoned walls will have to be removed; these costs should be included as well.

For typical ceiling, roof or wall insulations, basic price indications can be presented for 10 m^2 wall or roof 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 ratio.
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 ratio, being a lower cost ratio per added insulation value and thus a more economical (better) investment.

From each insulation option, the total cost should be analysed against the expected insulation value. Only in this way can an informed decision be made. The installation cost should be qualified in materials, skilled labour and unskilled work (done by the house owner). When the materials are supplied by the house owner, the material cost will be different than when purchased.

A drawing will assist when calculating the difference between the old and new solution. Along with the drawing, a calculation table of each insulation solution should be made.

The table in Annexe I listing the most common types of building materials should be referred to for calculating each layer of material. The specific weight is given in the second column and the $R_{material}$ value of that material in the last column. The total of the construction can be calculated by adding all the R_m values of the construction and the specific transmission factors for inside and outside constructions. The following is a small sample of the complete table in Annexe I.

W=Watt, m=meter, K=Kelvin, $R_m = 1/\lambda$. 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.*

#	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*

The material to air transmission values are also given in the Annexe I table as follows:

	Transmission Resistance	λ=W/m.K	R_s=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 in meters of the material times the R_m value. Light green boxes are added up to the dark green box. The cost of removing the old materials can be added in the right-hand section.

In the second section, the proposed or new construction material 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 to the blue box.

The material costs are mentioned in the right-hand side of the table. In this case, all the values have been calculated for a 10 m^2 section, a common surface size in houses. These costs are divided in material costs, skilled labour (hired craftsman or contractor) and the unskilled labour.

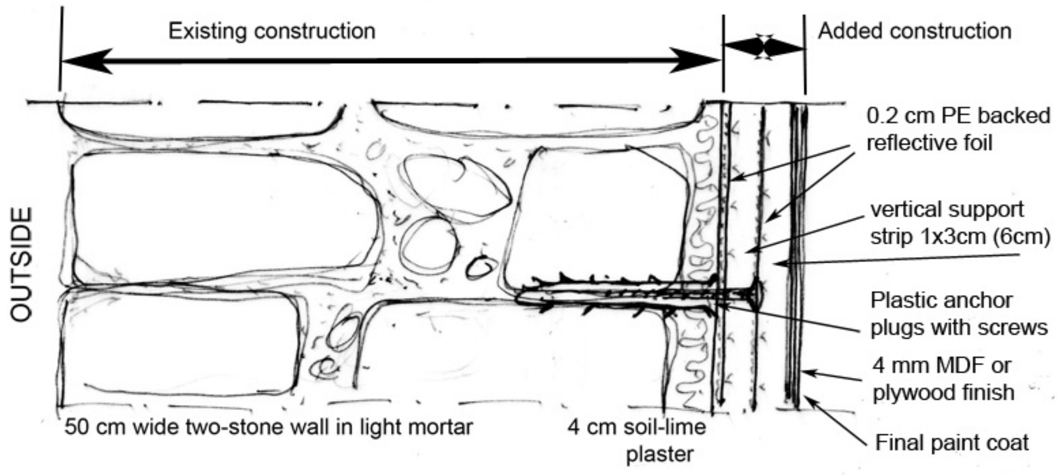
Added to the second section of the list are also the finishing costs, such as electric wiring, plumbing, paint, transport and cleaning, which of course do not have thermal insulation values. These values are added up per column and then added up as a total in the yellow box.

Construction: Two-stone wall with soil plaster inside, insulated with two layers of reflective foil and plywood finish					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	Finishing Material E						
13	Transport and Cleaning F						
Subtotal Newly Added Value R_c							
Total Values of R_c and Total Construction Cost 10 m²					*Total*	*Costs 10 m²*	
Altitude Above Sea Level Building		2200 m	Sun Hours	6	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.
Note: The financial figures are not real and serve only as an example.

Example 1

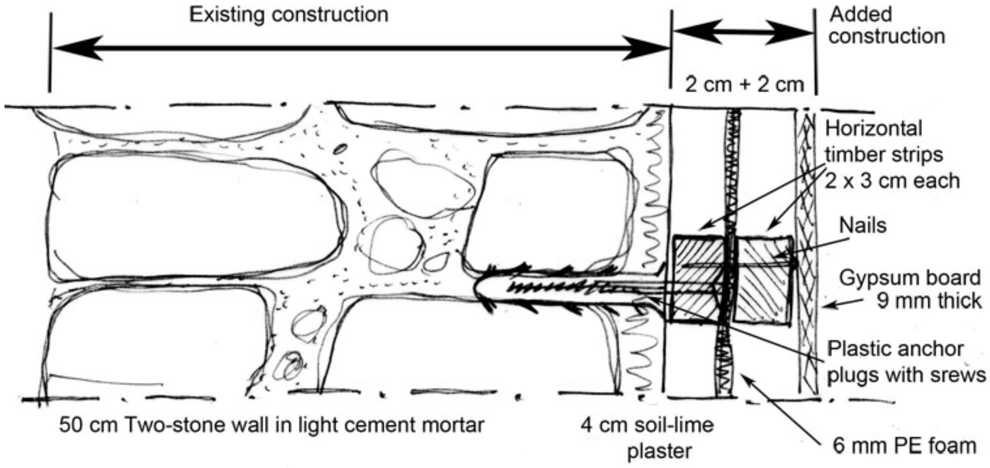


Construction: Two-stone wall with soil plaster inside, insulated with two layers of reflective foil and plywood finish					Surface Unit of Estimation: **10 m^2**		
#	Description of the Existing Construction Layers	Thick Meter	R_m	R_c	Material in PKR	Skilled Labour Cost	Non-skilled Labour
1	Outside transmission 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	One 0.2 cm PE reflective foil	=	=	0.65	*600*	*20*	*10*
11	1 cm x 3 cm support strips every 50 cm vertical	x	x	x	*100*	*30*	*15*
12	1 cm x 6 cm 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	=	=	0.65	*600*	*10*	*05*
15	1 cm x 6 cm support strips at joining sheets locations	x	x	x	*100*	*10*	*05*
16	Staples 6 mm long (25/m^2)	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*
20	Cleaning and waste removal	x	x	x	*x*	*x*	*self*
Subtotal Newly Added Value R_c				**1.584**	*3385*	*330*	*115*
Total Values of R_c and Total Construction Cost 10 m^2				**2.128**	*Total*	*Cost 10 m^2*	*3830*
Altitude Above Sea Level Building		2200 m	Sun Hours	6	Ratio = Total Cost / R_c Total		***1800***

A house owner should be presented with various calculation charts and sketches to compare the different insulation options.

Example 2

The house owner does not want the two reflective foils, but wants 6 mm PE foil 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					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	One air layer 2 cm vertical	=	=	0.175	*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	One air layer 2 cm vertical	=	=	0.175	*x*	*x*	*x*
16	Staples 6 mm long ($5/m^2$)	x	x	x	*10*	*x*	*x*
17	9 mm gypsum carton board	0.009	1.66	0.015	*1000*	*60*	*100*
17a	Closing joints with tape plaster	x	x	x	*200*	*100*	*x*
18	Painting white wash	x	x	x	*85*	*self*	*x*
19	Total transport costs to village	x	x	x	*400*	*100*	*x*
20	Cleaning and waste removal	x	x	x	*x*	*x*	*self*
Subtotal Newly Added Value R_c				**0.497**	*2895*	*410*	*180*
Total Values of R_c and Total Construction Cost 10 m²				**1.041**	*Total*	*Cost 10 m²*	*3485*
Altitude Above Sea Level Building		2200 m	Sun Hours	6	Ratio = Total Cost / R_c Total		***3448***

Because the material cost is slightly lower and the insulation value is much lower, the ratio of cost / R_c is almost twice as high. This second option is therefore NOT a good option if the first can be realised.

The same diagram and table can also 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 PE foam is both an insulator and a moisture barrier.

In theory, it is possible to calculate the economic recovery cost of any 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.

Data Development
The material characteristic chart in Annexe I provides an overview of the most relevant data and information on material density and thermal insulation.

