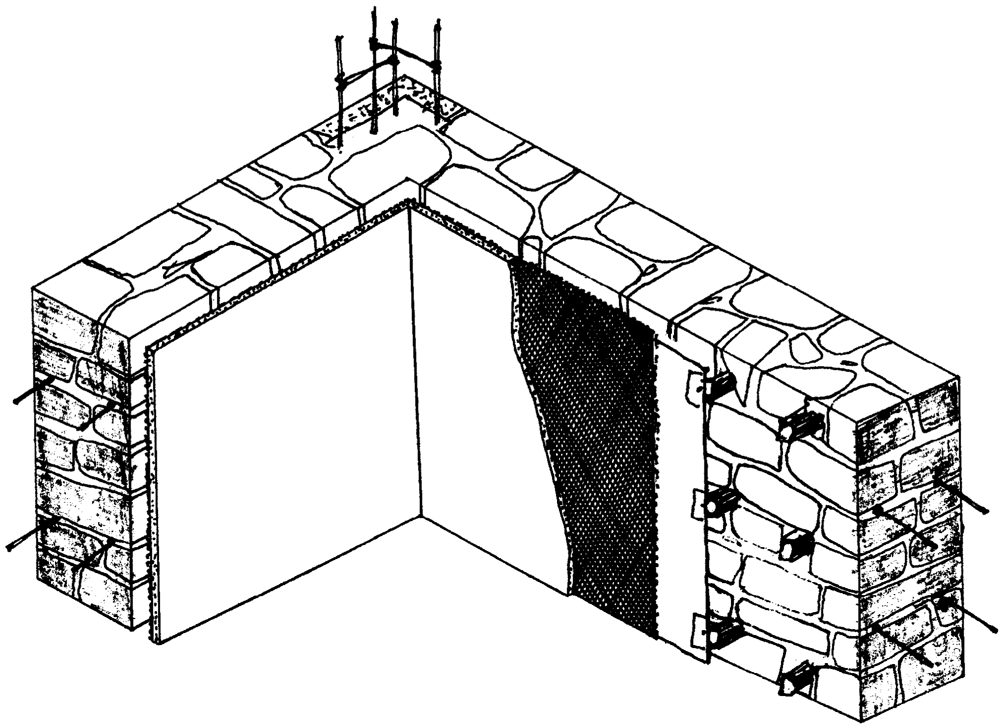
HUYS ADVIES

Wall Insulation Techniques for Buildings in High Mountain Areas

Local Designs for Existing or New House Constructions



VERIFIED BY THE NATIONAL INSTITUTE OF SILICONE TECHNOLOGY (NIST), PAKISTAN

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September 2000 (updated version in preparation 2009)

Abstract

The document describes the field experience of newly developed and installed wall insulation techniques, covering several thermal insulation methods for traditional stone and new cement block walls in the remote mountain areas of the Northern Areas in Pakistan. Traditional and modern building materials and construction techniques are incorporated in low-cost designs which can be locally replicated with available skills. Different wall insulation techniques with plastered wattle mats, expanded metal mesh and plywood are presented for existing, traditional and new wall constructions. The applied insulation methods lead to very high firewood savings, reduced drudgery for women and increased comfort. The paper includes the thermal conductivity calculations of each design method.

Key Words:
Remote mountain areas. Improved traditional techniques. Thermal wall insulation. Wattle. Expanded metal. Cavity walls. Straw. Plastic foil.

__Notes:__
The document was originally developed in the context of the implementation of a house improvement programme in the Northern Areas of Pakistan, 1998-2000, in conjunction with the AKF (Aga Khan Foundation) and the AKPBSP (Aga Khan Planning and Building Services, Pakistan), developing the

Building and Construction Improvement Programme (BACIP).

This paper is the old version of year 2000, and need to be updated with the new findings. In particular additional information has become available on the effect of condensation in cases where insufficient thermal insulation has been applied, adversely affecting plywood panelling.

New construction material has become available such as thin 5-6 mm thick PE foam with a backing of PVC-aluminium coated foils, enhancing substantially the thermal insulation value due to its infra red reflective properties (picture right).

The material is commonly used for pipe insulation, but has excellent properties for wall, ceiling and floor insulation.

Similarly, PVC- aluminium coated foils, when alternated with wool and bubble foil in multi layers, provide high insulation values (picture right).

