



HUYS ADVIES

# BASICS OF THERMAL INSULATION IN HIGH ALTITUDE AREAS OF THE HIMALAYAS

Technical Working Paper ~ Number 1



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*January 2012*  
*(updated)*



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## **Photo on Cover Page**

*House owner lifting the carpet to show the insulation of a thick grass mat.*

*The elevated floor also provides thermal insulation, as well as the storage space below.*

*Heat is lost from all the outside surfaces of the building by means of Infra Red radiation.*

*Insulating the sitting and sleeping area improves the comfort considerably and therefore requires less space heating by the central firewood stove, resulting in less firewood use and less smoke emissions.*

*Generally, in traditional houses, heat loss through the floor is less than through the ceiling or walls because the difference between the inside and outside air temperatures is much less at the foundation. When the outside air temperature is minus 15°C, the soil temperature under the house may be around 0°C. With an average room temperature of plus 15°C, the heat loss through the floor is then about half of the heat loss through the walls or ceiling.*

*Although less thermal insulation will be required for the floor, the direct contact with the floor makes the comfort difference. In many cases, the comfort factor is the determining factor for the house owner realising some improvement on the thermal insulation. Being warmer and dryer while sleeping saves energy and health.*

# 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 is 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 #1 gives a resume of the basic issues explained in thermal insulation training sessions given to local technicians. The objective is to develop the paper further and ultimately create the basis for curriculum development and vocational training.

Additional technical working papers will cover the various types of thermal insulation and technical details of roof, wall and floor constructions, windows, doors, etc. of the most efficient types of construction, taking into consideration cost, available local materials and level of skills.

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

- Why thermal insulation?
- Choice between thermal insulation and an improved space-heating stove.
- Where does the largest heat loss occur?
- Recommended insulation values per altitude.

The training of staff requires both practical experience and knowledge of the theory behind thermal insulation. Without understanding the theory, the building practice can be misapplied. This is especially the case where condensation may occur or when the thermal insulation reduces the amount of natural ventilation.

Capacity building of local entrepreneurs includes the traders of the materials required for the insulation and the craftsmen (carpenters, masons and interior decorators) who apply the technology in the houses. In addition, house owners applying the thermal insulation themselves are required to understand the possible effects of the insulation and the differences with improving the firewood or space-heating stove. Key persons in the villages need to be able to provide the right information to their peers to avoid expenses having insufficient effect.

This Technical Working Paper #1 is complemented by Technical Working Paper #2 providing calculation examples, and Technical Working paper #3 with the relevant tables for the calculations.

# 1. WHY THERMAL INSULATION?

The question is not only for cold region countries of the world, but for countries having houses situated in high altitude areas as well, such as the Himalayas covering many countries – Pakistan (Gilgit-Baltistan and Chitral – GB&C), Tajikistan (Gorno Baltistan Autonomous Oblast – GBAO), Afghanistan (Wakhan Corridor), Nepal, India (Sikkim), Bhutan and China (Tibet). These regions have many similarities – climate, physical and socio-economic conditions and building style/techniques, as well as ethnic aspects in some cases.

Houses in the high altitudes of the Himalayas (1500 - 4000 meter above sea level) have a very different design than houses in lower altitudes. This has many effects on the environmental temperature, humidity, house-heating needs, transport costs and the availability of building materials.

- *High altitudes experience long, cold winters.*  
The higher the altitude, the longer and colder the winters will be and the more house heating is required.
- *Stone or adobe constructions are poorly insulated.*  
Local building materials have advantages and disadvantages. One should understand the disadvantages to overcome them.
- *Extra high heat loss from poor window designs.*  
More light in the house with large windows are desired nowadays, but these cause additional heat loss from the buildings.
- *Low-efficiency heating and cooking stoves.*  
Most of the heat generated in a stove disappears through the chimney, warming the outside air and the mountaintops.
- *Biomass grows slowly at high altitude.*  
At higher altitudes, more fuel is needed for stoves and cooking, but the growth rate of biomass is much slower at those higher altitudes. Harvesting of biomass leads to desertification, lack of animal food, soil erosion, landslides and climate change.



*Treshkin is collected from many kilometres out of towns, depriving Yaks from their winter food and causing soil erosion and rapid run-off from rainwater.*

The direct effect of centuries-long collection of firewood and construction timber, goat grazing and agriculture without forest management or adequate re-plantation has caused the tree cover of the mountain areas to almost completely disappear. Erosion and climate change are the result.

The only trees growing in the valleys are on privately owned land. Even fruit trees are being cut down to provide firewood.

New and poorly insulated more modern cement block buildings require massive amounts of fuel wood to heat them during the long cold winters.

Additional fuel is needed for increased comfort and hygiene, such as water heating for dishwashing, showers and laundry.



*Centuries of deforestation and grazing has left all hills void of tree vegetation, bringing erosion.*

With greatly improved medicines becoming accessible in the 19<sup>th</sup> and 20<sup>th</sup> centuries, population growth increased rapidly. At the same time, the number and sizes of grazing herds of goat and sheep also increased to feed the population. Large families became a guarantee for old-age income and survival, reducing the importance of the existing community structure for caring for their older members. Without appropriate related technical and economic measurements to reduce dependence on natural resources for cooking and heating fuel, the damage to the environment has become almost irreversible during the 20<sup>th</sup> century.<sup>1</sup>

The rapidly growing population necessitated an increase in building volume to house the people, often resulting in building cheaper and faster due to lack of finances and resources. One of the immediate side effects was that houses were less thermally insulated.

The imbalance between the growth of biomass and the consumption of firewood at higher altitudes is shown in the following graph. The higher the altitude, the more fuel wood is needed to heat the houses, while the trees grow slower at higher altitudes. The graph shows the relation between growth and consumption of wood.

Large trees may produce about 100 kg of new wood at low (tropical) altitudes, but produce only 1/5 of that amount at an altitude of 2000 m due to the colder climate. At 3000 m, this is again reduced to half and at 4000 m, no trees grow at all.

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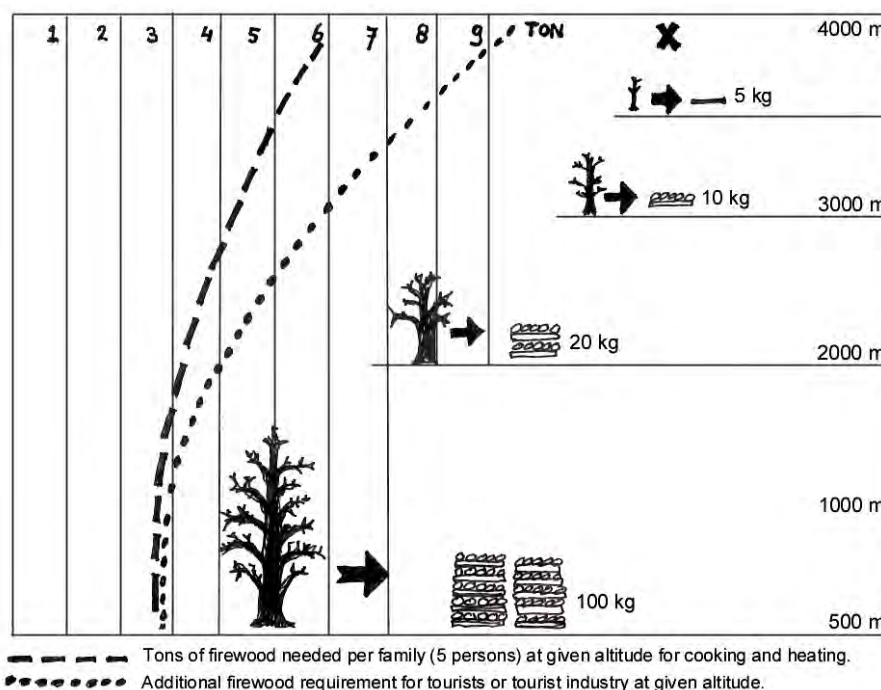
<sup>1</sup> In GBAO, the Russian occupation and industrialization caused additional population growth combined with very poor, non insulated building techniques. Free diesel fuel for space heating was supplied, but when the Russians left, this resulted in an acute fuel shortage, forcing villagers to cut all trees in sight.

A family of five persons at 500 m altitude consumes about three tonnes of firewood for cooking and warm water when using the commonly inefficient firewood stoves (burning efficiency < 15%).

Because of the colder high altitude environment above 1500 m, cooking is done indoors to benefit from the waste heat produced during the cooking process, using it for space heating. People living at altitudes higher than 1500 m consume additional firewood for space heating during the winter.

At 2500 m, the total wood consumption is increased to about four tonnes per year.

At very high altitudes and in traditional houses having basic thermal insulation, that amount increases to six tonnes of firewood for the same family. When (rich) people from low altitudes come to stay in these higher altitudes, the amount of firewood triples because they want more space heating and more warm water.



Comparing the amount of wood which grows annually with what is consumed, there is an increasing imbalance. Replanting (left sketch) will not produce a significant amount of firewood within a large number of years because the trees grow very slowly.

With the use of renewable energies, such as the sun for water heating and biogas for cooking (right sketch) and on the other side of the scale a large amount of firewood for cooking is replaced with LPG, NPG or kerosene, the balance adjusts a little. Methods to reduce the need for cooking fuel and space heating are: (1) increase thermal insulation of houses, (2) increase the heat gain of houses through solar windows, (3) change the cooking methods, and (4) improve the cooking equipment. The most sustainable and durable (and by far the cheapest) solution is to add house insulation on the left-hand side of the scale, whereby firewood consumption is reduced on the other side of the scale.

**Once a room is insulated, the firewood consumption for heating is reduced for the lifetime of the building.** Optimum thermal insulation will minimise the current over-exploitation of biomass for house heating and has a thermal resistance of  $> R_c = 5 \text{ m}^2 \cdot \text{K/W}$ .

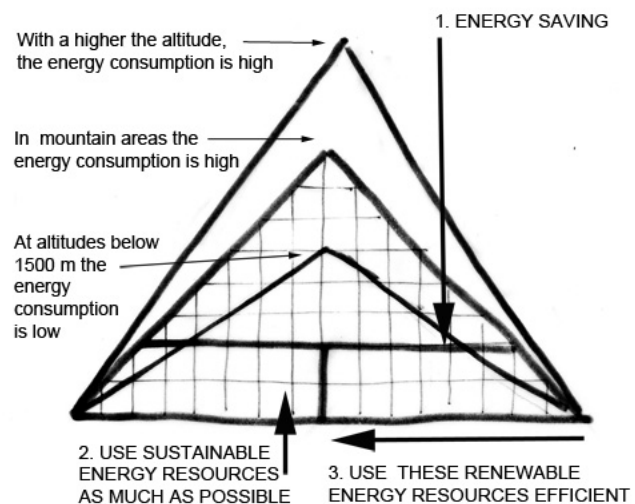
## 2. THE ENERGY TRIANGLE

The total amount of energy consumed by households in mountain areas is strongly related to the altitude at which the house is located. The higher the altitude, the more energy consumed, mainly for heating the house during the winter season, which is both longer and colder as the elevation increases. The rest of the energy consumption is related to cooking and some energy for illumination.

The available energy supply is limited and becoming yearly more and more expensive. The first and most important point is to save energy consumption, mainly by **thermal insulation** of houses and by adapting our **cooking methods**. More than 75% of the current energy consumption can be saved by taking these two measures alone.

The second point is to use sustainable energy sources. In principle, firewood is sustainable as long as each year the same amount is **grown back** for own consumption (replanted). This, unfortunately, is not the case. In general, local communities use far more firewood than the annual amount grown in their environment.

THE ENERGY TRIANGLE



At high altitudes, this leads to the irreversible burning of *treshkin* and *tapack* (dried cow dung), being respectively a food source for yaks and fertilizer resource.

The third point is to use the renewable and sustainable energy resources as efficiently as possible. Currently cooking practices are highly inefficient, partly because the cooking and space-heating stoves are inefficient. For illumination, using tube lights and CFL are about five times more efficient than incandescent bulbs.

Hydroelectric power is a fairly sustainable source, but there is often not enough waterpower in the winter to illuminate the houses, requiring only 1% of the total energy needs including space heating. Space heating with electric power is still out of reach economically, especially when the real costs of the hydroelectric power generation are considered. Changing bulbs for TL and CFL that resists voltage fluctuations is an option. In areas having large voltage fluctuations, the cost of the voltage stabilizing equipment must be taken into account.

Type of Lamp and Voltage	Expected Lifetime in Hours	Light Efficiency in Lumen per Watt	Energy Efficiency A-E
Incandescent bulb (glow lamp)	1,000	8 - 13	E
Halogen lamp (12 V)	2,000	14 - 26	D
Ecohalogen lamp (12 V)	4,000 - 5,000	21 - 28	C
Halogen lamp (220-240V)	1,000 - 2,000	12 - 15	D - E
Ecohalogen lamp (220-240V)	2,000 - 4,000	12 - 21	B - C
Fluorescent lamp (TL)	10,000 - 50,000	60 - 105	A
Compact Fluorescent Lamp (CFL)	6,000 - 12,000	36 - 58	A
Light Emitting Diode (LED)	20,000 - 50,000	21 - 57	B - A

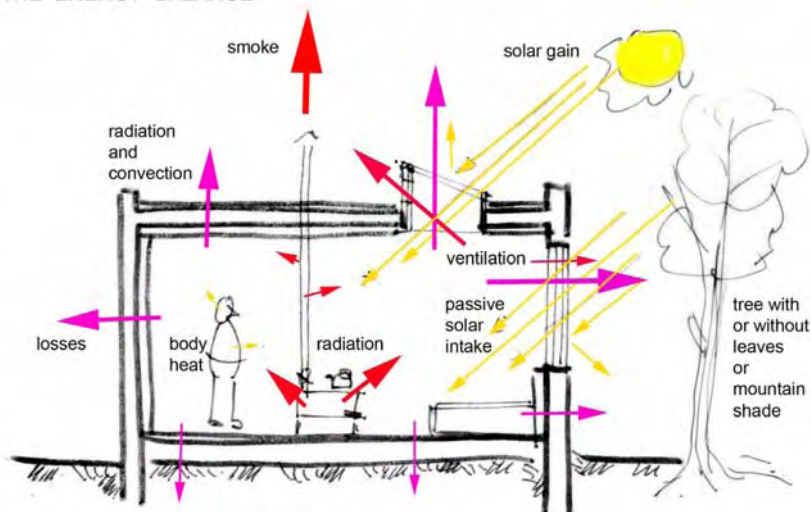
Coal is available in large quantities in some areas, but often not always of good quality. Coal, however, is not a sustainable energy source and by burning biomass or coal, large amounts of CO<sub>2</sub> are emitted into the atmosphere causing negative effects on the global and local climate.

## 2.1 The Energy Balance

When heating a house to the comfort level and maintaining that temperature, there exists a balance between the energies brought into the house and the energies leaving the house. When the house is poorly insulated and it is cold outside, extra energy (firewood, electricity) is required because a considerable amount of energy disappears out of the house through different mechanisms.