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 during one 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.
  - ◊ The presence of a fireplace with an ongoing fire. This consumes oxygen in 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, this is 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.

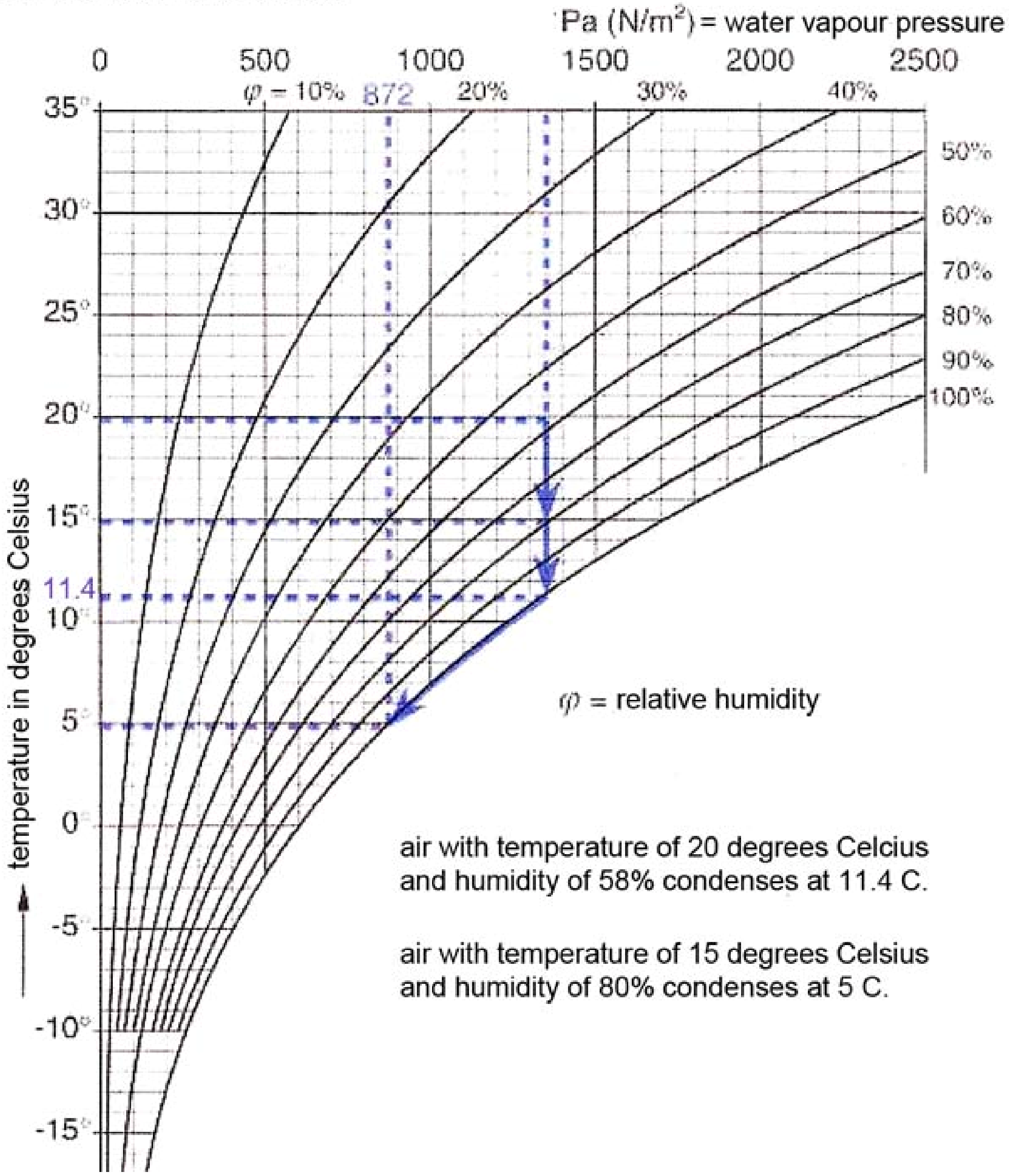
1.3 Mollier

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 construction. That way the humidity cannot enter into the construction. Such a foil seal should be precise and without gaps. Adjoining plastic foils need to overlap and be stapled or taped together. For reflective foils, aluminium coated tapes are available in the market.

MOLLIER DIAGRAM



In mountain areas, the outside air humidity drops to low levels during the winter. When the dry air enters the 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 one night, people breathe out about one litre of 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 room structure (roof or walls).

Kerosene or gas space heaters also produce large amounts of water vapour as exhaust gasses.

1.4 Calculation of the Dew Point

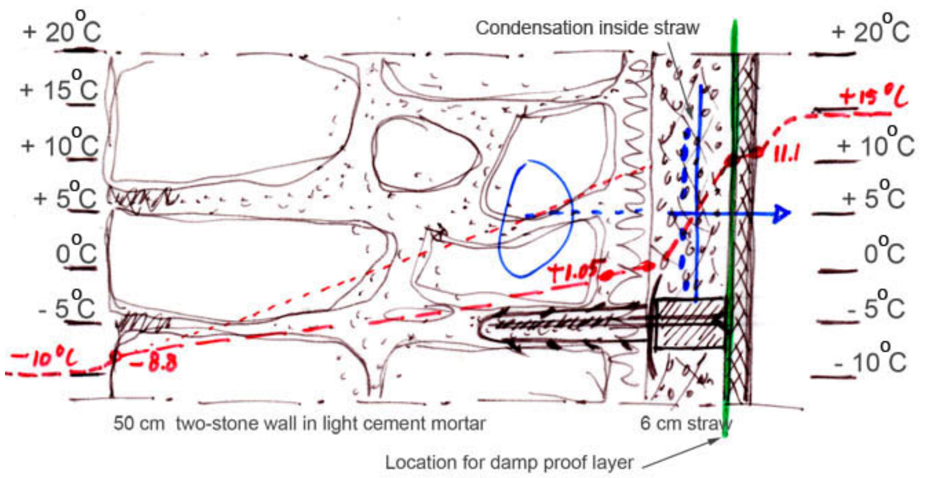
To calculate the condensation point, the same type of table as above is used, but an extra column is added for the temperatures per construction layer; the point temperature difference (T_p).

$$T_p = \frac{\text{Insulation value } R_c \text{ of total construction before the measuring point}}{\text{The total insulation value } R_c \text{ of total construction}} \quad X \quad (\triangle T \text{ inside - outside})$$

T_{p1}	=	0.040/0.837	x	25°C	=	**1.19°C**	difference	**-10°C**	**plus**	**1.19°C**	=	**- 8.8°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°C**

Construction: Two-stone wall with 2 cm soil plaster and 6 cm straw insulation and gypsum board finish on the inside						Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_m	R_c	Temp	Material in €	Skilled Labour	Non-Skilled
0	Outside temperature				**-10°C**			
1	Outside transmission factor	=	=	0.040	**-8.8°C**			
2	Two-stone wall in light mortar	0.5	0.66	0.330	**+1.05°C**			
3	Soil lime plaster inside 2 cm	0.02	1.1	0.022	**+1.07°C**			
4	One layer straw 6 cm	0.06	5.0	0.300	**+10.67°C**			
5	9 mm gypsum carton board	0.009	1.66	0.015	**+11.12°C**			
6	Inside transmission factor	=	=	0.130	**+15°C**			
7	Inside room temperature				**+15°C**			
Total Values R_c and €				**0.837**	**25°C**			
					△T			

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 or PE foam.