The foil is readily available in many countries as it is used by food packing industries for chips and chocolate bars etc.. The thickness varies from 0.01-0.04 mm. Local manufacturing of this multi layered insulation material with waste wool is a possibility. Combinations with the above mentioned PE foam and bubble packing foil can be made. **Using these foils instead of the simple PVC foil mentioned in this document will substantially increase the insulation values.**

TABLE OF CONTENTS

TABLE OF FIGURES

<u>Drawings by:</u>

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FOREWORD

The Building and Construction Improvement Programme (BACIP), operating in the Northern Areas of Pakistan, is a project under the Aga Khan Planning and Building Services, Pakistan (AKPBSP). The programme is financed by PAKSID, a collaboration between the Canadian International Development Aid (CIDA) and the Aga Khan Development Network. The BACIP Programme Director is contracted through the Netherlands International Development Co-operation Programme (DGIS). BACIP works in co-operation with other Aga Khan Development Network Institutions (AKDNI) in the Northern Areas and Chitral, Pakistan. During 1999 and 2000 some 40 staff members, consisting of architects, engineers and social workers, have been involved in the BACIP programme activities. In addition, more than 200 village-based male and female resource persons assist on a voluntary basis in the implementation of the programme.

The present programme (to end-December 2000) consists of the development and introduction of house improvements (more than 40 different types) for traditional and new houses which are useful for villages in remote areas. Technology and skills development among local entrepreneurs has been initiated to enhance the delivery of the house improvements locally. Participatory cluster and village planning is a part of the process as well and community discussions have begun for determining appropriate housing locations to avoid building in geographically hazardous areas. Parallel to these mainstream activities, attention has been given to the design of new schools. As many of the technologies being applied in the new school designs can also be applied in houses, the demonstration effect would have a high impact on the youth and future house builders.

The present report gives an overview of the four types of wall insulation that have been developed by BACIP. The designs are based on the realisation of light cavity wall constructions on the inside of heavy stone or cement block exterior wall constructions. The designs have been made in such a way that they can be applied in either existing or new houses.

Each of the four insulation designs have been applied in a number of houses and research data collected. In general house owners were very happy with the insulated walls as their annual firewood consumption was reduced by up to 40%. In addition, the National Institute for Silicone Technology (NIST) in Islamabad (Pakistan) confirmed the high effectiveness of the designs by means of theoretical calculations.[1]

The following people have been intensely involved in the development of the house improvement designs, the testing and realisation of the prototype improvements:
- Mr. Qayum Ali Shah, Manager Field Operations of BACIP, in the manufacturing and development.
- Mr. Noor-ud-Din, Draftsman from AKPBSP, in making numerous modifications in the drawings.
- Mr. Mubarak Ahmed, Technical Illustrator of BACIP, in illustrating the fabrication process of the various house and school improvements.
- All other BACIP support staff without whom the realisation would not have been possible.
- Mr. Hadji, Mason, who installed the first models in a number of houses together with the villagers.
- Dr. Irshad Ahmed of NIST, in writing a report on the theoretical insulation properties, assisted by Dr. Baqar Raza, Research Officer, and Dr. Parvez Akhtar, Director General.

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[1] *Thermal Performance of BACIP Wall Insulations in Northern Areas of Pakistan*, prepared by Dr. Irshad Ahmad, National Institute for Silicon Technology, June 2000. The report can be obtained from NIST, 25, H-9, Islamabad, Pakistan. Tel: +92-051-448470-71, Fax: 448469, E-mail: shamsi@comsats.net.pk

INTRODUCTION

Most of the BACIP house improvements focus on thermal issues and earthquake engineering aspects. The thermal issues include: smoke control, ventilation, illumination, wall and roof insulation, leakage and dampness control. Earthquake engineering solutions are being developed for traditional stone, soil block and cement block constructions.

Especially in mountain villages with limited availability of wood, efficient and economical use of firewood is important. During the course of an entire year, villagers spend an average of two working days per month, plus one entire month in the autumn, in collecting firewood. Per trip a villager can collect 30 kg of firewood. If in one season a family requires more than 1000 kg of firewood, this translates into about two months full-time work. In many of the higher villages, the annual firewood consumption per family is often 2000 kg or more. The roof-hatch window[2] and the wall insulation introduced by BACIP will reduce the firewood or fuel requirement to half or even less, thus resulting in considerable savings of time in collecting wood and maintaining the fire.

Comfort Criteria Number One: Increased Thermal Comfort and Less Firewood
In assessing the requirements of the villagers, the most prominent problems identified were the cold in winter, the large amounts of firewood used and the difficulty in keeping the house warm (and with that the related smoke problem associated with a wood-burning fire).