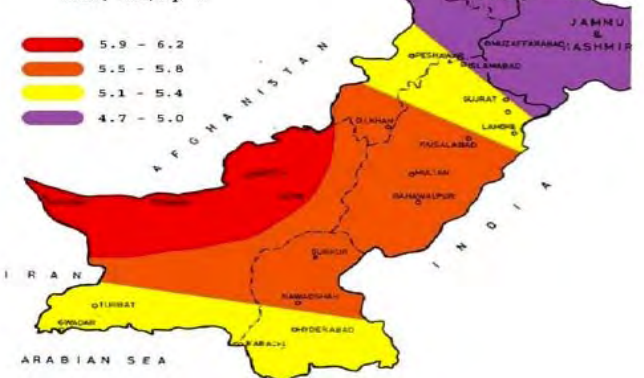
The sketch illustrates some of the energies going in and out of the house, depending on its design.

THE ENERGY BALANCE



- (1) Firewood (energy) is imported into the house. The stove and chimney generate heat, but most of the current stove heat escapes through the chimney.
- (2) Part of the warmed air escapes through the roof window, side windows and doors, including due to excessive ventilation.
- (3) People generate body heat, about 1 W/hour per kg body weight when lightly dressed. Several people in the same room, therefore, generate some heating energy. The same amount of energy is produced by cattle; several cattle weighing 1000 kg produce 1 kW/h.
- (4) Sunlight brings heat into the house; at high altitudes and during winter, 1 m<sup>2</sup> vertical and clean glass surface produces about 2 kW/h with clear skies. The emphasis is on clean glass; otherwise, the light is blocked. A 2 m<sup>2</sup> solar window facing due south can generate 20 kW in a five-hour period. Electric heaters can produce that heat, provided there is electricity. Designing the house to benefit from the winter sun is important. Trees should not block solar intake during the winter. Houses in the winter shadow of mountains need additional insulation.
- (5) Infrared radiation (from high to lower temperatures) causes substantial heat loss from all around the house, whereas roofs cause more heat loss than the wall per m<sup>2</sup> and the walls more than the floor. Reducing this heat loss is the objective of thermal insulation. By doing so, less energy needs to be produced by the space-heating stove, which then reduces the amount of cold air from outside to maintain the burning process.

Annual average mean daily Solar Radiation in Pakistan, kWh/sq. m

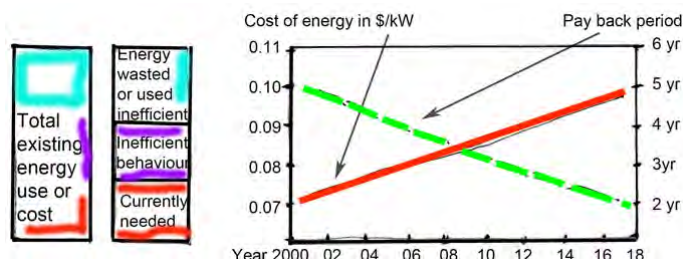


Considering the low thermal insulation values of current traditional houses ( $R_c \approx 0.5 \text{ m}^2 \cdot \text{K/W}$ ) and the very low thermal insulation values of the more modern houses built with cement mortar and reinforced concrete ( $R_c \approx < 0.3 \text{ m}^2 \cdot \text{K/W}$ ), thermal insulation has the highest priority in energy saving.

## 2.2 Early Investment in Insulation

The longer one waits before applying thermal insulation, the more money is lost. The left box in the following graph represents the current total energy cost in a household. These costs include the purchase cost for the energy, the cost of labour the time, health expenses, additional food expenses and the lack of personal energy in general due to a cold environment. It is far more cost-efficient to spend money on saving energy than to continue paying for wasted energy.

Energy saving can have a financial return efficiency of 20% (five years).



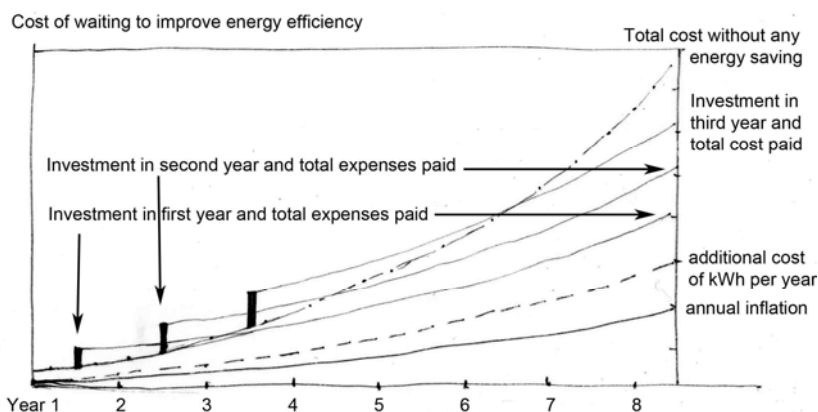
The amount in the left box can be divided into three parts:

- (1) Energy wasted by poor thermal insulation and inefficient cooking methods.
- (2) Inefficient behaviour, such as leaving windows (roof) open, overheating the space-heating stove or using it for cooking, burning wet firewood or sleeping on the cold floor.
- (3) Amount of energy (space heating and cooking) really needed given the current state of technology and family economy in the region. Although there are other energy-saving technologies worldwide, some of them are simply not accessible in the mountain areas or are very costly<sup>2</sup>.

The above diagram illustrates that the payback period for thermal insulation is about five years, but with the rising energy costs, this period will gradually reduce to two years or less. In some instances, for example by using a pressure cooker in high altitude areas or using a Heat Retention Box with the cooking, the payback period is less than one year.

## 2.3 Insulate More, Rather Than Less

Saving money by insulating less than the recommended minimum is not a good saving at all. Once the house owner has done an outside wall or ceiling, it is unlikely he/she would again insulate the same wall or ceiling better after a couple of years. The effect is that over the entire future lifetime of the insulated construction, energy still leaks out of the building and thereby costing money. This point relates to the fact that the annual cost of energy is increasing more than the annual national inflation.



This increasing difference is caused by international pressure on governments to reduce national subsidies on energy and limit the importation of energy, such as gas, diesel fuel and kerosene.

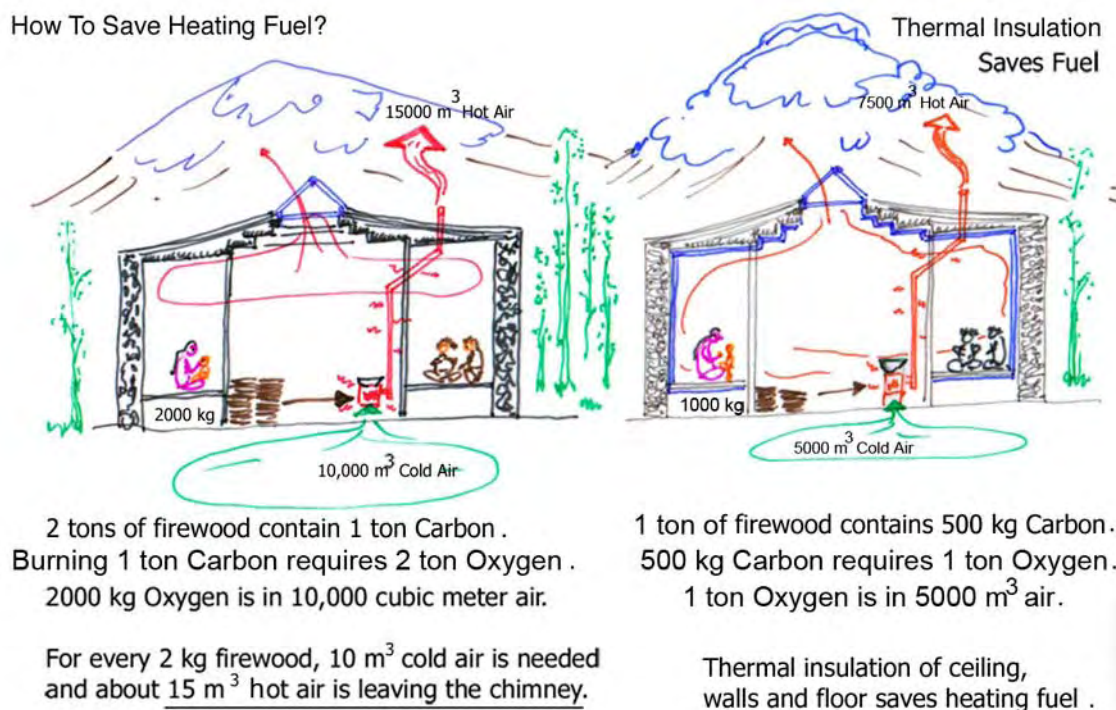
The graph illustrates that the earlier one invests in energy saving, such as thermal insulation, the more one saves in the medium and longer term.

<sup>2</sup> Heat pumps by which heat stored in the earth and groundwater are very efficient but cost several thousands of Euros for purchase and installation, and constant electricity supply is needed to guarantee operation.

Energy loss is related to (a) the total surface, (b) the temperature difference, (c) the thermal resistance of that surface, (d) the exchange of air or ventilation, and (e) the exchange of humidity. Air exchange has a large influence with people using wood fires since these require large amounts of air to burn. Humidity exchange has relatively little influence.

Firewood or coal heating stoves, require large quantities of oxygen (fresh air) for the burning process.

**For burning 2 kg dry firewood, about 10 m<sup>3</sup> of fresh air is needed.<sup>3</sup>**



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, less firewood is needed and less air is pulled into the house for the stove to burn.

The heat loss of a construction is directly related to the temperature difference  $\Delta T$  as well as the size of the surface. One can compare a heat leaking house with a water leaking container. To save water, the largest holes need to be closed first for maximum water saving. This means that the insulation values in a room should be about the same for walls, windows and roofs. On the other hand, a house owner would not insulate again the same wall or room twice. The house owner will eventually insulate an other wall or room, but will not easily redo a poorly insulated wall because those wall surfaces are already finished. For a house owner the costing (the initial outlay and the economic return period) are important elements to consider.


**The cost of an insulation measurement must be related to the actual insulation value of that section to make an economic comparison.**

<sup>3</sup> The amount of oxygen in the air is about 20% only (1/5<sup>th</sup>). 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).

### 3. INCREASED COMFORT

#### 3.1 Why are we cold?

The first question to ask is: Why are we cold, or why do we feel cold? Although the answers may be obvious to some, analyzing the answers give us a good indication on how to solve the problem.

#	Answers	Possible Solution	Reasons
1	Not wearing (enough) clothes	More warm woollen clothes; several layers of clothes	Woollen clothes contain the body heat (insulate) because wool material (or layers) contain air between the fibres (layers).
2	Not moving, sitting still	Move more, shiver, hard work	Movements require energy by the body and that generates heat.
3	Poor health, no food, insufficient fresh air (oxygen)	Eat better energy food and ensure the body gets enough fresh air	Food and oxygen (fresh air) are needed by the body to support the burning process in the cells, which generate warmth. Constant smoke in the room affects the lungs. In a fully sealed room, gas or kerosene heaters consume the oxygen.
4	Temperature difference between body and air or floor/wall	Insulate with clothes or insulation material where the body makes contact with floor/wall	Heat is lost by radiation (away from the body) and contact with air (convection) or contact with materials (conduction). Insulation reduces these three factors.
5	No (good) heating system	Improve heating system	The heating system will raise the room temperature and reduce the temperature difference between body and air.
6	Building is cold; not insulated	Improve the insulation or improve the heating	Every person produces about 100 W/hour warmth. With a non-insulated or poorly insulated building, this heat is lost in space.
6a	Roof is open or has an open hole	Close and insulate the hole in the roof and make a chimney to the stove to evacuate the smoke	Warm air rises upwards and causes a stacking effect. With a stove or fire, most of the heat goes directly out of roof hole. The Pamiri house design accelerates this effect. 
6b	Thick stone walls are cold	Insulate walls on the inside (fast result) or outside (slow result)	When a room is heated, the stone walls absorb considerable heat before their temperature is raised a little bit. Inside insulation works faster.
6c	Moist or wet roof	Ensure the roof remains dry	Wet (insulation) material has a lower insulation value than dry materials. The roof needs to be waterproof and remain dry in the winter.
6d	Cement block or concrete building	Thermal insulation inside or outside	Cement or concrete materials have a much higher heat conduction than traditional materials such as adobe. Therefore, the heat loss is much larger than in traditional houses.
7	Ventilation with cold air	Reduce exchange of cold air between outside and inside	Especially biomass (firewood) and coal stoves require a lot of cold fresh air from outside, which first needs to be heated.
8	Loss of warm air; also No. 6a	Reduce the loss of hot air through the chimney; install heat exchanger	Low-efficient stoves allow a lot of hot flue gasses to escape through the chimney. This can be reduced through better stoves. More effective is better insulation of the house so the stove is less needed (also No. 7 above).
9	Water evaporation from moist surfaces	Keep cooking pots closed with a lid to avoid steam	Nature will balance humidity levels between inside and outside. That includes evaporation of water, which requires large energy amounts.

### 3.2 Thermal Insulation or Improved Stoves?

When we think of raising the in-house temperature or saving firewood, the first thing that comes to mind is to improve the stove. Why? Because the stove is the source of heat; so when the heat source is better, the temperature will increase.

By optimizing the heating energy of a stove, firewood-efficient cooking stoves (ICS) produce the same amount of heat using less firewood or bring more heat into the cooking pot with the same amount of fuel. The cooking performance is improved, but less heat will radiate away from the stove. However, most households use the stove for both cooking and space heating. Thus, in the winter with an ICS, not enough heat will radiate from this firewood-efficient (cooking) stove to warm the room.

Most of current metal space-heating stoves have an efficiency of about 20% because most of the heat is going directly out of the room through the chimney. Chimney smoke or flue gasses have a temperature of between 150°C and 250°C with a wood fire, but can go above 400°C with coal-fuelled stoves. When it is cold outside (freezing), the house owner wants an inside room temperature of about 20°C. However, when the smoke gasses of a woodstove exit the house with a temperature of 200°C or more, it means that 80% of the energy is going straight out through the chimney. In addition, the stove needs large quantities of freezing cold outside air to enable the combustion (burning) process. By doubling the insulation value of the house or room, only half the amount of firewood is needed to produce the same in-house temperature.



*Three examples of chimneys going directly to the outside and removing all hot smoke gasses.*

With a more efficient space-heating stove, the house can be made warmer with the same amount of firewood. The house owner wants to increase the temperature in the house, especially if the former space-heating stove could not get the house warm. However, without thermal insulation **more heat will be lost from the house** because the heat loss is largely related to the temperature difference between inside and outside, especially near the ceiling.

By insulating the house or room, not only will less firewood be used (also with an old space-heating stove), but less cold air from outside will be needed to keep the fire burning.

Two statements can be made:

- (A) Thermal insulation will reduce the firewood needs for the entire future of the building and keep the house longer warm after heating.
- (B) Improved stoves will produce more space heating when burning, but do not save much firewood with higher room temperatures. Improved stoves can save firewood for cooking.

### 3.3 Chimney Pipes and Heat Exchangers

For every 2 kg firewood (or 1 kg coal), about 10 m<sup>3</sup> fresh air is required to burn the firewood. That (cold) air comes from outside, mixes with the room air to be drawn into the heating stove and finally escapes with the high temperature flue gasses out through the chimney. Thick metal or asbestos chimneys emit very little heat into the room. Improving the efficiency of these space-heating stoves, therefore, is primarily by incorporating a heat exchanger in the chimney. Measurements indicate that up to 40% fuel efficiency can be obtained with heat exchangers alone.