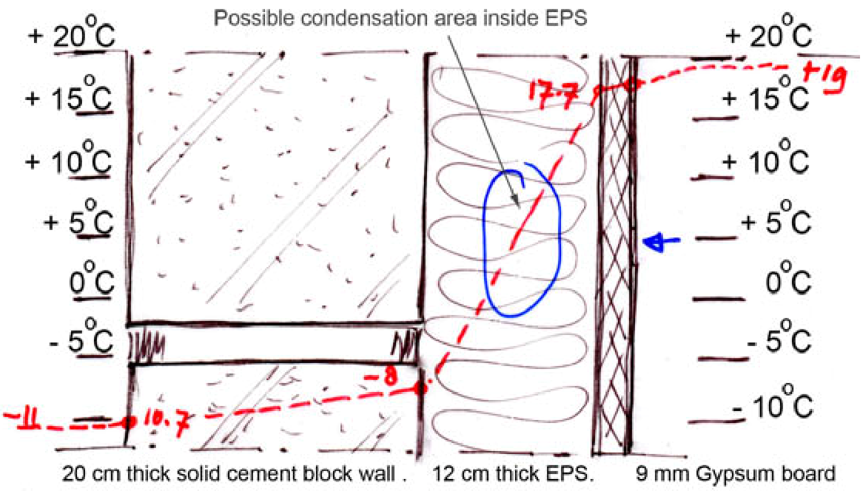
If the inside straw insulation did not exist, the condensation would have occurred inside the two-stone wall in the blue circled zone.

The following example shows a solid cement block wall with an Expanded Polystyrene (EPS) insulation on the inside, covered with a 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 and 6 cm straw insulation and gypsum board finish on the inside						Surface Unit of Estimation: **10 m²**		
#	Description of the Existing Construction Layers	Thick Meter	R_m	R_c	Temp	Material in €	Skilled Labour	Non-Skilled
0	Outside temperature				**-11.0°C**			
1	Outside transmission factor	=	=	0.040	**-10.7°C**			
2	Cement block wall in mortar	0.2	1.54	0.308	**-8.0°C**			
3	One layer EPS 12 cm	0.12	25.0	3.00	**+17.7°C**			
4	9 mm gypsum carton board	0.009	1.66	0.015	**+17.9°C**			
5	Inside transmission factor	=	=	0.130	**+19.0°C**			
6	Inside room temperature				**+19.0°C**			
Total Values R_c and €				**3.493**	**30.0°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.



Since many constructions are similar per region (the old situation as well as the possible new situations), the development or training organisation can develop a folder with the 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 in Annexe II can be used.

1.5 Effect of Ventilation

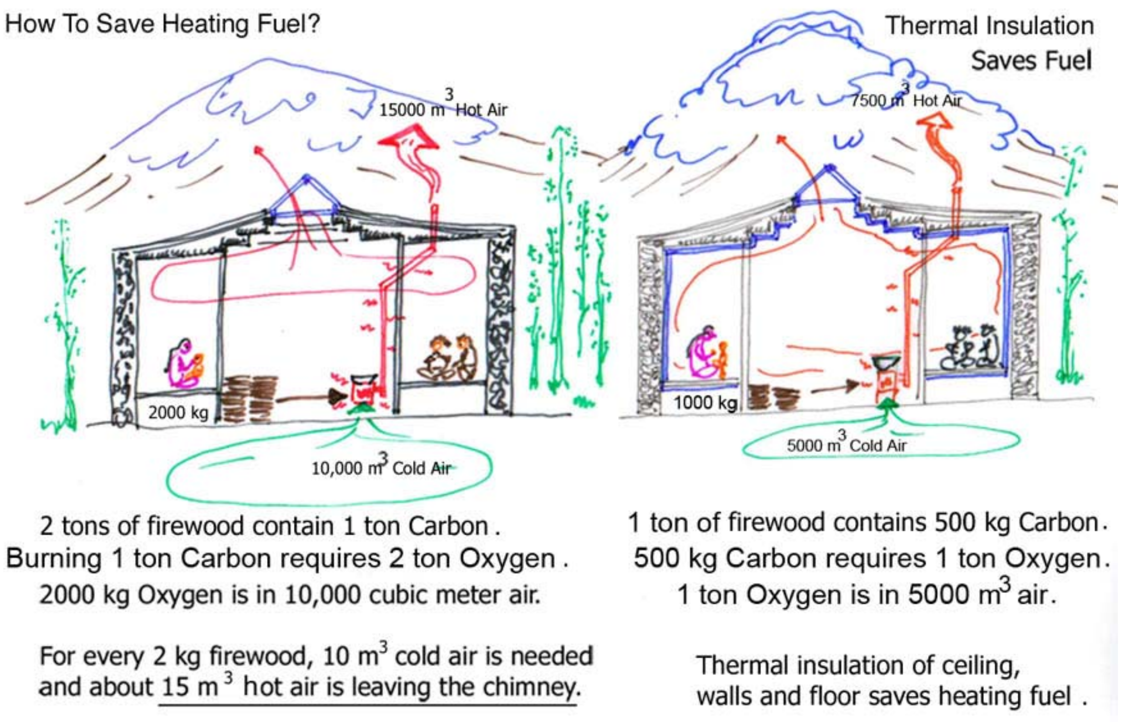
Heat loss through building materials and constructions is caused by three main factors:

- 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%).
- Convection of air circulating around the materials. The air picks up heat from warm surfaces and releases the heat against colder surfaces (~ 15%).
- Radiation (infrared) from a warm surface to a colder environment (~ 65%).

In addition, there is some heat loss from the humidity exchange passing through these building materials. In frost areas, this is little.

Air has a low heat storage capacity. This is why it is possible to ventilate a 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 stony materials.

Firewood or coal heating stoves, however, 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.[2]



This large quantity of fresh air is coming from outside as long as the stove burns and thus adding to the need for heating. Making hermetically closed doors and windows with a fuel-consuming stove is not good. For the above reason, it is double effective to insulate first before modifying the stove because with better insulation, the stove is less required.

---

[2] 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 Need for Trickle Ventilation

Apart from supplying oxygen for the burning process in the space-heating stove, ventilation is necessary for expelling the used air and supplying fresh air in a room. Constant trickle ventilation is therefore important for living rooms and especially in bedrooms. For rooms without a fuel-burning device, a recommended minimum amount of trickle ventilation opening of 12 cm^2 (2 sq.in.) per person is advised. 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 one 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 a non-electric space-heating stove in the (bed) room, such as firewood (requires a chimney), charcoal, kerosene or gas stoves, need a large amount of additional ventilation to remove the (poisonous) burning gasses and the humidity from the room and refresh the air. These stoves should not be used during sleeping hours.

The photo shows the large amount of condensation (on 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 of the walls will reduce, causing more heat loss.

2. COMPARISON OF CALCULATED VALUES

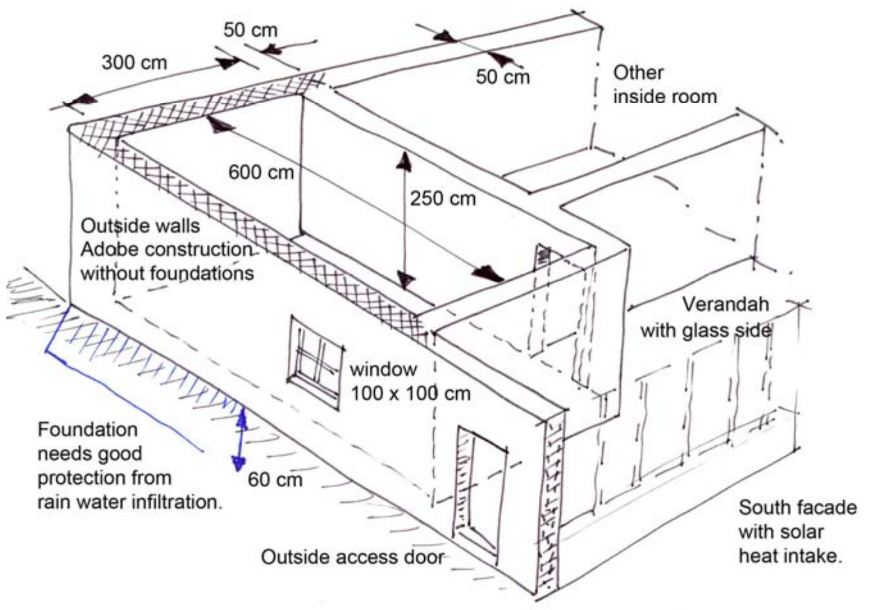
The farmhouse sketch below has a large veranda with one inside room of 3 m x 6 m. The insulation values of the outside walls, ceiling, window and floor were calculated. The figures have been collected in the table below with current and proposed insulation values. The pink values of the ratio are based on the 10 m^2 surface unit. The cost estimates are in Tajik Somoni.