A side effect of the so-called "modern" reinforced concrete and cement block constructions is their large heat transmission coefficient and heat (cold) storage capacity. In the cold periods of late autumn, winter and early spring, such buildings become very cold and require large amounts of firewood to warm the inner space. It was observed that in the winter the cement block buildings were so cold inside that invariably the villagers retreated to their old "traditional" house, leaving their "modern" house empty until the spring. Although the villagers may not possess the exact scientific knowledge of why the old "traditional" houses were warmer, they somehow knew that it had to do with the soil construction and/or the mud plaster.

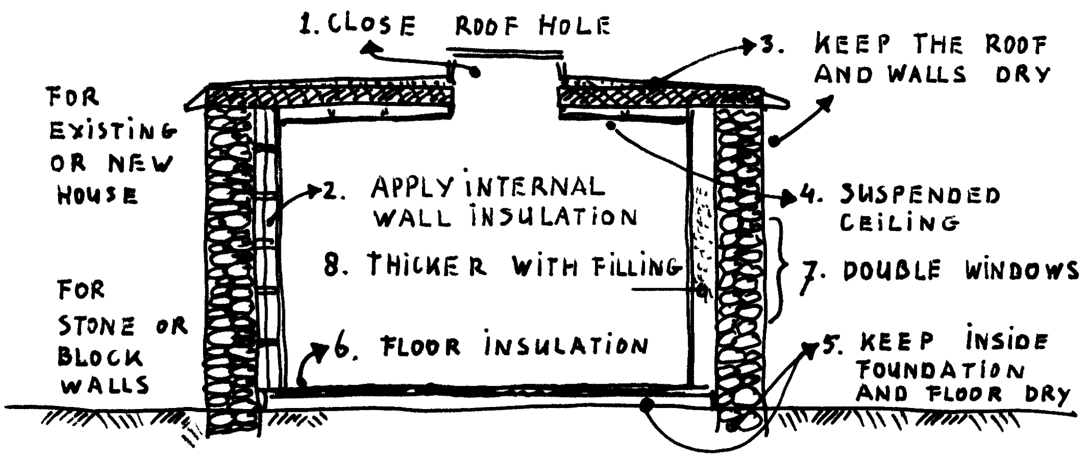

FIGURE 1. EIGHT LEVELS OF INTERVENTION TO IMPROVE THERMAL INSULATION

[2] See the BACIP publication entitled *Research Report on the Roof-Hatch Window* (May 2000) for precise information on the high insulation effect of the application of the roof-hatch window.

User Criteria Number Two: Application in Either Existing or New Houses

The new designs for thermal insulation must allow for its application in either existing houses or new houses, thus affording everyone the opportunity to improve their heating situation. Realisation of the wall insulation in more remote (off-road) areas was also a consideration. For remote villages, this often means carrying all building materials on the backs of donkeys and/or villagers (both men and women). Therefore the technology should include as much as possible locally available materials in the design.

FIGURE 2. AMOUNT OF FIREWOOD REQUIRED TO KEEP ONE ROOM WARM IN THE WINTER

User Criteria Number Three: Low Cost, Use of Local Materials

Most houses are built by the villagers themselves using the maximum amount of local materials and skills. Skills development on how to apply the new wall insulation technique must therefore be considered; the construction technique must be simple to replicate. People prefer to use cement for plastering the walls rather than mud plaster, even though cement is more costly and long curing with water is necessary. The dilemma here is that they do not really like the soil-plastered walls and are willing to pay extra for the more durable cement-plastered walls and floors, but these are very cold. Several construction techniques for the insulation design have therefore been proposed, each with different quantities of local or imported materials, costs and skills requirement.

Building Off-Season

The application of some of the wall improvements requires the use of cement mortar. When the insulation is applied on the inside walls of the house, the room will be unusable for at least a week and the room temperature will drop. BACIP looked at the possibility of applying the wall insulation just before the winter period when the inside house temperature is still above freezing.

The higher the village, the shorter is the building season (see table below), particularly when building with cement mortar is concerned. This is because cement requires a minimum temperature of at least +5 degrees Celsius for continuing the hardening process. Because the temperature at high altitudes drops quickly at night, the concrete or cement becomes too cold and the curing process stops.

Once the spring arrives and the ground thaws, all building activities cease and the villagers turn their attention to tending the agricultural fields, being their livelihood in the remote areas. Construction should therefore be made suitable for realising during the winter period.