The principal of heat exchangers is that the hot flue gasses (smoke) of the stove will heat the thin metal of the large surface of the heat exchanger and this in turn will warm the surrounding air. The larger the metal surface, the better the heat exchanger works. The disadvantages are that the smoke heat exchangers have purchase and installation costs and are large and voluminous. Heat exchangers designed to work as bread-baking ovens (with an extra insulating cover) have an extra utility advantage besides producing more room heating.

In this respect, chimney heat exchangers and longer chimney pipes are low cost, highly effective and are far better options than a new stove. The chimney should be inclined from the stove towards the ceiling, crossing the space diagonally or in front of a wall. Both the extended chimney and heat exchanger need regular cleaning.



*New double level heat exchanger and improved bread oven heat exchanger.*

### 3.4 Planning of Priorities

Improving the thermal insulation of a house requires planning of priorities, time, resources and finances. For the planning, it is important to understand the differences between the various effects of a new stove and better thermal insulation of the construction.

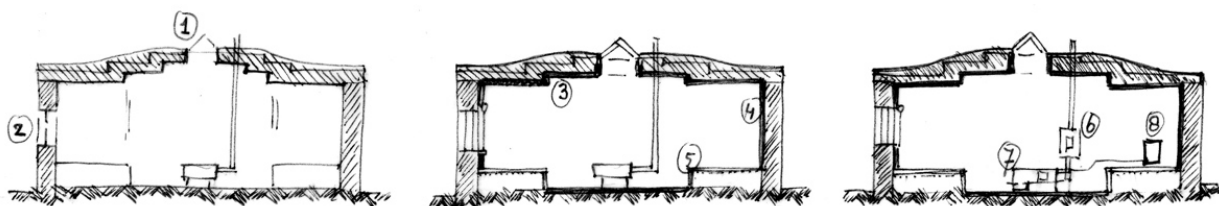
Other considerations need to be taken into account. For example, when making a building extension, it is usually most economical to realise better thermal insulation at the same time. However, when improving an existing room or building, the inconveniences of the building process (lack of space, labourers in the house, stretched finances, etc.) need to be assessed.

Each intervention has advantages and disadvantages. Only the house owner can decide whether the advantages outweigh the disadvantages, especially if paying for the product him/herself. In the decision making process, the economic return period must be considered, not only the purchase cost.

### 3.5 Preferred Sequence of Action

The most efficient way to increase the inside temperature of the house and save energy is to:

- (1) Close the openings in the roof and double or triple insulate the roof window (no ventilation).
- (2) Improve the insulation value of the windows by double/triple glass, curtains and shutters.
- (3) Ensure a waterproof roof and improve the damp proofing and insulation of the ceiling.
- (4) Insulate the outside walls, either on the inside (low cost) or outside (weather resistant).
- (5) Insulate the sitting, sleeping areas (low cost) or the entire floor area (contact).
- (6) Install a heat exchanger on the chimney (low cost), eventually one for baking bread.
- (7) Improve the efficiency of the heating stove, if a new stove is needed anyhow.
- (8) Connect a water-heating facility to the new stove (use of waste heat from stove).



*Preferred Sequence of Action*

Several years of practice in Pakistan Northern Areas demonstrates that by improving only the roof window and installing a warm-water facility on the stove, already 40% firewood was saved and the house was considerably more comfortable.<sup>4</sup>

Depending on the stove and building design, a chimney heat exchanger can be considered as option number 3, after closing the roof openings and improving the thermal insulation of the roof and other windows. Depending on the stove and chimney design, as well as the size of the heat exchanger, the efficiency of the stove can be improved by 10-50%.

### 3.6 Making the Most Effective Choices – Checklist

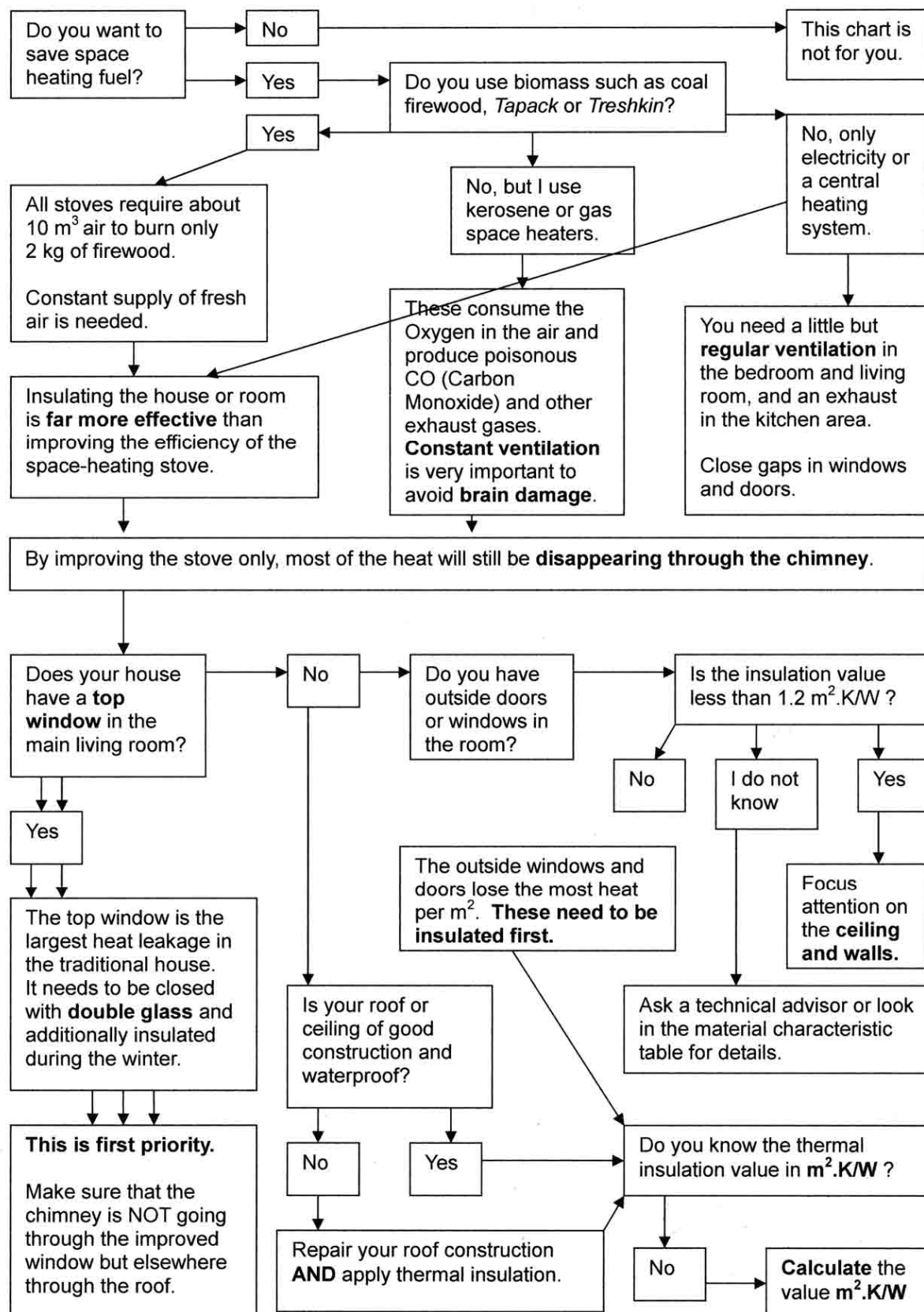
The following checklist can assist the house owner with making the most effective choices:

- ☐ Are there openings in the roof through which warm air and smoke escape? These have to be closed first. It also means that the firewood stove needs a chimney.
- ☐ Would it become too dark in the room when the hole in the roof is closed? Placing a larger, well insulated Roof Hatch Window (RHW) will give light and warmth.
- ☐ Is the modern or traditional roof well insulated? Making a calculation will answer this. Improving the roof insulation and RHW are often the most effective insulation measurements.
- ☐ Are the windows with double/triple glass and without openings? Repairing the double windows will improve comfort and reduce draft. Curtains can further improve the insulation.
- ☐ Does the outside door open directly into the living room? Making a vestibule or porch or replacing the position of the door will avoid large amounts of cold air entering at once.
- ☐ Is the wall adequately insulated? Making a calculation will answer this.
- ☐ Does the floor feel cold when sitting/sleeping on it? Elevating and insulating the sitting and sleeping areas will improve comfort and allow the space-heating stove to be less hot.

A checklist or decision flow chart can be made for every element in the house (roof, wall, floor, stove) to explain the different choices and help the house owner in making a decision. These charts should be developed based on the most commonly asked questions by house owners.

<sup>4</sup> Because the *buchari* stove in Pakistan is thinner than the thick stoves of Tajikistan and the chimney is 3" instead of 4", the chimney heat exchanger is slightly less effective in Pakistan than in Tajikistan.

### Thermal Insulation Flow Chart A

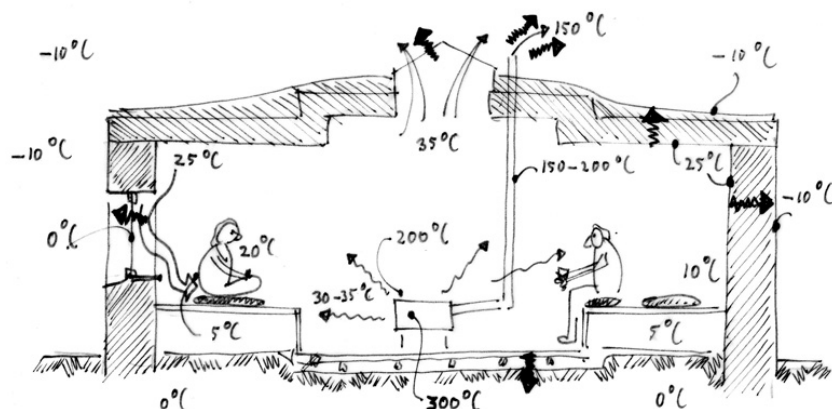


The above chart directs the house owner to look first at the roof window (RHW) before anything else. Then the other windows and doors are important. After that ceiling, walls and floor.

### 3.7 Stopping the Heat Loss

Notwithstanding the above advice, most house owners may insist that first the stove be improved. Understanding the mechanisms of heat loss and insulation may help in making a better decision.

The following sketch gives an impression of the temperature and heat distribution in a traditional Pamiri house design when the outside temperature is minus 10°C and inside the space-heating stove is being fired.



*The thick arrows indicate where the most heat is lost from the building.*

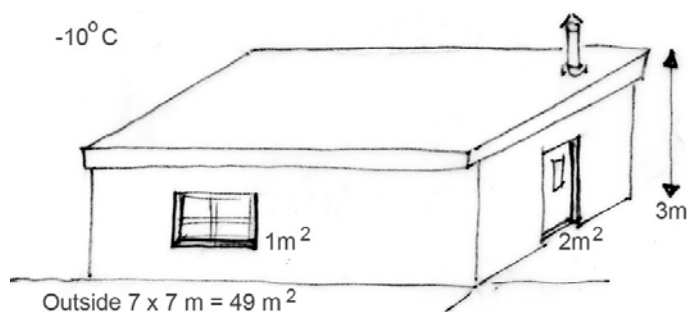
*The amount of heat loss is related to the difference between the inside and outside temperatures, and the insulation value of the window, roof, wall or floor constructions.*

The person sitting on the left feels warm in the front because of radiation, but has a cold draft on her back. Although the stove strongly heats up the air immediately around it, the air is immediately mixed with the colder room air. The temperature near the ceiling may be as high as 25-35°C, but it is cooled down by a 0°C window, giving a cold 5°C draft to the person sitting on the pillow.

Because of the shape of the traditional Pamiri roof, the hot air is stacking into the elevated ceiling and roof window opening and disappears immediately to the outside. Although the chimney may be as hot as 150-200°C, the warm air will also go directly out of the roof window. Closing and insulating the roof window, followed by insulating the side window, are therefore number ONE and TWO measurements needed to improve the comfort in the room (not improving the stove).

### 3.8 Energy (Heat) Loss in a House

A simple example is provided below to show the influence of the different building components on the total energy loss of a house.



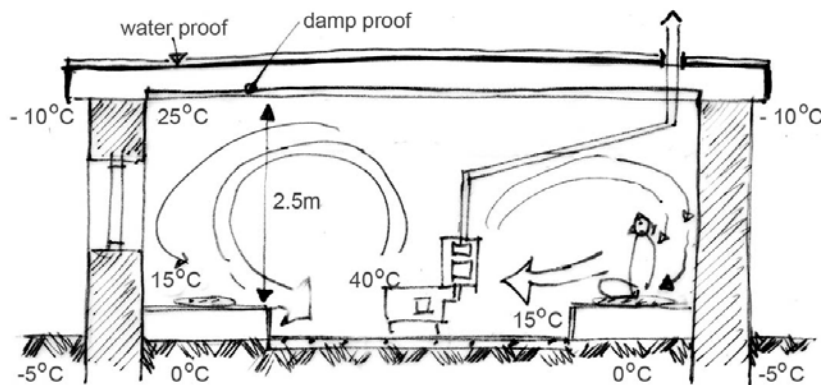
*The outside average daily air temperature is taken as being -10°C.*

*The average soil temperature may be only -5°C, while the soil temperature under the house may be just around 0°C.*

*In a poorly insulated house, the inside temperature fluctuates strongly between day and night or between the time the stove is on or not working.*

$\Delta T$  = difference between the inside and outside temperatures.

This  $\Delta T$  value is indicated in degrees Kelvin or absolute temperature.



When the stove is being fired, the air temperature near the ceiling would be at least 25°C.  $\Delta T_{\text{Roof}} = 35^\circ\text{K}$ .

The temperature near the floor would be about 15°C.  $\Delta T_{\text{Floor}} = 15^\circ\text{K}$ .

The average inside wall temperature will be about 20°C.  $\Delta T_{\text{Wall}} = 30^\circ\text{K}$ .

The heat loss from a building is calculated by dividing the  $(\text{Surface } \text{m}^2 \times \Delta T) \times R_C$  which is the specific insulation factor of that surface. The insulation factor or thermal resistance of the construction is  $R_C$  in  $\text{m}^2\cdot\text{K}/\text{W}$  in which K is the degrees Kelvin and W is Watt, the energy value.

If the insulation value of the floor, wall and roof are equal, the following comparison can be made:

The outside surface of the roof is  $7 \text{ m} \times 7 \text{ m} = 49 \text{ m}^2$  and the  $\Delta T_{\text{Roof}} = 35^\circ\text{K}$  (= **1715  $\text{m}^2\cdot\text{K}$** )

The outside surface of the walls  $2.5 \text{ m} \times 28 \text{ m} = 70 \text{ m}^2$  and the  $\Delta T_{\text{Wall}} = 20^\circ\text{K}$  (= **1400  $\text{m}^2\cdot\text{K}$** )

The inside surface of the floor  $6 \text{ m} \times 6 \text{ m} = 36 \text{ m}^2$  and the  $\Delta T_{\text{Floor}} = 15^\circ\text{K}$  (= **540  $\text{m}^2\cdot\text{K}$** )

Without the door and window, the total **wall** surface ( $70 \text{ m}^2$ ) has less heat loss than the **roof** ( $49 \text{ m}^2$ ). For that reason, the ceiling/roof often takes priority when insulating a building. Heat rises and must be retained inside the house. Although the room occupant feels that the wall or floor is cold (sitting/sleeping), in the above building the heat loss from the roof is three times greater than from the floor.