Tajikistan
Baljuvon District
Tupkhona Village
Altitude 1500 m

Request for thermal insulation of the 3 m x 6 m winter room with two outside walls.

Hand-packed adobe wall structure without foundation.

TYPICAL SITUATION SKETCH OF WINTER ROOM



Recommended for Altitude 1500 m		Current R_C = m^2.K/W	Surface Divided by R_C = Energy Loss in Watt / ºC / Hour	Proposed Type of Insulation with New R_C = m^2.K/W	Cost Estimate	10 m^2 Ratio = Cost / New R_C
Building Element	Inside Dimensions	x	Larger Surface = Larger Heat Loss	2.0	x	x
Ceiling	3 m x 6 m = 18 m^2	1.59	11.3	+16 cm straw-lime on top 3.19	TJS 212	36
Floor	3 m x 6 m = 18 m^2	0.245	73 see note (37)	Excavate +20 cm straw-soil + 4 cm EPS + board 1.85	TJS 702	251
Walls	(3+6 m) x 2.5 = 22.5 m^2	1.17	16.9	+2 reflective foils + board 2.08	TJS 810	170
Window	1.5 m^2	0.40	2.5 to veranda	Extra frame with single glass + roll curtain 0.65	TJS 250 1.5 m^2	2564
Door	2 m^2	0.2	Going to veranda	x	x	x
Total	Insulated 60 m^2	x	>>>>>>>>>>>>	Tajikistan	**1974**	Somoni

Notes: 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 the walls or roof with the same R_C.

The total amount of heat loss is a relation between the total surface (m^2), the total temperature difference between inside and outside ($\triangle T$), and the 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 value than the ceiling, but is almost five times better insulating than the floor. The $\triangle T$ 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 a 1 cm PE foam $R_C = 0.01 \times 22 = 0.22\ m^2.K/W$. Although the added insulation value is small, the added comfort is large and subsequently the heating demand and firewood consumption will be sharply reduced.

From the shaded column, it can be noted that the total heat loss from the existing window (2.5) is not very large due its location towards the veranda. The total heat loss to the floor (37) is three times that of the ceiling (11.3). The walls have in total 40% more heat loss (16.9) than that of the ceiling (11.3).

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 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).

Cost Analysis

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 (TJS 212), assuming the house owner supplies the straw himself.

Floor insulation is essential and can be mainly accomplished with local materials. The proposal includes the option of insulating the floor with EPS panels. This is a fast way to insulate the floor efficiently during any time of the year. The 4 cm EPS is not affected by moisture, is easy to transport and can be self applied (TJS 702).

The foundation needs additional protection against water infiltration from the outside. The cost of a gutter and/or water storage tank is not included in the above estimate, but is an important pre-condition for insulating the house and keeping it dry. The cost of applying the asphalt sheeting (TJS 45 / roll of 15 m^1) or that of 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 with 15-20 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 to 4 mm) having about the same purchase cost, but with lower transport cost and easier application (TJS 810).

The house owner must be informed of all the technical options with their insulation values and implied costs as ultimately it is the family who must make the final decision and this should be an informed decision based on detailed information.

ANNEXE I MATERIAL CHARACTERISTICS

W=Watt, m=meter K=Kelvin $R_m=1/\lambda$ Calculation of $R_c = R_m$ x thickness in m, value in $m^2.K/W$
Bold are tested figures. *Cursive is estimates based on comparison.*

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W
1	**0.05**	**Vacuum 95%**	**0.001**	**1000**
2	0.8	Krypton gas (insulation gas in double glass, high cost)	0.009	110
3	0.9	Argon gas (insulation gas between double glass windows)	0.017	59
4	30	Expanded vermiculite (made impermeable)	0.017	59
5	**1**	**Dry air at sea level**	**0.023**	**43**
6	**1**	**Air, low humidity**	**0.025**	**40**
7	**25**	**Gas-filled expanded Polyurethane**	**0.02**	**50**
8	10	Resol foam	0.02	50
9	30	Fibre glass fibres spray-blown with adhesive	0.02	50
10	20	Polyisocyanuraat foam (PIR) from Recticel (brand name)	0.02	50
11	25	Low Density Polyethylene foam underlay (PE), grey	0.045	22
12	**20**	**Extruded Polystyrene, Expanded Polypropylene (EPP)**	**0.034**	**30**
13	**22**	**Expanded Polystyrene (EPS), low-medium-high density**	**0.04**	**25**
14	20	Poly-Isocyanurate plastic foam (PIR), two-component material	0.03	33
15	10	Polyurethaan (PUR)	0.04	25
16	**11**	**Vermiculite**	**0.05**	**20**
17	**15**	**Sheep wool expanded blanket 90%, borax 10% (factory)**	**0.039**	**25**
18	15	WoolBloc™ or Latitude® natural wool	0.035	28
19	*200*	*Non-compacted corrugated cardboard from boxes*	*0.07*	*15*
20	125	Glass wool Ecotherm or Knauff (factory), joints sealed	0.03	33.3
21	**150**	**Glass wool, loose (6 to 12 cm blankets)**	**0.04**	**25**
22	**160**	**Rock wool, loose (6 to 12 cm blankets)**	**0.045**	**22**
23	*150*	*Finely fluffed-up yak wool + anti-insect herbs*	*0.06*	*16.7*
24	*200*	*Fine shredded cellulose + borax salt*	*0.025*	*40*
25	160	Paper pulp, shredded paper	0.04	25
26	200	Sheep wool, loosely thread spun (Doscha)	0.06	20
27	220	Felt from Yak wool	0.07	14.3
28	*240*	*Yak wool, fluffed, non-spun*	*0.08*	*12.5*
29	*300*	Wool carpet, densely spun sheep wool, synthetic wool carpet	*0.1*	*10*
30	*200*	*Empty PET + HDPE bottles in plastic bags*	*0.07*	*15*
31	240	Loosely stacked straw or thatch, dry	0.08	12.5
32	300	Straw, lightly compacted (human weight), dry	0.1	10
33	*320*	*Straw or thatch, little moist*	*0.2*	*5*
34	*400*	*Very moist or wet straw or thatch*	*0.4*	*2.5*
35	250	Loose wood shavings, curls, dry	0.085	12
36	*250*	*Loosely compressed fine dry branches (heather), not soil filled*	*0.1*	*10*
37	*280*	*Loose sawdust from sawmill, dry*	*0.09*	*11*
38	*290*	*Loose wood shavings from plane machine, dry*	*0.1*	*10*
39	**300**	**Soft board, low density, dry**	**0.1**	**10**
40	*300*	*Plastic waste, PP, PET, HDPE, foil crumpled*	*0.1*	*10*
41	**300**	**Straw or thatch for outside roofing, 40-50 cm thick**	**0.16**	**8**
42	**500**	**Roofing material, Ruberoid, asphalt paper**	**0.12**	**8.3**
43	*300*	*Branches, fine, packed, lightly compressed, with air*	*0.1*	*10*
44	*500*	*Branches, fine, packed, compressed with clay soil, dry*	*0.2*	*5*
45	**500**	**Gas concrete masonry blocks, dry**	**0.15**	**6.7**
46	**700**	**Gas concrete masonry blocks, dry**	**0.2**	**5**
47	**1000**	**Gas concrete, dry**	**0.47**	**2.13**
48	**1350**	**Poriso stone (Porotherm, factory made ceramic bricks)**	**0.38**	**2.63**
49	**715**	**Gypsum blocks – panels, average quality**	**0.16**	**5.9**
50	**850**	**Gypsum panels, fire retardant, waterproof, impact strong**	**0.25**	**4**

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W
51	**530**	**Plywood, tri-ply and multiplex, low density**	**0.14**	**7.15**
52	**700**	**Plywood, tri-ply and multiplex medium density**	**0.17**	**5.9**
53	**1000**	**Plywood, high density, waterproof**	**0.24**	**4.2**
54	**250**	**Fibre board and lightweight MDF**	**0.07**	**14.3**
55	**400**	**Fibre board and light MDF**	**0.1**	**10**
56	**600**	**Fibre board and Medium Density Fibre board (MDF)**	**0.14**	**7.1**
57	**800**	**Fibre board and MDF, high density**	**0.18**	**5.6**
58	**800**	**Hard board, medium density**	**0.2**	**5**
59	**850**	**Cement bonded wood fibre sheets**	**0.23**	**4.3**
60	**1000**	**Hard board, high density, (Masonite)**	**0.35**	**2.8**
61	**650**	**Linoleum, PVC flooring**	**0.19**	**5.3**
62	**820**	**Timber, pine wood, sawn air dry**	**0.20**	**5**
63	**750**	**Timber, Poplar, sawn, air dry**	**0.18**	**5.6**
64	**450**	**Chip wood panel, low density**	**0.25**	**4**
65	*700*	*Chip wood panel, high density, structural*	*0.4*	*2.5*
66	*500*	*Straw, wood shavings, compressed under load, dry*	*0.2*	*5*
67	**800**	**Fibre cement panels, lightweight**	**0.3**	**3.3**
68	**1500**	**Fibre cement high density roofing sheets**	**1**	**1**
69	**1000**	**High-furnace sinter-based concrete**	**0.31**	**3.2**
70	1000	Clay soil straw mixture (volumes 1:1), lime bonded, dry	0.35	2.9
71	*1100*	*Clay-soil straw mixture (volumes 1:1), lime bonded, moist*	*0.7*	*1.43*
72	*1200*	*Clay-soil straw mixture (volumes 1:1), lime bonded, wet*	*1*	*1*
73	**1300**	**Clay-soil straw mixture (volumes 2:1), dry**	**0.6**	**1.67**
74	*1400*	*Clay-soil straw mixture (volumes 2:1), humid, moist*	*1.2*	*0.83*
75	1300	Soil, not compacted, low clay/humus content, dry	0.71	1.4
76	1500	Soil, light compacted, cement stabilized (20:1), dry	0.8	1.25
77	*1500*	*Clay soil, compacted, dry*	*1.1*	*0.9*
78	*1600*	*Clay soil compacted, moist*	*1.2*	*0.83*
79	*1700*	*Clay soil compacted, wet*	*1.3*	*0.77*
80	*1700*	*Soil compacted, wet*	*1.2*	*0.85*
81	**1000**	**Hard plastics, artificial composite materials**	**2**	**0.5**
82	**1000**	**Water, cold**	**0.58**	**1.72**
83	**950**	**Ice**	**2.21**	**0.45**
84	*1000*	*Adobe two-block masonry with half filled joints (50 cm)*	*0.45*	*2.22*
85	**1100**	**Adobe blocks (dried clay-soil)**	**0.48**	**2.08**
86	**1400**	**Sand-soil cement mixture (volumes 10:1), dry**	**0.6**	**1.67**
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**
89	*2100*	*Sand-cement block solid, low quality, humid, moist*	*1.2*	*0.83*
90	**1500**	**Lime brick inside masonry in cement joints, dry**	**0.7**	**1.43**
91	**1500**	**Terazzo flooring, broken marble in lime-cement mortar**	**0.41**	**2.44**
92	**2000**	**Ceramic tile flooring/walls in cement mortar**	**1.5**	**0.67**
93	**1800**	**Baked brick outside masonry in cement joints, dry**	**0.85**	**1.17**
94	**2000**	**Baked brick, high density, non-porous masonry**	**1.3**	**0.77**
95	**2100**	**Double baked hard flooring tiles**	**1.5**	**0.67**
96	**2000**	**Concrete stone for masonry, good quality**	**1.6**	**0.62**
97	**800**	**Gypsum board (paper two sides), “dry wall” panels**	**0.6**	**1.66**
98	**1000**	**Gypsum plaster on wall, dry**	**0.7**	**1.43**
99	1100	Light clay-soil lime plaster on wall, dry	0.8	1,25
100	**1400**	**Lightweight lime-sand plaster on wall, dry**	**0.9**	**1.1**
101	**1800**	**Sand-cement plaster on wall (volume 10:1), dry**	**1.15**	**0.87**
102	**1900**	**Sand-cement plaster on walls (volumes 8:1), dry**	**1.3**	**0.77**
103	*2000*	*Sand-cement plaster on walls (volumes 10:1), humid*	*2*	*0.5*
104	*1500*	*Loose two-stone/rubble masonry (70-80 cm) with little clay*	*1.2*	*0.83*
105	*1600*	*Loose two-stone masonry (40-50 cm) in full clay soil-adobe*	*1.4*	*0.72*
106	*1800*	*Non-dressed stone masonry, 10% cement mortar (8:1) gaps*	*1.5*	*0.66*

#	Density kg/m³	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W
107	*1900*	*Dressed 2-stone masonry, 10% cement mortar (8:1) and gaps*	*1.6*	*0.62*
108	2000	Dressed 2-stone masonry, 30% light cement mortar (10:1) dry	1.7	0.6
109	2200	Two-stone masonry in 30% strong mortar (6:1), dry	2	0.5
110	2000	Hollow concrete floor elements LOOOOI	1.16	0.86
111	**2100**	**Concrete, low quality, not reinforced, high W/C factor**	**1.7**	**0.59**
112	300	Aired lightweight concrete (expanded gas concrete)	0.17	5.9
113	500	Aired lightweight concrete	0.24	4.2
114	700	Aired lightweight concrete	0.32	3.1
115	2300	Reinforced concrete, low density	1.6	0.62
116	**2400**	**Reinforced concrete, good quality density (vibrated)**	**2.3**	**0.43**
117	**1750**	**Lime-sand stone**	**1.52**	**0.66**
118	**2150**	**Sandstone**	**1.75**	**0.57**
119	**2200**	**Slate stone**	**2.2**	**0.45**
120	**2500**	**Granite**	**2.8**	**0.35**
121	**2550**	**Basalt, marble**	**3.5**	**0.28**
122	**2500**	**Glass window**	**0.9**	**1.1**
123	**7800**	**Metal sheet, roofing sheet, siding, corrugated iron**	**50**	**0.02**
		Transmission Resistance	**λ=W/m.K**	**R_s=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
HORIZONTAL In ceiling		**Reflective Side of the Aluminium towards Heat Source** Precisely fitting with 10 mm airspace on reflective side	**λ=W/m.K**	**R_c=m².K/W**
Metalized thin plastic highly reflective foil, simple, 3 mm PE backing, joints taped together or overlapping with < 5% support structure interrupting foil			inclusive	0.8
Metalized thin plastic highly reflective foil, simple, 2 mm PE backing, joints taped together or overlapping < 5% support structure interrupting foil			inclusive	0.7
Inside floor with shiny side upwards; floors not fully sealed will become dusty and reflective effect will be greatly reduced after some time			inclusive	0.3
VERTICAL		**Reflective Side of the Aluminium towards Heat Source** Precisely fitting with 10 mm airspace on reflective side	**λ=W/m.K**	**R_c=m².K/W**
Metalized thin plastic reflective foil with 3 mm Polyethylene (PE) backing, and <5% support structure interrupting foil			inclusive	0.7
Metalized thin plastic reflective foil with 2 mm Polyethylene (PE) backing, on sheet METAL support frames, interrupting the foil layer			inclusive	0.6
Thin FACTORY assembled high reflective aluminium foil on 5 mm PE backing with joints taped with aluminium tape (available in Europe)			inclusive	0.9 – 1.0

The total R_c value (total thermal resistance of the different layers in a wall, ceiling or floor) can be calculated by adding the various thermal resistance values of each layer or cavity together, plus inside and outside resistances. In addition, the inside and outside transfer resistance must be added **between the outside air and the wall** (R_{so} = variable depending on the roughness of the wall and wind speed) and the transfer resistance **between the inside air and the wall** (fixed R_{si} = 0.13 m².K/W for horizontal transmission).