The insulation value of a door or window is often only one quarter of the wall insulation. These openings require extra attention in insulation. In many houses, a  $1 \text{ m}^2$  window loses as much heat as a  $4 \text{ m}^2$  wall construction. Windows can be insulated with double/triple glass, a transparent plastic window or roll curtains. The main entrance to a house can be insulated by creating a vestibule and placing a heavy curtain inside the door. The vestibule reduces large ventilation with cold outside air.



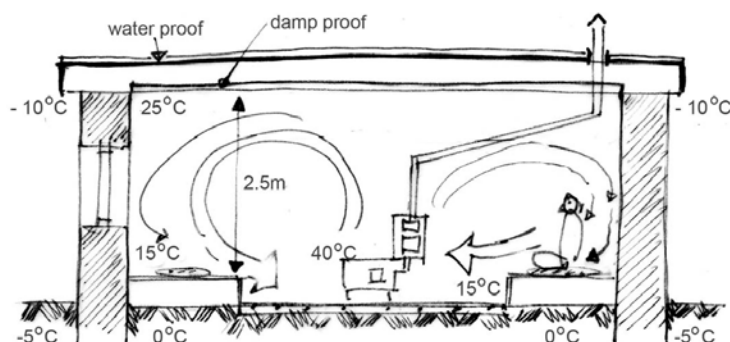
*A heavy curtain hanging in front of the door against the wall and to the floor will create an insulating air layer and reduces draft.*

The insulation values of the different construction components in a house are seldom equal. Taking the same building above, if the insulation value of each component is known, then an additional comparison about the heat loss between all the building elements can be made.

The formula for calculating the total heat loss of a building with given temperatures is:

$$\frac{\text{Surface A in } \text{m}^2 \times \Delta T \text{ in K}}{R_C \text{ in } \text{m}^2\cdot\text{K}/\text{W}} = \frac{\text{A in } \text{m}^2 \times \Delta T \text{ in K} \times \text{W}}{R_C \text{ in } \text{m}^2\cdot\text{K}} = \frac{\text{m}^2 \times \text{K} \times \text{W}}{\text{m}^2\cdot\text{K}} = \text{W (energy/hour)}$$

In the example below, the  $3 \text{ m}^2$  for the window and door are taken off from the wall. The  $R_C$  is the thermal insulation value of the construction.



$$R_C \text{ roof} = 0.6 \text{ m}^2 \cdot \text{K/W}$$

$$1715 / 0.6 = \mathbf{2858 \text{ W}} \text{ heat loss}$$

$$R_C \text{ wall} = 0.4 \text{ m}^2 \cdot \text{K/W}$$

$$1340 / 0.4 = \mathbf{3350 \text{ W}} \text{ heat loss}$$

$$R_C \text{ window} = 0.15 \text{ m}^2 \cdot \text{K/W}$$

$$R_C \text{ door} = 0.15 \text{ m}^2 \cdot \text{K/W}$$

$$1 \text{ m}^2 \text{ window} + 2 \text{ m}^2 \text{ door} \times 20^\circ \text{K}$$

$$60 / 0.15 = \mathbf{400 \text{ W}} \text{ heat loss}$$

$$R_C \text{ floor} = 0.3 \text{ m}^2 \cdot \text{K/W}$$

$$540 / 0.3 = \mathbf{1800 \text{ W}} \text{ heat loss}$$

The total heat loss of this house in the given climate and insulation conditions is **8408 W**.

Because of the lower thermal insulation value of the wall than that of the roof, the total heat loss from the wall is now more than the heat loss from the roof as compared with equal insulation values in the first sketch. In addition, 400 W (from the window heat loss) needs to be added to the wall heat loss. Increasing the window size will further increase the heat loss.

The house owner has to decide whether to insulate the walls (70 m<sup>2</sup>), roof (49 m<sup>2</sup>), window + door (3 m<sup>2</sup>) or central floor (36 m<sup>2</sup>); each insulation type having a certain cost per m<sup>2</sup>. Based on the cost calculation (surface x cost/m<sup>2</sup>), the benefit from that measurement can be calculated when the additional insulation value is known. Firewood savings for space heating will be proportional to the improvement of the thermal insulation.<sup>5</sup>

In the above house, improved thermal insulation would have the following effect:

• Roof insulation, new:	$R_C \text{ roof} = 1.8 \text{ m}^2 \cdot \text{K/W}$	then	$1715 / 1.8 =$	<b>953 W</b>
• Wall insulation, new:	$R_C \text{ wall} = 2.1 \text{ m}^2 \cdot \text{K/W}$	then	$1340 / 2.1 =$	<b>638 W</b>
• Window-door insulation:	$R_C \text{ window-door} = 0.5 \text{ m}^2 \cdot \text{K/W}$	then	$60 / 0.6 =$	<b>100 W</b>
• Floor insulation, new:	$R_C \text{ floor} = 1.0 \text{ m}^2 \cdot \text{K/W}$	then	$540 / 1.0 =$	<b>540 W</b>

With a new total of:

**2231 W**

**Or about 1/4 of the amount of firewood as in the non-insulated house<sup>6</sup>.**

The above energy saving also means that the house owner saves  $\frac{3}{4}$  the time in firewood collection or  $\frac{3}{4}$  of the funds for the annual purchase of firewood for the duration of the existence of the room or house insulation; every year this saving applies.

The house owner also needs to consider the desired comfort increment. Although for keeping the same temperature inside the house will require  $\frac{1}{4}$  the amount of firewood, only improving the sitting area and reducing the draft from the window will improve the comfort because in that case the house occupants will feel less cold from the floor and subsequently may reduce the heating from the stove. Just an insulating bed, therefore, can reduce a substantial amount of firewood being consumed because of the increased comfort, but will not improve the overall insulation value of the building.

The house owner and the local artisans must understand how thermal insulation works, what effect it will have on the comfort level and the recurrent costs. In most cases, the house owner will realise the insulation room by room or step by step, spreading the investment.

<sup>5</sup> In traditional houses, space heating usually goes together with long cooking periods.

<sup>6</sup> Each kg dry firewood produces about 4.3 kWh, but in a good stove burns with an efficiency of 25%. Each kg good quality coal produces 8 kWh, but current stoves burn with only 40% efficiency.

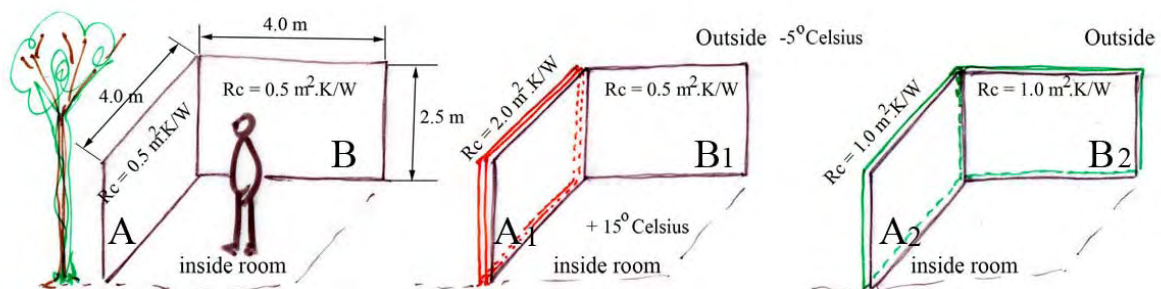
### 3.9. Which surface to insulate most?

The former paragraph explained the relation between  $\Delta T$ , insulation value and heat loss of the main building components.

When different surfaces in a room have different insulation values, most heat will be lost through the surface with the lowest insulation. Therefore low insulation areas such as windows and doors need to be improved first. A calculation shows the effect.

In the room below the two walls A and B are of similar size, each  $10 \text{ m}^2$  and have a poor thermal insulation of only  $R_C = 0.5 \text{ m}^2 \cdot \text{K/W}$

Comparison of the effect of insulation



With a temperature difference between inside and outside of  $20^\circ \text{C}$ , the  $\Delta T = 20 \text{K}$ .

Walls A and B each have the value  $20 \text{K} \times 10 \text{ m}^2 = 200 \text{ m}^2 \cdot \text{K}$ , or together  $400 \text{ m}^2 \cdot \text{K}$

The energy loss from wall A =  $(400 \text{ m}^2 \cdot \text{K}) / 0.5 \text{ m}^2 \cdot \text{K/W} = 800 \text{ Watt/hr}$ . Total A+B = **1600 W**

If we insulate one wall reasonably and the other wall not, the situation changes.

Wall A1 has now an insulation value of  $R_C = 0.5 \text{ m}^2 \cdot \text{K/W}$ , but wall B1 remains the same.

Wall A1 has a value  $20 \text{K} \times 10 \text{ m}^2 = 200 \text{ m}^2 \cdot \text{K} \rightarrow$  energy loss  $(200 \text{ m}^2 \cdot \text{K}) / 2.0 \text{ m}^2 \cdot \text{K/W} = 100 \text{ W}$ .

Wall B1 remains the same with  $(200 \text{ m}^2 \cdot \text{K}) / 0.5 \text{ m}^2 \cdot \text{K/W} = 400 \text{ Watt/hr}$ . Total A1 + B1 = **500 W**

If we insulate both wall half of the insulation of wall A1, the situation changes again.

Wall A2 has now an insulation value of  $R_C = 1.0 \text{ m}^2 \cdot \text{K/W}$ , as well as wall B2.

Wall A2 has a value  $20 \text{K} \times 10 \text{ m}^2 = 200 \text{ m}^2 \cdot \text{K} \rightarrow$  energy loss  $(200 \text{ m}^2 \cdot \text{K}) / 1.0 \text{ m}^2 \cdot \text{K/W} = 200 \text{ W}$ .

Wall B2 has the same value and energy loss of  $200 \text{ W}$ . Total A2 + B2 = **400 W**

From the above comparison it is shown that it is not wise to insulate one surface of the room very good, while not adequately insulating another surface. The heat will continue to leak out of the least insulated surface.

On the other hand the cost of the insulation and the finishing of the wall or ceiling needs to be taken into consideration. Also, the heat-loss through the floor is always less than through the ceiling/roof, because the temperature difference ( $\Delta T$ ) at the floor is about half of the  $\Delta T$  of the roof, therefore the floor will lose half the amount of heat in the same time period.

### 3.10 Humidity

Air inside the house is humid due to people exhaling and cooking on the stove. Cooking without a lid on the pot increases the humidity level. The roof is supposedly waterproof to prevent rain and melt water from snow from entering the house. In the above sketch, the roof waterproofing has a temperature below  $-5^\circ \text{C}$ . If there is poor quality damp proofing on the warm side of the roof, the air

humidity from inside will pass through the construction and condensate in the upper part of the roof, under the outside waterproofing and cause:

- Wet roof construction and insulation material; reducing the insulation value.
- The development of fungus and eventually rotting of biodegradable materials, such as timber.
- Fungus may cause respiratory problems, such as asthma.
- With poor roof insulation, the amount of water condensation will increase, drip down and cause brown spots on the ceiling.
- Eventually the roof will seem to be leaking water, although the waterproofing is in tact.

The same condensation of humidity from the inside air will occur with walls. Dark grey or black mould may form on the wall sections where the largest heat leaks occur. With outside temperatures far below  $-10^{\circ}\text{C}$ , the condensation can freeze inside the wall and break off pieces of outside plaster. The condense water may slowly flow down inside the wall and create humid areas near the foundation, showing moist spots both on the inside and outside of the wall. With cement walls, white crystals will appear.

Humidity in the air will condensate on the coldest surface of the room. This is usually the window surface (picture right). The amount of humidity will be greatly increased by cooking in the room and the use of gas or kerosene heaters having insufficient ventilation to get rid of the burned gasses.

Window and windowsill designs should be made in such away that condensation water does not infiltrate into the lower wall, but is drained outside. Double or triple windows will reduce condensation on those windows, but may increase condensation inside the walls or ceiling.

Knowing the different insulation layers and calculating their values in combination with the dew point will indicate whether or not there exists the risk of condensation inside a construction. Damp proofing on the warm side will reduce or eliminate condensation inside constructions (when all joints are carefully taped with aluminium foil).



The paint on the gypsum board ceiling in the photo on the left has been totally damaged due to condensation dripping from the above non-insulated or poorly insulated roof construction. In this case, the roof was fully waterproof galvanised iron sheets and the humidity was caused mainly from the cooking in the kitchen and human air exhaled.

The photo on the right shows black spotted mould on the interior side of the outside walls of the house. This can also occur in shower rooms and kitchens (higher humidity) and behind cabinets (less air circulation).

The formation of fungus indicates a high level of humidity in the air and the temperature of the inside finishing of the construction being so low that this humidity condenses. The air always contains fungus spores, but these will only grow when conditions are favourable, such as a humid surface.

Fungi growing inside a hollow construction cannot be seen, but it will cause rotting of low-quality timber, leading to structural weakness of support beams in roofs and floors.

Stopping the infiltration of humidity and ensuring sufficient ventilation will prevent the formation of condensation and fungus.



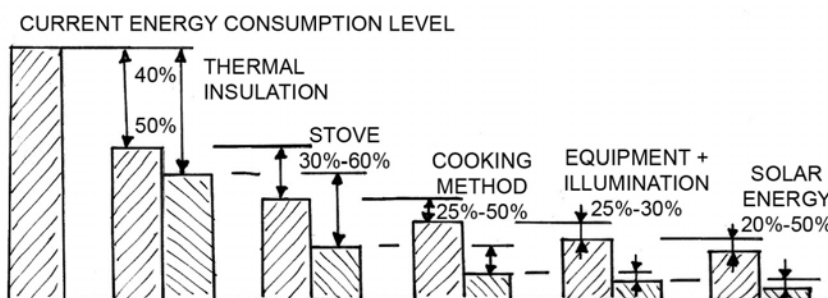
### 3.11 Points to Consider

The following five technical aspects require special attention:

- Where are the largest heat losses in the building?
- What type of insulation provides the best comfort improvement?
- Where is humidity produced and, consequently, where to place the damp proofing?
- How much ventilation is required after insulating to ensure sufficient oxygen in the house?
- What is the cost efficiency of each solution as compared with other solutions?

The cost effectiveness can only be determined by knowing the difference between the old and new insulation value of the chosen construction or building component. This needs to be calculated.

The graph below shows the possible cumulative energy savings with the different measurements at an altitude of about 1500 m for common housing. For thermal insulation, the range of 40% and 50% saving is represented by the two columns. For an average household living at an altitude of 1500 m, the different energy savings can amount to 80-95% when all aspects are taken into account. Half of that amount is related to thermal insulation only; the other figures are percentages of the remaining amount. As the altitude increases, the savings on thermal insulation and cooking will be larger, whereas the amount saved on a better stove will be smaller.