The temperature per layer = $R_c$layer/$R_c$total x ΔT (=T_{inside} - $T_{outside}$). Mollier graph for determining dew point.
Air insulation needs to be calculated according to its position, whether horizontal or vertical.
Vertical air spaces between material surfaces of different temperatures cause convection or air circulation, reducing substantially the insulation value of that air space. The insulation value also changes depending on whether the heat is coming from below (warm room below) or from above (hot sun on a metal roof).

If the heat from outside (sun radiation) needs to be stopped, metalized reflective foils or the aluminium foils need to be facing the heat source. In ventilated cavity walls or horizontal spaces under the roof where the air is ventilated, dust will settle on the metalized or aluminium foils and reduce the effectiveness of the foil over time to about half its value in the table.

If humid air from inside the house condenses inside the wall or roof construction, that humidity needs to be evacuated to avoid fungus (summer period) or freezing (winter period). If not done, both situations will damage the construction. Any moisture blockage needs to be on the warm and humid side of the construction. Any moisture inside a construction will lower the thermal insulation value. This occurs often in the winter.

Warning

With the application of impermeable plastic or metalized foils in the walls of a room, ventilation must be adequate to guarantee sufficient oxygen for the inhabitants. The metalized reflective foils avoid heat loss, but have the disadvantage that additional ventilation becomes more important because the natural ventilation that exists through traditional walls is blocked by the plastic.

The use of open, transportable kerosene heaters or bottled gas heaters for space heating have three important disadvantages: (1) they rapidly burn op the oxygen in the room, much faster than ten people breathing; (2) they produce large amounts of humidity as part of the exhaust gasses; and (3) they produce CO_2 gasses as exhaust.

When the oxygen amount in the room becomes very low, the combustion will be incomplete and the exhaust gasses of the kerosene and gas burners will produce CO, an odourless poisonous gas causing people to lose concentration, become drowsy, get red faces, fall asleep and die. The combination of well-sealed rooms and open kerosene and gas burners can therefore be deadly without sufficient ventilation, especially in bedrooms.

TABLE OF RELEVANT CONDUCTIVITY AND RESISTANCE FIGURES TOTALS TOTALS FOR VERTICAL AND HORIZONTAL CAVITIES: R_m=m^2.K/W

Thickness of Air Layer in mm	Thickness of Air Layer in Inches Approximate	Horizontal Cavity with Warm Side Below (ceilings) Upward resistance ⇑	Vertical Cavity Transfer Resistance Horizontal Measure ⇔	Horizontal Cavity with Warm Side Above (hot roofs, floors) Downward Resistance ⇓
5	¼”	0.11	0.11	0.11
7	1/3”	0.13	0.13	0.13
10	½”	0.15	0.15	0.15
15	5/8”	0.16	0.17	0.17
20	¾”	0.16	0.175	0.18
25	1”	0.16	0.18	0.19
50	3+1/8”	0.16	0.18	0.21
100 - 300	4” - 1 ft.	0.16	0.18	0.22
>1000	> 3ft	0.16	0.20	0.25

The above table shows that a vertical air cavity of larger than 2 cm (¾”) will be less effective than when the same space is filled with 2 cm wood shavings (R_C = 0.02 x 12 = 0.24 m^2.K/W) or 2 cm straw (R_C = 0.02 x 15 = 0.3 m^2.K/W); this is due to the increased air circulation for wider spaces. Air cavities wider than 2 cm (¾”) therefore need to be filled with air storing materials.

Adjoining rooms and closed roof areas (attic) that are not heated act as a temperature buffer. The table gives the combined values for the two wall-to-air transfer resistances together. The inside and the outside wall or roof insulation value needs to be added to this value.

A vertical air space of about 7 cm (3”) has about the same conductivity as adobe blocks (λ = 0.45). R_C = 0.07 x 2 = 0.14 m^2.K/W. This means that when a vertical air space is 2.5 cm (1”) or larger, it is essential to fill the cavity with EPS, loose straw, empty plastic waste (PET bottles) or similar materials containing air.

Non-filled vertical cavities wider than 2 cm need to be interrupted with horizontal barriers (supports) to stop the vertical air circulation. Stapling foils (plastic, PE and reflective) onto strips of timber will reduce air circulation and improve the insulation value.

Relevant Insulation Value or Thermal Resistance of Windows (Including Frame)

Most relevant situations for the selected geographical area. The given value does not have to be multiplied by the thickness of the construction, but is the value per m² wall/ceiling surface.

	Type of Window with Glass R value = 1/λ	1/U= R_g Glass: **R=m².K/W**	R_f Value Window Frame	R_w Value of Total Window
	Single Glass			R/m²
1	Wooden window frame with whole glass sheets 3-4 mm thick. Glass window closes precisely in window frame with double (insulating) joint structure.	1/5.8 = 0.172	0.417	**0.19**
2	Wooden window frame with whole glass sheets 3-4 mm thick. Window closes precisely in frame with single joint structure.	1/5.8 = 0.172	0.312	**0.18**
3	Wooden window frame with whole glass sheets 4 mm thick. Glass window does not close precisely with single joint.	1/5.8 = 0.172	0.20	**0.17**
4	Wooden window frame with cracked glass sheets 3 mm thick. Glass window does not close precisely, small gaps single joint.	1/6.5 = 0.154	0.20	**0.15**
5	Wooden window frame with broken glass sheets 3 mm thick, 50% areas covered with plastic foil. Glass window does not close precisely in frame with small gaps in single joint.	1/8 = 0.125	0.20	**0.12**
	Double Glass	R_g Value Glass: **R=m.K/W**	R_f Value Window Frame	R_w Value of Total Window
6	Wooden window frame with double whole glass sheets 4 mm thick, space between glasses 2 cm. Window closes precisely in frame with double (insulating) joint structure.	1/2.8 = 0.357	0.417	**0.36**
7	Wooden window frame with double whole glass sheets 3-4 mm thick, space between glasses 2 cm. Window closes precisely in frame with single joint structure.	1/2.8 = 0.357	0.312	**0.32**
8	Wooden window frame with double whole glass sheets 3-4 mm thick, space between glasses 2-3 cm. Glass window does not close precisely in frame with small gaps in single joint structure.	1/2.8 = 0.357	0.2	**0.27**
9	Wooden window frame with double whole glass sheets 4-12-4 mm thick, space between glasses 12 mm. Glass window closes precisely in frame and has sealed joint structure.	1/3.0 = 0.33	0.2	**0.30**
10	Wooden window frame with laminated glass sheet 3-1-3 mm. Window closes precisely in frame without gaps, single joint.	1/3.7 = 0.270	0.312	**0.28**
11	Wooden window frame with laminated glass sheet 3-1-3 mm. Window does not close precisely in frame (some ventilation).	1/3.7 = 0.270	0.312	**0.15**
12	Wooden or PVC plastic (metal core) window frame with insulation glass 4-20-4 mm thick and dry air filling. Window closes precisely in frame with double joint structure.	1/2 = 0.50	0.50	**0.50**
12	Wooden or PVC plastic (metal core) window frame with insulation glass 4-20-4 mm thick and dry air filling. Window does not close precisely in frame with single joint structure.	1/2 = 0.50	0.40	**0.45**
13	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and dry air filling with thermal reflective inner coating. Window closes precisely in frame with double joint.	1/1.2 = 0.83	0.50	**0.75**
14	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and Argon gas filling with thermal reflective inner coating. Window closes precisely in frame with double joint.	1/1.0 = 1	0.50	**0.9**
15	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and Krypton gas filling with thermal reflective inner coating. Window closes precisely with double joint structure.	1/0.8 = 1.25	0.50	**1.2**

16	Add-on window 3 mm glass without reflective coating, 2 cm air.			**0.2**
	Triple Glass Windows			
17	Three ordinary glass windows in timber frames, well closing			**0.45**
18	Triple glass window in wide single timber frame without heat reflective coating or gas filling 4-6-4-6-4 mm.	1/ 2.4 = 0.41	0.50	**0.44**
	Metal Window Frame	R_g Value Glass: **R=m.K/W**	R_f Value Window Frame	R_w Value of Total Window
20	Metal window frame profile with 4 mm glass, good closing.	1/5.8 = 0.172	0.125	**0.143**
	Plastic Table Cloth Insulation Curtain			R_C Value
30	Single full transparent thick (0.13 mm) plastic foil screwed and sealed against the whole window frame. Air 2 cm.			0.1
31	Double full transparent thick (0.13 mm) plastic foil screwed and sealed against the whole window frame. Air 2 x 2 cm. Winter Insulation Insert (Wii) for RHW.			0.2
32	Single full transparent thick (0.13 mm) plastic foil screwed against only the glass frame. Airspace < 2 cm.			0.08
33	Single decorative or blinding roll curtain, closing against the window frame or wall. Air space to glass < 8 cm.			0.07
34	Single decorated or blinding roll curtain, closing less precise against all walls around the window. Air space to glass > 8 cm.			0.06
	Polycarbonate (Plastic) Hollow Honeycomb Sheet			
40	Clear, fully translucent, 6 mm thick, separators 10 mm, only.			0.13
41	6 mm Polycarbonate, 2 cm in front of an existing glass window and adequately air sealed around the sheet.			0.28
42	Clear, fully translucent, 10 mm thick, separators 10 mm only.			0.27
43	10 mm Polycarbonate, 2 cm in front of existing glass window and adequately air sealed around the sheet.			0.40

The Recommended Minimum Average R_c Value for buildings with about 5 son hours per day.

The Recommended Minimum Average R_c Value $$= \left\{0.5 + \frac{\text{Altitude in m}}{100\text{ m}}\right\}\ m^2.K/W.$$

This value needs to be adjusted for the amount of solar heat intake.
The insulation value of the ground floor should be minimum half of the above values. This is because the △T between room air and ground temperature is about half of the △T between room air and the air outside the ceiling or wall.
The amount needs to be added with R_c 0.1 m^2.K/W for every sun hour less.
In a mountain environment such as the Himalayas, the shadow of the mountains can leave buildings in the shade for half a day or longer when the winter sun is low. For fully shadowed or overcast regions in the winter, it means adding R_c = 0.5 m^2.K/W.

Recommended Minimum Average R_c Value for Buildings with About 5 Sun Hours/Day

Minimum Winter Temperature Celsius	Approximate Altitude Above Sea Level	Minimum Insulation R_c in m^2.K/W	Recommended Minimum R_c in m^2.K/W 5 Sun Hours/Day	Recommended R_c in m^2.K/W Only 2.5 Sun Hours	Recommended R_c in m^2.K/W Without Sun Hours
0º C	1200 m (4000 ft)	R_c = 1.2	R_c = 1.7	R_c = 1.95	R_c = 2.2
-5º C	1500 m (5000 ft)	R_c = 1.5	R_c = 2.0	R_c = 2.25	R_c = 2.5
-10º C	1800 m (6000 ft)	R_c = 1.8	R_c = 2.3	R_c = 2.55	R_c = 2.8
-15º C	2200 m (7500 ft)	R_c = 2.2	R_c = 2.7	R_c = 3.95	R_c = 3.2
-20º C	2700 m (9000 ft)	R_c = 2.7	R_c = 3.2	R_c = 3.45	R_c = 3.7
< -30º C	3000 m (10,000 ft)	R_c = 3.0	R_c = 3.5	R_c = 3.75	R_c = 4.0

Ground floor values are minimum half of the above values. When sleeping on the floor, the insulation should be higher.

ANNEXE II 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:					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 Values of R_c and Total Construction Costs 10 m^2						Total	Cost 10 m^2	
Altitude Above Sea Level Building		m	Sun Hours		△T	Ratio = Total Cost / R_c Total		

ANNEXE III PRACTICAL EXAMPLES

The following are examples of possible thermal insulation recommendations for an adobe village house (1500 m). The negative effects of water infiltration should be considered along with thermal insulation as well.

Left – High road side required roof gutter and rainwater evacuation.
Right – 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.

Fuel Consumption

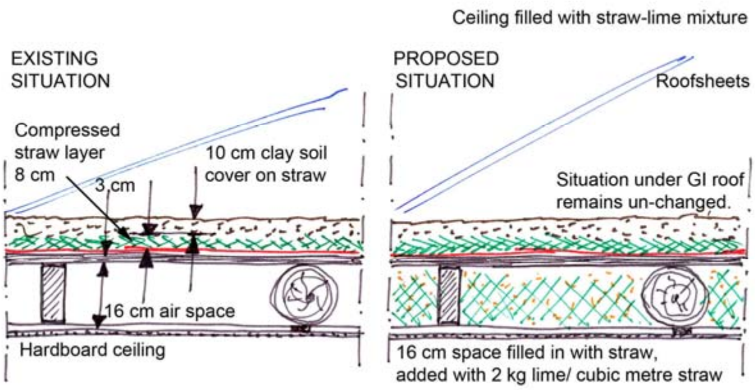
The family uses *tapack* and firewood for fuel. Total winter consumption is 2100 kg, measured mixed on a scale. Fuel used for cooking and space heating were recorded together, but excludes fuel used in the outdoor *tandori* for bread making. There is no electricity in the winter.

Ceiling

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

Recommendation: Ceiling Insulation Option 1 – Insulation Value $R_C = 3.51$ m^2.K/W.
See following table for calculation of values.

Ceiling Option 1
Remove (painted) board ceiling
Add 16 cm straw-lime mix inside cavity
Replace the board ceiling



Ceiling Option 1 - Construction: Filling in of traditional ceiling with 16 cm straw-lime					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			
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 air space (see table)	0.16	x	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*
11	Mixing lime @ 2kg per cubic meter For 10 m^2 = 4 kg	x	x	x	*8*	*4*	*2*
12	Removing and replacing ceiling (materials are nails)	x	x	x	*10*	*20*	*10*
13	New cover strips from timber for joints between sheets and cornice	x	x	x	*15*	*10*	*5*
14	New ceiling paint white wash	x	x	x	*20*	*10*	*5*
15	Cleaning and waste removal	x	x	x	*x*	*x*	*self*
	Subtotal Newly Added Value R_c			**1.92**	*63*	*59*	*32*
Total Values of R_c and Total Construction Cost 10 m^2				**3.51**	*Total*	*Cost 10 m²*	***154***
Altitude Above Sea Level Building Recommended Insulation Value R_C=2.0		1500 m	Sun Hours	6	Ratio=Total Cost/R_c Total		***44***

Note:[3] For the real estimate, the 10 m^2 unit needs to be multiplied with 1.8 for a ceiling of 18 m^2.

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 and painting may increase costs as well.

Considering the insulation quality of the existing ceiling is fairly good, only a little additional thermal insulation is needed. 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.

Outside Door

Insulating the door to the outside entrance area is important, but difficult because it is a single door. Sealing the winter room door with a high-quality new door is out of the question because this door is the main ventilation opening for the space-heating stove. It is more effective to make a small vestibule (1.5 m x 1.5 m and connecting to the 3 m high ceiling) enclosing the current two outside doors (blue). The vestibule should have only one outside door with a spring closure. This way a buffer is created so cold air does not immediately enter the living rooms and the two rooms are connected internally. The room door can be further improved by hanging a heavy curtain on the inside to reduce draft.

[3] TJS = Tajikistan Somoni April 2011: Euro 1 = Somoni 6.60
Prices in TJS need to be verified based on local information and estimated time for labour.

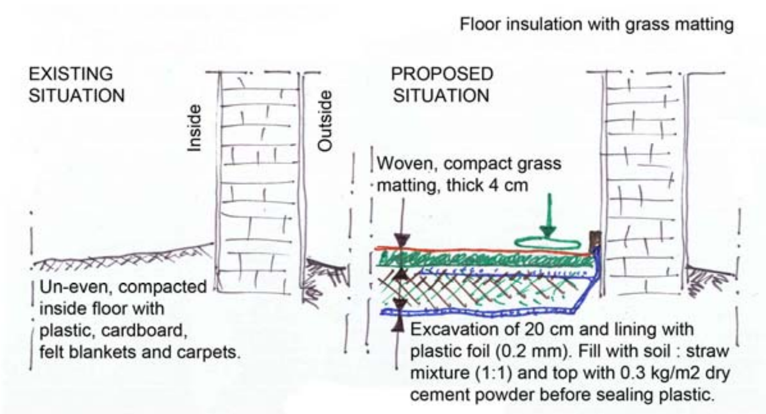
Floor

The floor in the winter room has no insulation, but is reasonably dry. The foundation needs protective measurements on the higher road side.