*Very large energy gains can be obtained by having large and clean south-facing window designs in a house, but this also requires large investments for existing houses. For new houses, solar heat gain is an important element to consider in the design.*

## 4. RADIATION, CONVECTION AND CONDUCTION

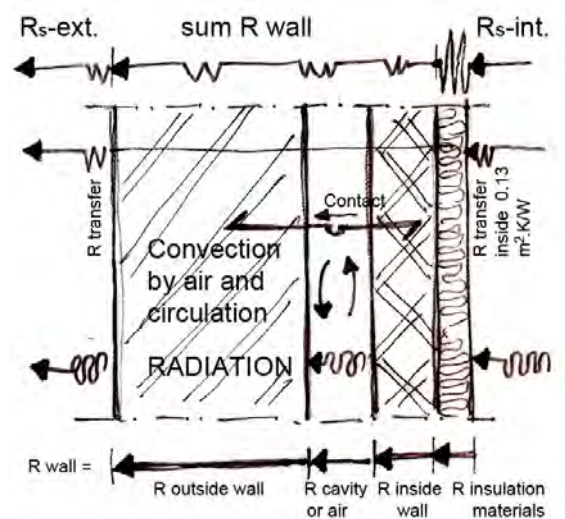
Heat loss occurs through three different physical mechanisms. Radiation (infrared and at all temperatures), convection (air movement) and conduction (through materials). In air cavities the radiation, convection and conduction all work at the same time.

While air insulates, the radiation through the air transports heat to opposite surfaces in cavities. Materials blocks heat loss through radiation and convection, but most structurally strong building materials are also large heat conductors because of their large density.

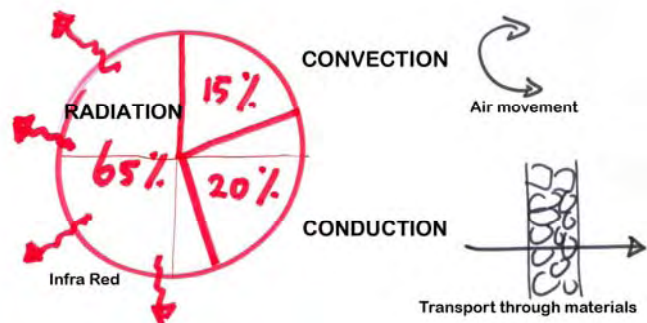
The graph shows the different heat transfer mechanisms in a cavity wall by which the heat flow goes from the right inside (warm) to the left being the outside (cold).

First there is a transfer resistance caused between the warm room air and the material of the wall. Second there exist two different conduction resistances of the inside wall. Third, inside the cavity are both convection by air circulation and radiation from the inside wall to the outside wall.

Fourth there is conduction through the outside wall structure. Fifth or last there is a small transmission resistance from the outside wall to the outside cold air. Increasing the air circulation outside will reduce the transmission resistance. All these factors together create the total insulation value.



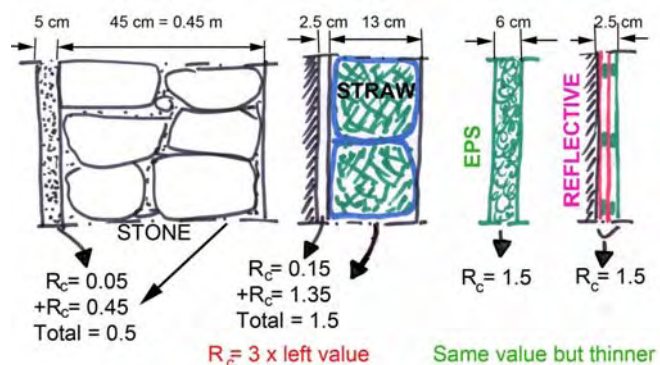
Thermal insulation is achieved by increasing the thermal resistance of one or more of these factors. Radiation however, is the largest factor with 65% of all energy loss. Radiation is stopped with the application of reflective foils inside the construction. These reflective foils work best if they have a high reflectivity. These foils should not make contact with the solid material otherwise they work less.



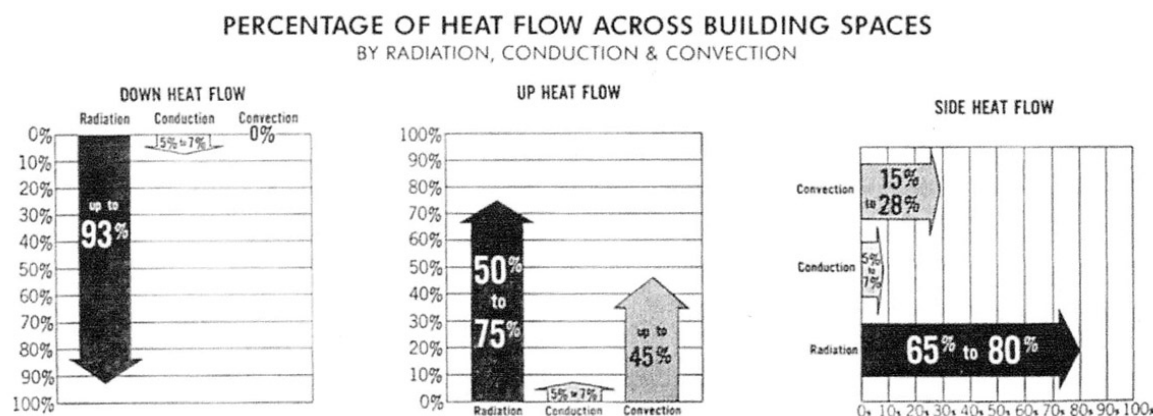
All materials have different conductivity of heat. These figures are supplied in the Technical Working Paper #3, Tables.

A 50 cm thick stone wall may have a thermal resistance of only  $R_c=0.5\ m^2.K/W$ , while a straw bale insulation of 13 cm thick will have an insulation of  $R_c=1.5\ m^2.K/W$  or three times as high as that of the stone wall.

Expanded Polystyrene (EPS) has a similar good insulation with 6 cm  $R_c=1.5\ m^2.K/W$ , but two layers of reflective foil have the same insulation value with half that thickness.



The following chart depicts the differences between the three main heat loss aspects.



Source: "Air Spaces Bounded by Bright Metallic Surfaces" from ASHREA, American Society of Heating and Airconditioning Engineers

The first chart shows that for the downward heat flow such as with hot roofs or warm floors above a cold ground under the house, radiation is the main factor of heat loss because heat convection goes upwards. Reflective foils work very well in this situation, provided that these foils do not have dust settled on them. Dust or oxidation on reflective foils will diminish their effect.

The second chart shows the heat loss towards the ceiling of a room. Here convection plays a major role, also because warm air flows upwards. Closing any opening or poorly insulated areas in the ceiling is very important.

The third chart applies to wall constructions. Because the wall surfaces in a house are usually larger than roof or floor surfaces, insulating windows and walls is most important for house insulation after closing any holes in the ceiling.

Inside a cavity or air space between construction elements, a combination of these three factors occurs. One cannot calculate only with the very high thermal insulation value of air. In small or thin cavities the heat loss through radiation will reduce the air insulation to about 50%. In wider cavities the convection of air is playing a role.

**TABLE OF RELEVANT RESISTANCE FIGURES TOTALS (including the air layer)  
FOR VERTICAL AND HORIZONTAL CAVITIES without reflective foil:  $R_C = m^2.K/W$**

Thickness of Air Layer in cm	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 ↓
0.5	¼"	0.11	0.11	0.11
0.7	1/3"	0.13	0.13	0.13
1.0	½"	0.15	0.15	0.15
1.5	5/8"	0.16	0.17	0.17
2.0	¾"	0.16	0.17	0.18
2.5	1"	0.16	0.18	0.19
5.0	2"	0.16	0.18	0.21
10 - 30	4" - 1 ft.	0.16	0.19	0.22
>100	> 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 ( $R_C = 0.02 \times 12 = 0.24 m^2.K/W$ ) or 2 cm straw ( $R_C = 0.02 \times 15 = 0.3 m^2.K/W$ ); 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.

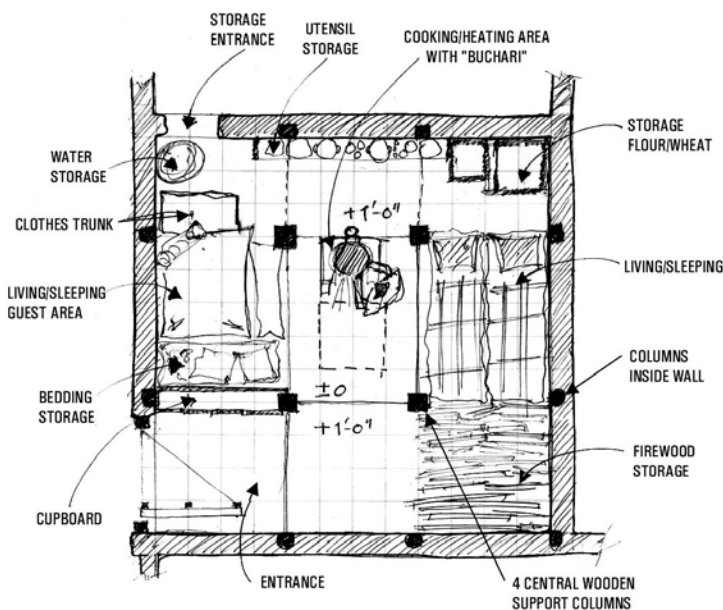
## 5. THREE FIREWOOD SAVERS

The following three house improvements were the most popular among the villagers in a project area because they provided increased comfort and firewood savings:

- A. Roof Hatch Window (RHW) – closes the small central hole in the roof and allows more light into the room. If oriented south it produces solar heat intake.
- B. Polyethylene (PE) closed cell foam – the strong, flexible and lightweight insulation material is placed under the carpet or other floor covering.
- C. Warm Water Facility (WWF) – a heat exchange pipe in the *buchari* stove connecting to a 120-litre High Density Polyethylene (HDPE) barrel provides heated water for washing.

All three interventions work effectively as firewood savers in the traditional Pamiri house, but for different reasons. To understand these issues better, a basic house plan and cross-sections with an explanation of each of the three elements is provided.

The traditional Pamiri house has a nearly square floor plan with the outer walls measuring 6-7 meters. The floor plan is divided into nine sections, each with its own function. In front of the entrance, a sub-section of minimal 2 m x 2 m is used for stacking the pre cut firewood. Approximately 2 tons is stocked at the beginning of the winter and replenished from an outside storage when the supply is getting low.



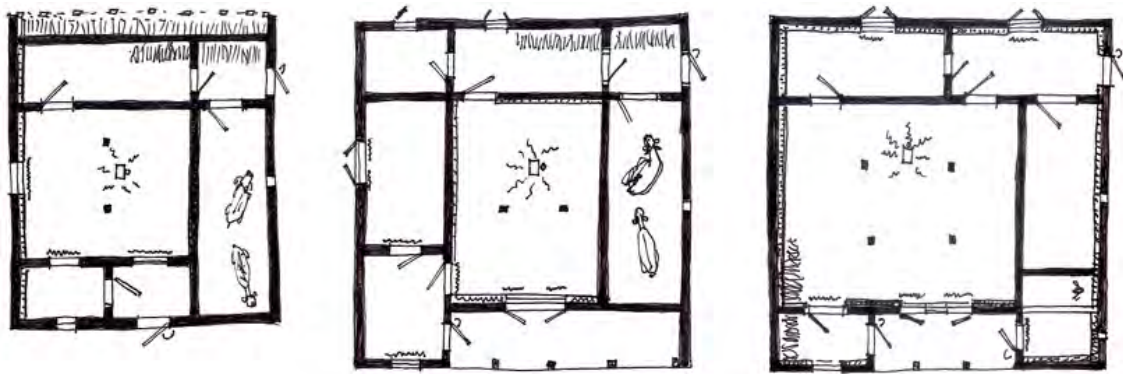
The photo is of the open hole in the roof. The light beam is actually caused by the dust in the air, the light being reflected from the dust particles. The amount of smoke originated dust particles is massive and compounded by dust from old carpets, quilts and clothing.<sup>7</sup>



The open hole in the roof is by far the largest heat leak in the house. During the winter, the hole is often partly covered with a thin plastic foil, which reduces ventilation and light intake.

The thermal insulation aspect of this central room of the traditional house is often improved by the surrounding spaces, such as food and implements storage, cattle shed and vestibule areas. Different configurations are indicated below. The basic thermal insulation value of the walls of the traditional house is at best  $R_C = 0.6 \text{ m}^2 \cdot \text{K/W}$ .

<sup>7</sup> Internal Air Pollution (IAP) is a main cause of early death caused by degenerated lungs and related diseases. In some houses, the dust particle count was very high due to opium smoking habits of the occupants.

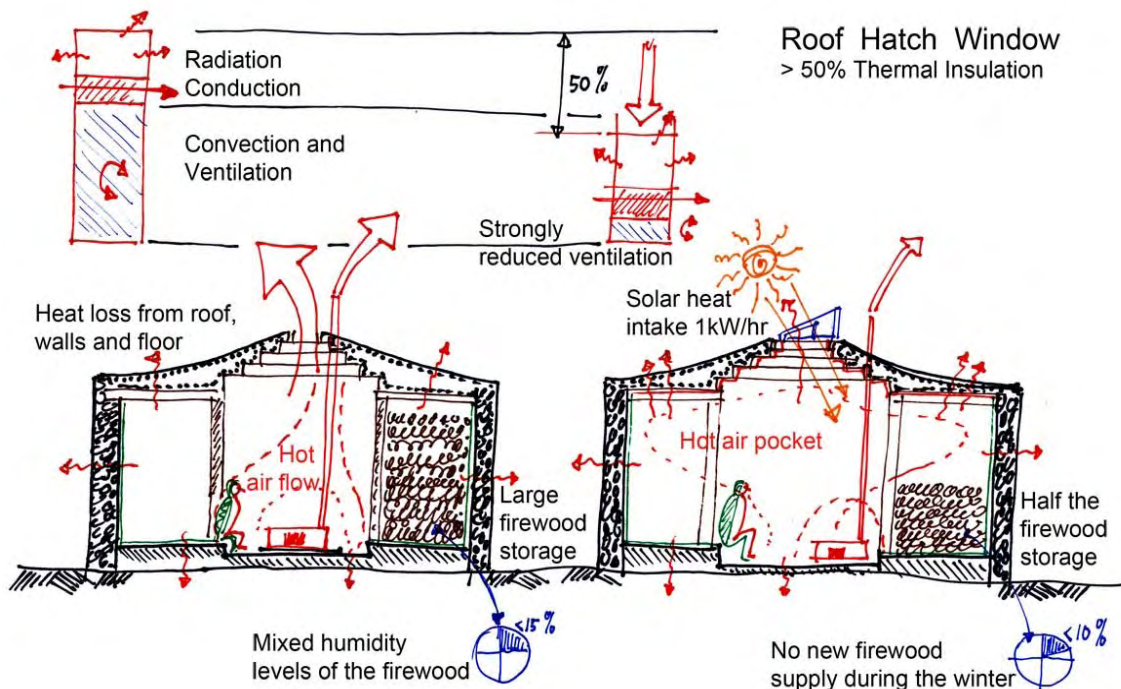


Each additional space provides a thermal insulation value of another  $R_C = 0.6 \text{ m}^2.\text{K/W}$  for the second wall plus the room value of  $R_C = 0.2 \text{ m}^2.\text{K/W}$ , bringing the total to  $R_C = 1.4 \text{ m}^2.\text{K/W}$ . A cow generates about 1 W/kg of heat. If cows are housed in an adjacent room, there will be no energy loss on that side of the main living room.

The minimum recommended thermal insulation value at 1500 m altitude is  $R_C = 2.0 \text{ m}^2.\text{K/W}$  between the heat source and the outside, thus being four times higher than a traditional wall or 30% higher with an additional room in between. For higher altitudes the recommended insulation is higher.

### A. Roof Hatch Window

The following sketch provides an estimate of the energy saved by installing a simple single glass RHW. These preliminary estimates were based on interviews realised after the winter period of 1998.