Recommendation: Floor Insulation Option 1 – Insulation Value R_C= 1.16 m^2.K/W.

Considering the house owner's request for low-cost options, 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 (0.2 mm) and filled in with a dry straw-soil mixture (1:1). The mix should be topped with dry cement powder before being sealed by folding the plastic foil. A 4 cm woven mat should be placed on top of the plastic and PE foam under the sleeping mattresses.

Floor Option 1
Excavation
Plastic foil (0.2 mm)
Refill with 20 cm straw-soil
Cover with 4 cm grass mat
PE foam (5 mm)



Floor Option 1 - Construction: Excavating soil and refill with 20 cm straw-soil in plastic bag; plus grass mat					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
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 mixing 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 over grass	0.005	22	0.11			
16	Cleaning and waste removal	x	x	x	*x*	*x*	*self*
	Subtotal Newly Added Value R_c			**0.91**	*210*	*45*	*15*
Total Values of R_c and Total Construction Cost 10 m^2				**1.16**	*Total*	*Cost 10 m^2*	*260*
Altitude Above Sea Level Building Recommended Insulation Value R_C=2.0		1500 m	Sun Hours	6	Ratio=Total Cost/R_c Total		***23***

Note: For the real estimate, the 10 m^2 unit needs to be multiplied with 1.8 for a floor of 18m^2. (See also footnote 3)

Because the family sleeps on the floor, the insulation value needs to be increased. It is therefore recommended to apply a 5 mm Polyethylene foam (PE) sheet under the carpet. This increases the insulation value with R_C = 0.005 x 22 = 0.11 m^2.K/W. The additional insulation will substantially increase the comfort level and subsequently reduce heating demand and fuel consumption.

Walls

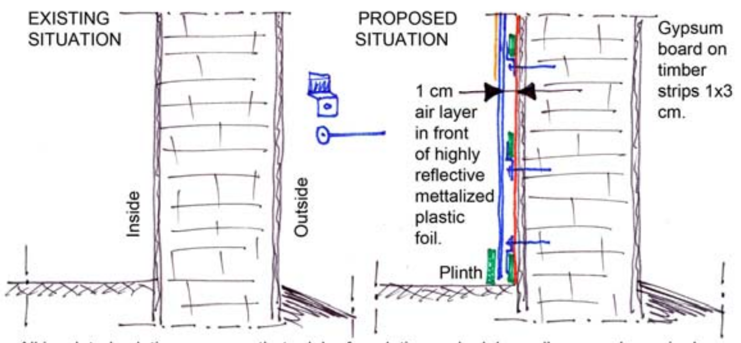
Given the small space for the six family members sleeping in the room, the wall insulation (33 m^2) should be kept thin by using a single reflective foil. The adjoining internal wall with the next room (10 m^2) does not need to be insulated. However, the short wall section linked to the porch does need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

Recommendation: Wall Insulation Option 1 – Insulation Value R_C = 2.08 m^2.K/W.

Wall Option 1
Single foil
Gypsum board finishing

The wall insulation should be applied after the installation of the floor insulation and double window.

One reflective foil + gypsum board on inside 50 cm adobe wall.



All insulated solutions assume that adobe foundation and adobe walls are and remain dry.

Wall Option 1 - Construction: Single reflective foil with gypsum board					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	x	x	0.7	*60*	*10*	*x*
11	Timber strips 1 x 3 cm per 10 m^2	x	x	x	*10*	*10*	*5*
12	Fixing materials per 10 m^2	x	x	x	*10*	*10*	*5*
13	Gypsum-carton board 8 mm	0.008	1.66	0.013	*150*	*20*	*10*
14	Joints cover	0.04	5	0.20	*10*	*10*	*x*
15	Painting two coats of white wash	x	x	x	*20*	*x*	*20*
16	Cleaning and waste removal	x	x	x	*x*	*x*	*self*
	Subtotal Newly Added Value R_c			**0.913**	*260*	*60*	*40*
Total Values of R_c and Total Construction Cost 10 m^2				**2.08**	*Total*	*Cost 10 m^2*	*360*
Altitude Above Sea Level Building Recommended Insulation Value R_C=2.0		1500 m	Sun Hours	6	Ratio=Total Cost/R_c Total		***128.5***

Note: For the real estimate, the 10 m^2 unit needs to be multiplied with 1.98 for the walls. (See also footnote 3)

Window

An additional window frame (1.2 x 1.7 m^2) should be placed on the inside of the existing window frame, thus creating a double glass window.

Comparison Table

Recommended for Altitude 1500 m		Current R_C = m^2.K/W	Surface Divided by R_C = Energy Loss in Watt / °C / 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	2.0	x	x
Ceiling 1	3 m x 6 m = 18 m^2	1.59	11.3	+16 cm straw 3.51	TJS 277	44
Floor 1	3 m x 6 m = 18 m^2	0.245	73 see note (37)	+20 cm straw-soil+grass 1.16	TJS 468	23
Walls 1	(3+3+6+1 m) x 2.4 = 31.2 m^2	1.17	27	+1 reflective foil; gypsum 2.08	TJS 1230	129
Window	1.7 m^2	0.15	11.3	0.4	TJS 250 1.7 m^2	3676
Door	2 m^2	0.2	Construct Vestibule 3 m^2	x	TJS 2000	x
Total	Insulated 69 m^2	x	>>>>>>>>>>>>	Tajikistan	**4225**	Somoni

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 same R_C.

The total amount of heat loss is a relation between the total surface (m^2), the total temperature difference between inside and outside ($\triangle$T), and the thermal insulation value (R_C).

As can be seen from the above table, the insulation values (R_C) of the existing situation show very large variations. The ceiling is already reasonably insulated, whilst the window is the least insulated. The thick adobe wall has 30% less insulation value than the ceiling, but is almost five times better insulating than the floor. The $\triangle$T of the floor, however, is only half that of the walls or ceiling.

These figures confirm that the family sleeping on the floor is very uncomfortable and cold because the mattress is placed directly on the floor.

From the shaded column, it can be noted that the total heat loss from the existing window (11.3) is as much as from the entire ceiling (11.3), but the heat loss to the floor is **almost 3 times as large** (37) as from the ceiling. The walls have 240% more heat loss (27) than that from the ceiling (11.3) because of their larger surface.

Although in many situations the ceiling is the first area of attention (because heat rises), this is not the case in this house. Especially when people sleep on the floor, thermal insulation of the floor (particularly the sleeping area) is priority ONE. Stopping the draft from single glass windows is priority number TWO.

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 (TJS 277). This is based on the house owner supplying the 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 (TJS 468). 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. Such options should be explained to the house owner.

In priority, the walls definitely require insulation before adding insulation to the ceiling. Because insulating the walls with straw will reduce the room space too much, 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 to 4 mm) having about the same purchase cost, but with lesser transport cost and easier application (TJS 468 +1230).

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.

Hanging a transparent roll curtain will further increase the insulation value.

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

Constructing the new outside vestibule will be by far the largest cost factor with TJS 2000 or more for glazing the many windows if included in the design.

A new space-heating stove may be purchased (TJS 400), preferably along with a heat exchanger-bread oven (TJS 150). The heat exchanger-bread oven will substantially reduce the heating time and allows baking bread inside the house rather than in the very inefficient outdoor *tandori* bread oven. With the outdoor oven, no use can be made of the waste heat.

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.

Baking round breads (25 cm diameter) has the best results in heat exchanger models having an additional cover (+TJS 100) to retain the heat while baking. After completing the bread baking, the two insulating halves of the cover are removed and stored.

****