Since the cooking process is on the same space-heating stove, it is difficult to make a precise division between cooking and space heating. However, with the new RHW installed (closing the hole), the cooking time on the thing metal *buchari* was adequate to heat the house without the need of prolonging the fire burning exclusively for space heating.



*For example, this woman is standing in front of the stack of firewood left over from the winter period 1998, indicating an overall firewood saving of more than 60%.*



The immediate side effects of the large firewood saving are the following:

- (a) Less time is required for collection and chopping of firewood (by women or men). Reducing the firewood requirement for the winter by 2 tons results in a saving of 40 loads of 50 kg or 40 days' work.
- (b) 50% reduction in time spent attending to the fire.
- (c) 50% reduction of smoke emissions.

Because the autumn-collected firewood stays longer inside the house, the average humidity of the firewood will reduce slightly. In most cases, deadwood is collected, already having low humidity content due to the high altitude. Collecting firewood in the winter is now avoided (often snow covered and wet when brought inside). Moist firewood reduces the burning efficiency.

The high firewood saving of the RHW is the result of substantially reducing ventilation through the roof hole. The pyramidal shape of the room (shown in the cross-section diagram and photo of the roof hole) causes an accelerated stacking effect of the warm air above the stove. Firewood saving is obtained by three aspects:

- (1) Warm air does not escape any more through the open roof hole, reducing firewood consumption to warm up freezing cold air entering to replace the lost warm air (represented by the bar diagram above the sketch). Other energy loss elements (conduction/radiation) remain about the same.
- (2) Lower average amount of humidity in the firewood due to avoiding replenishment from outside stockpiles during the second half of the winter; dry wood burns more efficiently.
- (3) Solar heat intake through the south-oriented RHW. At high altitudes, the solar heat intake during winter is equivalent to 2 kW/h with clear skies and clean glass. On average, it can be assumed solar heat intake will provide minimal 4 hours  $\times$  2 kW/h/m<sup>2</sup> with clean glass.



*The difference between the “before RHW” situation (left) with very high dust particles in the air and the “after RHW” situation (right) with more and better light distribution is visible.*

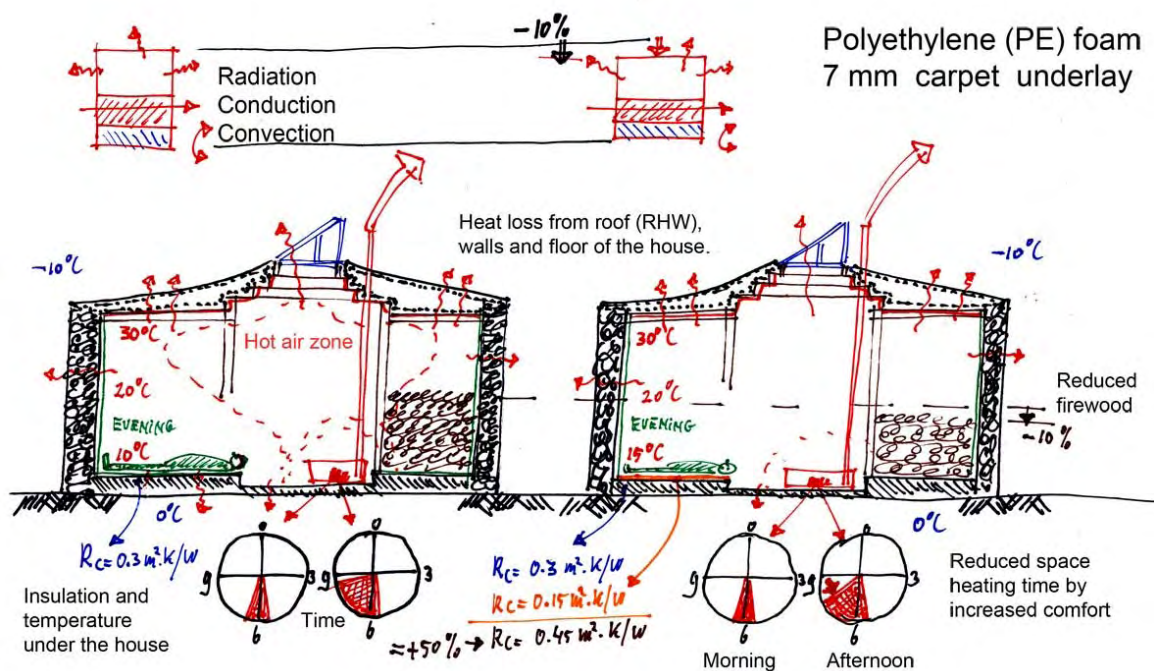
## B. Polyethylene (PE) Foam

The reason why the PE foam is efficient is technically different from the RHW. This is related to creating personal comfort, as well as to its (rather limited) thermal insulation aspects. The PE foam has such a positive effect because people living in traditional houses sit and sleep on the floor. This intense contact with the floor for over 16 hours (minimal 4 hours sitting and 12 hours sleeping) causes the body to lose heat by conduction. The carpets, sleeping mattresses and quilts are often of rather poor quality and do not provide sufficient thermal insulation.

The amount of energy loss from a body or building is partially related the  $\Delta T$  between the inside and outside temperature. For the roof of a traditional house  $\Delta T = +30^{\circ}\text{C} - (-10^{\circ}\text{C}) = 40\text{K}$ ; at the middle of the wall  $\Delta T = 30\text{K}$ ; while under the house  $\Delta T = 10\text{K}$ .

The average floor insulation value is at best  $R_{\text{Construction}} = 0.3 \text{ m}^2\cdot\text{K/W}$ . However, the  $\Delta T$  of the floor is much lower than the  $\Delta T$  of the roof, and thus the heat loss through the floor is much lower. Nevertheless, when sleeping on the floor, the contact with the floor is both intense and long, resulting in a high discomfort level due to the cold being felt.

The 7 mm thick PE foam<sup>8</sup>, having an  $R_{\text{Construction}} = 0.15 \text{ m}^2\cdot\text{K/W}$ , increases the floor insulation value by 50% and with that reduces possible condensation of body humidity into the mattress, both increasing a person's sleeping temperature and comfort. Because of the increased comfort level, the fire is extinguished earlier and thus firewood is saved. The roughly estimated saving is at least 10% of the remaining firewood use after placing the RHW.



*Although the actual thermal insulation value of the PE foam sheet is not very high, the 50% increment of the floor insulation factor has a large impact because people sit and sleep on the floor and therefore have intense contact with the floor.*

<sup>8</sup> The  $R_{\text{Material}}$  of PE foam  $R_M = 22 \text{ m}^2\cdot\text{K/W}$ . With a thickness of 0.07 m, this translates to  $0.154 \text{ m}^2\cdot\text{K/W}$

### C. Water Warming Facility (WWF)

The third most popular house improvement is the warm water facility connected to the space-heating stove. A galvanised iron pipe is placed inside the stove and due to the thermo-siphon effect of the heated water, the water in the 120-litre barrel is gradually heated during the cooking periods.

This warm water is used for dishwashing, body washing and some laundry, improving substantially the personal hygiene of the house occupants.<sup>9</sup>

*A new thin metal flat buchari fitting two pot sizes, one large and one smaller. The buchari is fitted with a round heat pipe, which will be connected to the water storage barrel using two flexible hoses.*

By having minimal 20 cm vertical distance between the inlet and outlet of the barrel, the thermo-siphon action keeps the water flowing through the system.<sup>10</sup>



The WWF is firewood efficient for two main reasons:

- (1) Water is automatically heated without affecting the cooking power of the *buchari* space-heating and cooking stove. This stove has a calculated water heating and cooking efficiency of approximately 25%.<sup>11</sup>

The large cooking pot remains above the hottest area of the fire and the heat pipe draws its heat from the hot flue gasses next to that hottest area. The fire doesn't need to be kept burning just to heat washing or laundry water. The heating of laundry water is often done outdoors on the very inefficient three-stone fire (efficiency below 15%).



- (2) The water stored in the barrel has a very large heat storage capacity.<sup>12</sup> The heat storage capacity of air is 0.208W/°C.kg. The heat storage of water is 1.153W/°C.kg. When the barrel is half full (60 litres) and warmed up to 40°C, its heat loss over night can be 10°C, being still sufficiently warm for washing in the morning. This heat loss represents 10°C x 60kg x 1.153 W = 692 Watt. The heat is transmitted (convection) to the air in the room. A room measuring 7 x 7 m x 2.5 m contains 122 m<sup>3</sup> or about 120 kg air (1m<sup>3</sup> ≈ 1 kg). For heating this air 1°C the amount of 120 x 0.208W = 25 W is required.

<sup>9</sup> It is common for villagers not to wash themselves during the winter months due to lack of (warm) water. Dark crusts of dirt cake onto their face, hands and feet.

<sup>10</sup> The 20 cm is 10% of the distance between the fire and the centre of the barrel. If the distance between the fire and barrel is increased, the barrel should be placed higher, ensuring a 10% slope.

<sup>11</sup> The water-heating efficiency of the thin metal *buchari* has been calculated at 25% using the standard water-boiling test (WBT). The WBT is done with one single pot over the large front opening. The test does not include the space-heating aspect of the stove.

<sup>12</sup> Heat storage capacity of water = 4.15 kJoule/kg.K. = 1.153 W/kg.K For air, this is 0.75 kJoule/kg.K = 0.208 W/kg.K. 1 m<sup>3</sup> air = 1 kg. 3600 Joule = 1 Watthour or 3.6 kJ = 1 Watt

The theoretical heating of this 120 kg air overnight by 10°C loss the water is  $692/25 = 27.7^{\circ}\text{C}$ . However, if the room is not well insulated, most of the air heat will be lost on warming up the ceiling and the walls and lost to the outside.

The overall effect of the heat stored in the water barrel is that the air temperature in the room will be better maintained, possibly keeping the average room temperature about 4°C to 5°C warmer than would be the case without the barrel of warm water.

This difference of a few degrees will substantially increase the comfort level in the room and reduce the space-heating time in the evening or early morning.



In some smaller houses, the house owner does not like the position of the barrel next to the sitting area and wants it nearer the kitchen area because of dishwashing. In such cases, with a longer pipe distance between the *buchari* and the barrel, the location of the pipes needs to be well thought out. If installed in an outside wall niche, that niche wall should be additionally insulated so heat exchange is not directly lost to the surrounding walls.

### **Behaviour Change**

When applying a house improvement for thermal insulation or firewood saving, the effect of the improvement is strongly influenced by the behaviour of the occupants of the house.

Some examples:

- If an improved cooking stove (ICS) or solar box cooker is introduced, the cook (usually the female in the household) needs to use the equipment; otherwise the potential firewood saving will not be obtained. If the ICS is used only during the summer because the old *buchari* warms up the house too much, or in the winter the ICS does not heat the house<sup>13</sup>, half of its saving potential is lost.
- If a chimney heat exchanger and bread oven has been bought, but the user does not know how to make good tasting bread in such an oven, the double benefit of the oven will be lost.
- If the glass of the RHW is not cleaned regularly, benefit from the additional solar light intake and solar heating will be strongly reduced.
- The WWF system needs to be installed at the proper height to ensure the thermo-siphon action and for easy filling. An inclination of 10% between fire and inlet is needed.

These examples illustrate the need for user manuals.

In most households where thermal insulation has been applied (RHW and PE foam), the villagers will eventually increase their comfort level by increasing the average room temperature. That is because, compared with the year before, they now have extra (non-burned) firewood available. Part of the efficiency gain is therefore reduced by the increased room temperature and comfort.

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<sup>13</sup> In this case, when the ICS is not used in the winter because it does not radiate sufficient heat to the room, it actually means that the house is not adequately insulated and the thermal insulation requires attention.

## Additional Measurements

As indicated in the sketches of the three improvements, the roof and walls (including windows and doors) have not yet been thermally insulated and have low thermal insulation aspects. To improve the overall thermal insulation of the house further, additional measurements need to be realised. These will incur expenses to install, but will have a permanent fuel saving effect. Because of the spectacular effects of the first three insulation measurements, villagers will not be easily inclined towards taking further measurements unless they are convinced these will also bring additional savings in firewood consumption, reduced firewood collection time, improved health and finances.

Other firewood saving elements in order of priority are:

- Roof insulation, including making the roof lighter and waterproof.
- Wall insulation, especially the inside face of the outside walls of the main room.
- Making a porch to the house with an insulated door and spring closing.

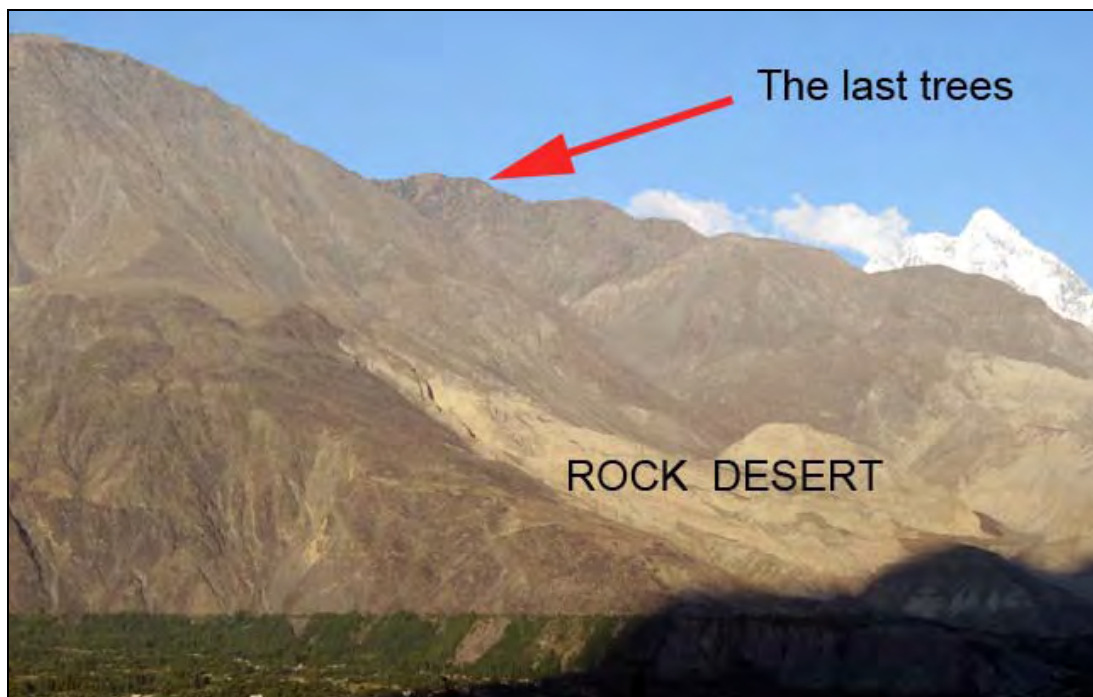
After applying the above-described thermal insulation options, the use of an ICS and a heat retention box/bag are the most effective elements to reduce firewood for cooking. For the winter, the chimney heat exchanger and bread oven will also save fuel.

*A simple spring on an outside door can have important firewood savings.*



## Resume

- The three items together (RHW, PE foam and WWF) have in most traditional (Pamiri) houses a firewood saving of well over 60%.
- A possible change in behaviour, such as raising the average room temperature with the firewood saved, can reduce the overall savings.
- For each item, a small user manual is advised; “what to do, what not to do”.
- Further thermal insulation remains the best option for recurrent savings on firewood.

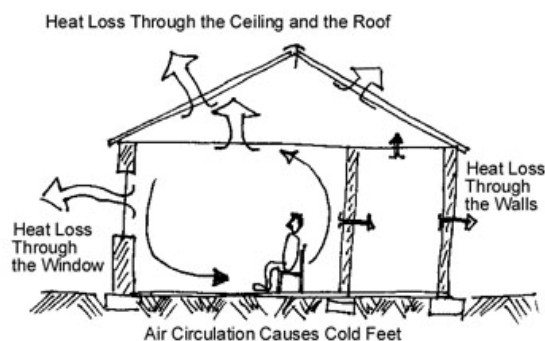


*The only free trees growing near towns are more than 3000 ft above the town, out of reach.  
Insulating their house will reduce their daily heating expenses. People buy now LPG.*

## 6. RECOMMENDED INSULATION VALUES

The most relevant house improvements either increase the comfort inside the house or reduce the annual expenses or labour for heating fuel (firewood and coal). Thermal insulation does both. It is best applied on the outside shell of the building (roof, walls and floor). Windows (wall and roof) and doors cause relatively large heat leakages and require special attention.

A poorly insulated window is noticeable because the cooled air descending along the windows causes draft and is uncomfortable. Maximizing the insulation of the window will increase the comfort and reduce heat loss. Window insulation will bring comfort to the room. Making larger windows will have the benefit of letting more light into the room, but will result in more heat loss during the winter.



For the entire mountain area of the Himalayas, double glass windows and add-on windows are recommended.<sup>14</sup> Curtains (cloth, roll or fixed transparent foil) and shutters will further improve the insulation value of double glass windows. Heat radiation to the outside of the house occurs constantly from all surfaces, including the floor. Every section of insulation, therefore, helps to reduce heat loss and thus energy expenses.

The total heat loss of a house is the sum of all the heat loss of each area determined by:

- The temperature difference between inside and outside ( $\Delta T$ ). The larger the temperature difference, the larger the heat loss.
- The total surface of an area subject to the  $\Delta T$ . The larger the area, the larger the heat loss.
- The thermal insulation value of the selected construction area. The lower the insulation value, the more heat loss will occur.
- The amount of cold air entering the building or warm air leaving the building. This is considerable with biomass-fuelled space-heating stoves requiring lots of fresh air.
- The amount of moisture evaporating inside the house. Evaporation costs energy.

As indicated before, room insulation is, far more effective than stove improvements. Also reducing the ventilation will reduce the energy loss. However, ventilation remains necessary in areas where people live, and even more necessary when fuel stoves are used that do not have chimneys.

When a kerosene or gas stove is used to heat the room, the oxygen in the room is burned and fresh air is constantly needed in the room; to loose the flue gasses and replenish the oxygen. The residue gasses from such kerosene and gas stoves do not smell and unknowingly the room occupants get less and less oxygen. A person will begin to feel drowsy, get a red face, fall asleep and eventually die of carbon monoxide (CO) poisoning. **Constant room ventilation with a gas/kerosene space-heating stove is essential.** An electric heater requires less refreshing of the air and is safer, but electricity shortages occur in the winter in many mountainous regions.<sup>15</sup>

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%).

<sup>14</sup> Special insulating gas-filled double windows work exceptionally well, but are not available and are very expensive.

<sup>15</sup> Electric power in the Himalayas is often generated by hydroelectric installations fed from melting glacier/snow water.

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

The above indicates that radiation causes twice the amount of heat loss (65%) than conduction and convection together (35%). Infrared heat radiation is blocked or reflected by shiny metallic surfaces. That is why shiny metallic reflective foils are so effective as thermal insulation.<sup>16</sup>



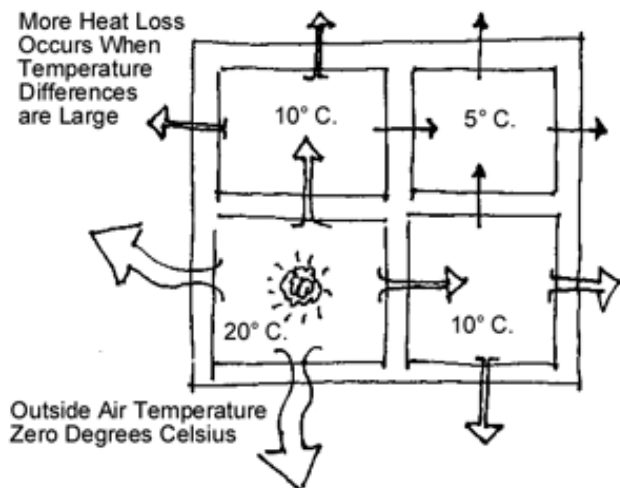
*Metalized reflective foils separated by 2-3cm air layers have a very high insulation value because they block the infrared heat radiation. More than three reflective foils do not have added value.*

Standing air is an effective, low-cost thermal insulator. However, air circulation (convection) needs to be avoided; otherwise, the insulation value will reduce. See also the table on the material characteristics for the different values of cavities in Technical Working Paper #2 – Calculation.

In the Technical Working Paper #3 the various values of materials have been listed for making the calculations. Including is also the insulation table for different reflective foils.

Dry air has a very high  $R_{\text{Material}} = 43 \text{ m}^2 \cdot \text{K/W}$ . Five mm air has a theoretic  $R_C$  of  $0.005 \times 43 = 0.22 \text{ m}^2 \cdot \text{K/W}$ , however, only half of that value can be taken into consideration because of convection and radiation. A cavity of 2 cm therefore has an effective thermal insulation value of  $R_C = 0.11 \text{ m}^2 \cdot \text{K/W}$ . In the case of reflective foils different aspects play a role such as the emissivity of the surface.

Adjoining rooms and closed roof areas (attic) that are not heated act as a temperature buffer. For spaces larger than 1 meter the values of the table on page 20 can be added with the values for the two wall-to-air transfer resistances. The inside and the outside wall or roof insulation value needs to be added to this value. This shows that in-between roof have a good insulating effect.



Different areas in the house will have different levels of heat loss.

- The temperature difference between the inside room and the outside air will differ between heated and non-heated rooms. When the temperature at the ceiling of a warm room is  $+30^\circ\text{C}$  (or  $303^\circ\text{Kelvin}$ ) and the outside temperature is  $-20^\circ\text{C}$  (or  $253^\circ\text{Kelvin}$ ), the difference is  $50^\circ\text{K}$  in total.

<sup>16</sup> Infrared radiation occurs at all temperatures, even below  $0^\circ\text{Celsius}$  ( $= 273^\circ\text{Kelvin}$  or  $\text{K}$ ). Kelvin is the absolute temperature of a material. Absolute zero is  $0^\circ\text{K}$  or minus  $273^\circ\text{C}$ .

- When in the same room the temperature of the floor is  $+20^{\circ}\text{C}$  (or  $293^{\circ}\text{Kelvin}$ ) and the underground outside is  $5^{\circ}\text{C}$  (or  $278^{\circ}\text{Kelvin}$ ), the difference is  $25^{\circ}\text{K}$ . This means that with the same insulation value, the heat loss from the ceiling is twice as high as from the floor. For this reason the recommended minimum thermal insulation value for floors is only half that for the walls or the roofs.
- The outside surface of a construction has an additional chill factor. With cold winds, rough outside surfaces cool off more than smooth surfaces. Under a fully covered but open roof, the wind-chill factor is low, but the roof insulation is also zero.

Therefore, in cold areas it is better to have smooth outside surfaces rather than open or deep joints in between the building blocks. The joints in the masonry should be filled out flat. Plastering stone walls will substantially improve the thermal insulation (picture right).



The humidity of the air is another factor in the comfort level. Humid cold air feels colder than dry cold air, mainly because the conductivity of humid air is larger and therefore causes more heat loss from the body. Frost will reduce the humidity in the air, but people exhale humid air and that humidity remains inside the house until it condensates, is ventilated away or levels out slowly. Condensation may make the ceiling or walls wet, substantially reducing their insulation value. The humidity on the surface of inside constructions may cause fungus, often visible as black spots. If the condensation inside the stone construction freezes, it can cause damage to the construction. Humidity blocking plastic foils should therefore always be on the warm side of the construction.

## 6.1 Traditional Stone and Adobe Houses

Thick construction material not only increases the insulation value of the construction, but its thermal mass (weight) as well. Very old houses are often built halfway into the ground, mainly because the earth is not as cold as the winter air. Because the temperature difference is less in the ground, there is less heat loss.

Thick stone and adobe walls insulate better than thin-masoned walls for two reasons:

- (1) Because the inside stones of the wall do not make contact with the outside stones, the heat transmission is less than masoned walls where the cement mortar acts as a bridge for heat conduction. The joints are often not completely filled out with adobe and it contains many insulating air pockets.
- (2) Dried adobe has incorporated air in between the soil particles. Adobe with chopped straw

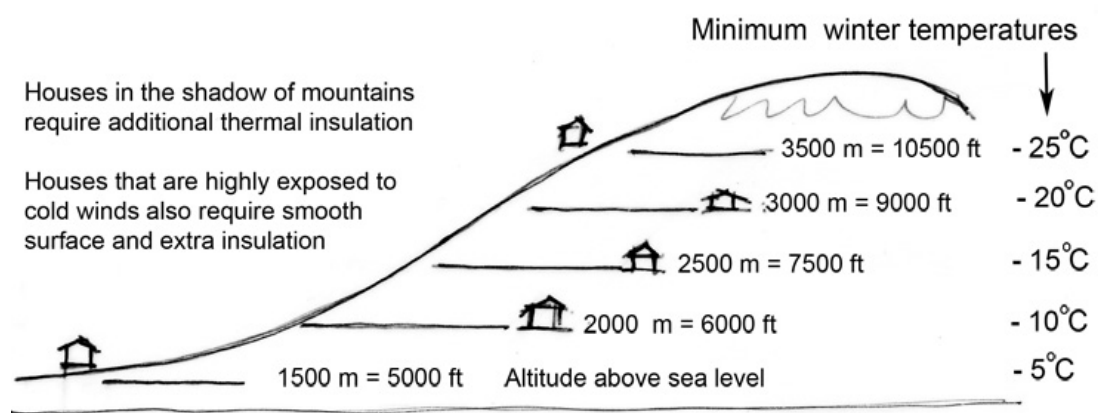


insulates even better. Traditionally one can notice in very cold areas that house owners prefer building with adobe and plastering the outside walls smooth. Adobe stabilises the air humidity inside and therefore creates a comfortable interior climate.

With construction costs rising, house owners are making thinner outside walls of adobe or stone (thus less thermal insulation). In addition, people want larger windows in the walls, again reducing the overall thermal insulation value of the building. Larger windows facing south for solar heat intake need to be double glazed and additionally insulated for the night to retain the heat.

## 6.2 Recommended Minimum Insulation Values

Many traditional stone and adobe houses have thermal insulation values of only  $R_C = <0.8 \text{ m}^2.\text{K/W}$ . This is much less when these are masoned with cement mortar ( $R_C = <0.6 \text{ m}^2.\text{K/W}$ ). The so-called modern houses with a lot of cement and concrete have still lower insulation values ( $R_C = <0.4 \text{ m}^2.\text{K/W}$ ). These values are considerably insufficient for all Himalayan mountain regions.<sup>17</sup>



*The minimum thermal insulation thicknesses and values recommended for the Himalayan areas. Many houses currently have an existing wall or ceiling insulation value of only  $R_C = <0.5 \text{ m}^2.\text{K/W}$*

With every 100 m rise in altitude, the average environmental temperature is approximately 1°C lower. When at 1500 m the daily summer temperature is 25°C, then at an altitude of 3500 m (2000 m higher), the average air temperature is about 5°C and the freezing point in summer is at about 4000 m.

During the winter period, when the sun intensity is less the temperatures are much lower; the recommended thermal insulation values therefore need to be higher with increasing height. For environmental reasons these values should be additionally high because at higher altitude less biomass is growing to supply the necessary fuel.

The following formula for the recommended minimum average building insulation value is based on the altitude at which the building is located. Although these values are much higher than the current insulation values of existing buildings, they are substantially lower than the official minimum thermal insulation values applicable under similar climate conditions in Europe.

**In Europe, by 2012, the obligatory minimum thermal insulation values are twice as high.**

<sup>17</sup> All heat can be valued in the energy measurement of Watt or W. The resistance amount of a construction  $R_C$  indicates the heat loss in degrees Kelvin multiplied by 1 m<sup>2</sup>. To calculate the real heat loss in Watt, the amount is multiplied with the total surface and the total temperature difference. For a whole building, every construction component needs to be calculated.

**Altitude in m**

**Recommended Minimum Average Value  $R_C = \{0.5 + \frac{\text{Altitude in m}}{1000}\} \text{m}^2.\text{K/W}$  for roofs and walls.**

The recommended value for ground floor constructions is half the above amount.

These values are calculated between the heat source (heated rooms) and the outside.

These values need to be adjusted higher when the building has no solar heat intake during the winter.

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 every hour of sun less than 5 hours per day, the average insulation value needs to be increased with  $R_C = 0.1 \text{ m}^2.\text{K/W}$ .

For fully shadowed or overcast regions in the winter, it means adding  $R_C = 0.5 \text{ m}^2.\text{K/W}$ .

#### **Recommended Minimum Average $R_C$ Value for Buildings with About 5 Sun Hours/Day**

*Amount needs to be added with  $R_C = 0.1 \text{ m}^2.\text{K/W}$  for each sun hour less*

*Values are related to the Himalayan range of mountains*

Minimum Winter Temperature in Degrees Celsius	Approximate Altitude Above Sea Level	Recommended Minimum $R_C$ in $\text{m}^2.\text{K/W}$  With 5 Sun Hours per Day	Recommended $R_C$ in $\text{m}^2.\text{K/W}$  With Only 2.5 Sun Hours	Recommended $R_C$ in $\text{m}^2.\text{K/W}$  Without Sun Hours
0° C	1200 m (4000 ft)	$R_C = 1.7$	$R_C = 1.95$	$R_C = 2.2$
-5° C	1500 m (5000 ft)	$R_C = 2.0$	$R_C = 2.25$	$R_C = 2.5$
-10° C	1800 m (6000 ft)	$R_C = 2.3$	$R_C = 2.55$	$R_C = 2.8$
-15° C	2200 m (7500 ft)	$R_C = 2.7$	$R_C = 3.95$	$R_C = 3.2$
-20° C	2700 m (9000 ft)	$R_C = 3.2$	$R_C = 3.45$	$R_C = 3.7$
< -30° C	3000 m (10,000 ft)	$R_C = 3.5$	$R_C = 3.75$	$R_C = 4.0$

When for example the existing insulation value of a construction is  $R_C = 0.5 \text{ m}^2.\text{K/W}$ , the following insulation materials can be applied to improve the overall insulation value of the construction.

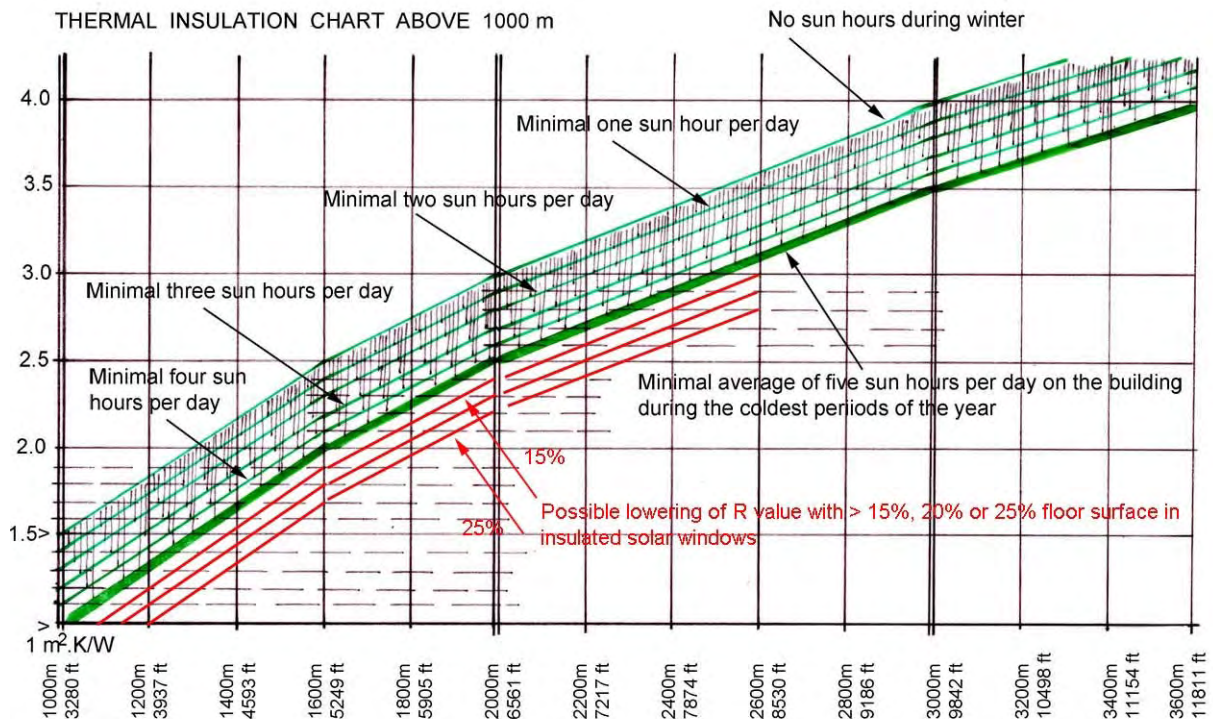
Minimum Winter Temperature in Degrees Celsius	Approximate Altitude Above Sea Level	Thickness of Insulation Type EPS, Glass or Sheep Wool $R_m = 25 \text{ m}^2.\text{K/W}$	Thickness of Insulation Type Dry Thatch or Packed Straw $R_m = 12 \text{ m}^2.\text{K/W}$	Insulation of the Materials in the Left Columns $R_C$ in $\text{m}^2.\text{K/W}$	Total new Insulation Value of Construction $R_C$ in $\text{m}^2.\text{K/W}$ 5 Sun Hours
0° C	1200 m (4000 ft)	4 cm	8 cm	$R_C = 1.0$	$R_C = 1.5$
-5° C	1500 m (5000 ft)	6 cm	12 cm	$R_C = 1.5$	$R_C = 2.0$
-10° C	1800 m (6000 ft)	8 cm	16 cm	$R_C = 2.0$	$R_C = 2.5$
-15° C	2200 m (7500 ft)	10 cm	20 cm	$R_C = 2.5$	$R_C = 3.0$
-20° C	2700 m (9000 ft)	12 cm	24 cm	$R_C = 3.0$	$R_C = 3.5$
< -30° C	3000 m (10,000 ft)	14 cm	28 cm	$R_C = 3.5$	$R_C = 4.0$

For regions at 1500 m altitude, the following averages are recommended for walls and roofs:

Constructions having an average insulation value of	2.0	$\text{m}^2.\text{K/W}$	(= very good)
Constructions having an average insulation value of	1.5	$\text{m}^2.\text{K/W}$	(= good)
Constructions having an average insulation value of	1.25	$\text{m}^2.\text{K/W}$	(= average)
Constructions having an average insulation value of	1.0	$\text{m}^2.\text{K/W}$	(= low)
Constructions having an average insulation value of	0.75	$\text{m}^2.\text{K/W}$	(= very low)
Constructions having an average insulation value of	0.5	$\text{m}^2.\text{K/W}$	(= totally insufficient)

The above values are relevant for the heated spaces (living rooms) where people spend most of the time. The building can therefore be organised in zones with good and lesser insulation.

The following chart gives a resume of the above figures per altitude region and sun shading. The red lines are the possible reduction of the minimum average  $R_C$  value with clean, double glass and south facing solar windows.



A well designed solar window can substantially improve the heat gain of a room during the winter.

An office was reviewed with two large south facing windows (single glass). By removing the mosquito wire mesh from the outside during the winter and keeping all the glass surfaces clean (both outside and inside) would avoid the need for any space heating. The window design must have a removable fly screen.

Double glass would further improve the comfort level and avoid heat loss during the night. An additional roll curtain will further reduce the heat loss during the night.

Because these windows in this building are already in place, fitting an add-on glass sheet on the inside is the most economical solution to make double glass windows.

These add-on glass windows need to be easy to open for cleaning on the inside before the winter. Usually, the cleaning of solar windows is only done once a year.



*By opening the dirty glass window, one can immediately feel the power of the solar heat.*

## 7. AWARENESS RAISING

Knowing how thermal insulation works is the first step towards implementation since a house owner needs to be convinced that it helps to create better comfort for the family and, in addition, how it will save money for all the future years. Professionals, such as sales people of insulation materials, masons, contractors and home installation specialists, also need to know these details in order to explain the different options to the house owner.

All advice should be based on real calculations of the amount of thermal insulation and the cost of the construction. The cost of the construction is related to the actual construction cost, the durability, the finishing materials, room space used and the maintenance cost. Only considering the purchase the cost of the insulation material alone is less relevant. For example, when thermal insulation is done with straw, the question should be raised of how long that straw will keep its characteristics or if it will deteriorate due to insects or humidity?

Comfort is often a more determining decision-making factor than economics. Rich people take the two aspects into account, the recurrent cost of the annual high fuel costs and the increased comfort due to the thermal insulation. Poor people often look only at the initial cost of installation, the cash layout. In addition, poor people do not consider their cost of collecting firewood.

Because thermal insulation of houses and schools works for the lifetime of these buildings, local communities should look for options to reduce overall firewood consumption from their mountain environment. Time saved in firewood collection, and health saved from smoking stoves, can be better invested in education and other community development. Village groups need to look for options to facilitate poorer villagers being able to apply effective thermal insulation and plan for methods to finance these house improvements. Possibilities for labour exchange should be investigated.

Having villagers talk about thermal insulation, space-heating stoves and cooking issues helps to improve their level of knowledge and change their way of thinking about the subject. Posters and leaflets will stimulate the discussion, especially when posters are located at places where people have to wait and have time to study the contents.

Realising demonstrations of thermal insulation in houses in a village allows the villagers to: (1) train local craftsmen in the application, (2) measure and observe the results, (3) hear the opinion of the house owners about the advantages and disadvantages, and finally (4) become motivated to do the same in their own houses.

Reaching the point of action or initiative for the application of an investment or activity requires four basis steps: (I) awareness of the issue and knowing solutions are available; (II) information about the details of the solution, such as technique and costs; (III) motivation to do something, either by do-it-yourself or hiring a craftsman, saving money and improving comfort; and (IV) action by which contracts are made, materials bought, the house is restructured, etc. Without these four steps, going directly into action may result in wrong decisions and results.

For each of these steps supporting documents and activities are required ranging from training, availability of materials and finance, transport, the best time frame to implement the activity, etc.

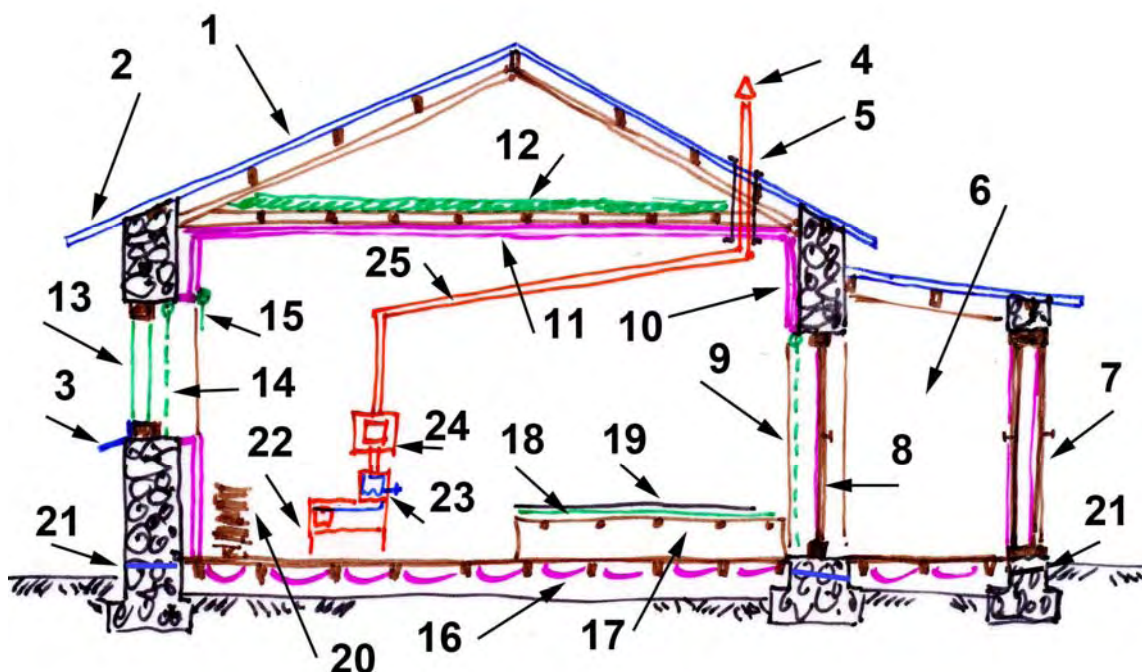
The poster ideas on the next two pages include two types of calculations:

- Adding up of the number of lines applicable (1-25).
- Adding up of the values behind the sentences.

By several people doing these calculations, comparisons can be made and a discussion started about the differences in the total scores and how to improve these scores with effective measurements.

# How many points do you have at home?

Count the numbers and think what you can improve for a better energy efficiency of your house during the winter.



1. Waterproof and no roof windows
2. Overhang to keep the walls dry
3. Windowsill to keep the wall dry
4. Chimney cap to avoid rain/snow
5. Waterproof roof passage
6. Vestibule/porch to stop the draft
7. Double or insulated outside door
8. Insulated door to warm rooms
9. Insulation curtain inside the door
10. Wall insulation conform altitude
11. Ceiling insulation conform altitude
12. Extra ceiling insulation in attic
13. Double glass window; ventilated
14. Fully transparent roll curtain
15. Decorative blinding curtain
16. Insulation under the floor
17. Elevated sitting-sleeping area
18. Polyethylene foam (PE) sheet
19. Insulated sleeping mattress
20. Well dried firewood
21. Waterproofing in foundation
22. Firewood efficient stove
23. Hot water storage in stove
24. Heat exchanger in the chimney
25. Long chimney pipe inside

Less than 5 numbers?  
Then you spend far too much on heating fuel.

Less than 10 numbers?  
You can improve a lot on thermal insulation.

**Improve your  
comfort and save  
money.**

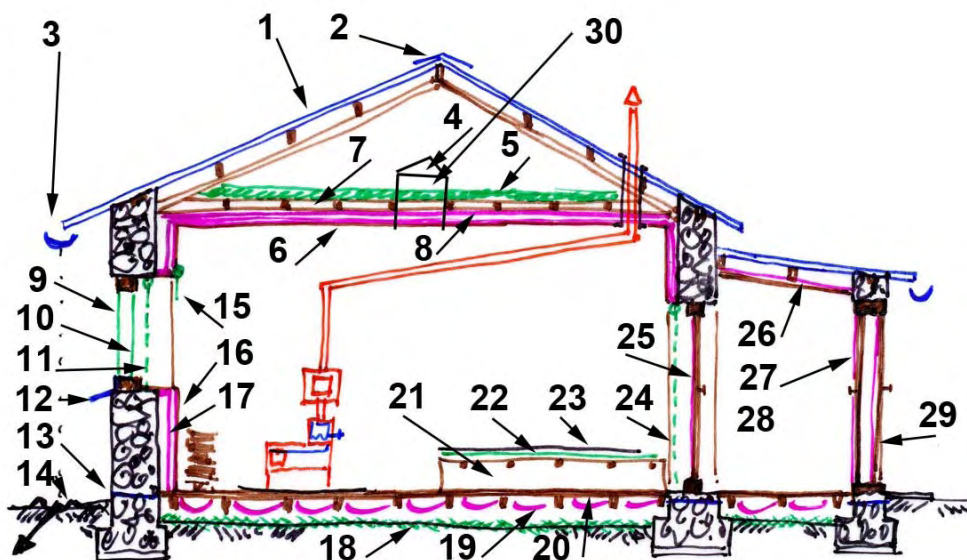
Space for other information, addresses, contacts, training possibilities, finance options, etc.

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# Thermal Insulation Improvements

How many points does your house have?



1. Waterproof roofing and closed attic: (+6) – Roofing without a closed attic: (+2)
2. Top ridge and side joints in roofing closed: (+1)
3. Rainwater gutter and drainage around the roof: (+1)
4. Roof window single glass: (-20). Roof window double glass all sides: (-10)
5. Roof window double glass and extra winter insulation insert: (-4)
6. 10 cm thick dry straw insulation on the attic floor or inside roof: (+10)
7. Suspended ceiling under roof with air space: (+4)
8. Additional horizontal air space inside the ceiling: (+3)
9. One reflective insulation foil between ceiling and roof: (+5) – Second reflective foil: (+5)
10. Single glass in good timber frames outside windows: (-5) – Broken glass: (-5)
11. Whole double glass outside windows in good quality frames: (-2)
12. Fully transparent plastic insulation curtains for the winter: (+2)
13. Windowsill avoiding water inside wall: (+1)
14. Waterproofing inside foundation wall: (+1)
15. Water drainage away from the foundation: (+1)
16. Extra insulation type roll curtain for closing at night: (+2)
17. Wall insulation with single reflective foil: (+5)
18. Second wall insulation with other reflective foil: (+5)
19. Permanent dry filling under the floor: (+1)
20. Reflective foil insulation under the floor: (+2)
21. Additional horizontal air space under the floor: (+1)
22. Elevated sitting and sleeping area with air space: (+1)
23. Insulation layer of thick grass mat or 5 mm PE foam: (+1)
24. Insulating sleeping mattress: (+1)
25. Curtain in front of door to reduce draft: (+1)
26. Insulation on a well closing door: (+1)
27. Insulation under ceiling of vestibule or porch: (+2)
28. Double door for the entrance or the living room: (+1)
29. Wind tight inside ante-room, vestibule or outside porch: (+2)
30. Insulated outside door: (+1)
31. Extra double plastic winter inside insulation for Roof Hatch Window: (+2)

**Adding up the figures:** 10 = not good, needs substantial amount of improvements, 20 = needs many improvements, 30 = can do better, 40 = average, 45 = fairly good, 50 = very good, you are an example of energy efficiency for others.



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