The following table is an approximation based on information obtained from local builders. Local contractors will often try to continue for two more weeks into the first night frost period, producing poor cement quality. In the table, a "+" indicates the weeks that cement can be used and a "-" indicates when it is too cold (less than +5° Celsius at night). Overnight evaporation of water will also contribute to the cooling down of fresh masonry. A minimum of four hours of daily sunshine has been considered. Shaded valleys or shaded building sites have a winter that is one month longer.

Village	**Altitude**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April - August**
	Above		autumn						summer
Gilgit	5000 ft.	++++	++++	++ - -	- - - -	- - - -	- - - -	++++	++++
Hunza	6000 ft.	++++	++++	+ - - -	- - - -	- - - -	- - - -	- +++	++++
Ghulkin	7500 ft.	++++	++++	- - - -	- - - -	- - - -	- - - -	- - ++	++++
Hoper	8000 ft.	++++	+++ -	- - - -	- - - -	- - - -	- - - -	- - -+	++++
Gartenz	8500 ft.	++++	++ - -	- - - -	- - - -	- - - -	- - - -	- - - -	++++

The choice of technical insulation designs and building materials must therefore try to accommodate the above climate conditions.

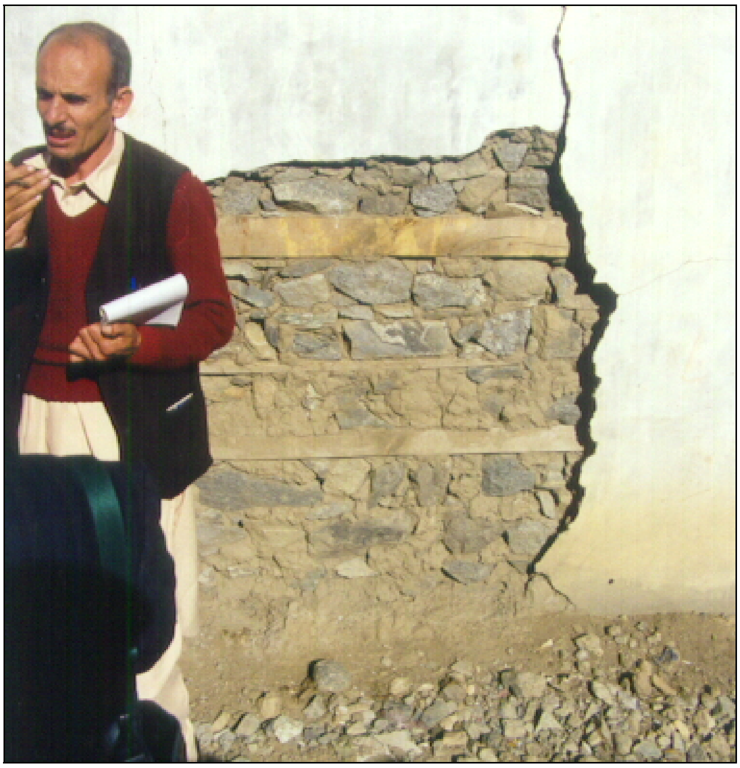

FIGURE 3. CEMENT PLASTER (WITHOUT EXPANDED METAL) WILL EASILY BREAK OFF STONE WALLS

1. INSULATION OPTIONS AND FIREWOOD SAVING

The table below gives an overview of the effect of the different thermal insulation options for traditional and new houses in the Northern Areas and Chitral.

Priorities (No. 1 is the Highest)	1. Roof-Hatch Windows	2. Wall Insulation Methods	3. House Design and Windows	4. Roof or Ceiling Insulation	5. Floor Insulation
Order of importance and effect on fuel energy requirements. Savings are on the remaining balance.	Most effective when a roof hole exists that cannot be regulated. Saves 50% of fuel energy requirements. Not applicable when no roof hole exists.	Most effective after the roof hole is closed or can be regulated. After the roof-hatch window, it saves up to 40% of fuel energy requirements. Insulation thickness needs to be increased in very cold areas.	Avoiding excessive draft, control ventilation openings and use of passive solar energy. Depending on situation, can save 30 to 40% of fuel energy requirements.	Highest for single storey houses with energy savings up to 20% for traditional roofs. Essential for GI sheet roofs (more than 40% fuel energy savings).	Effective when underground is humid due to water infiltration and with cemented foundations. Comfort level of sitting on the floor will be increased. Energy savings up to 10%.
General for all houses.	Window should be oriented towards the morning sun. In cold areas GI shutter or insulation blanket should be used.	Exterior walls of the house should be insulated first. Own mass of insulation or cavity wall should be small. Do not forget the sanitation rooms.	Avoid high rooms. Windows on north with double-glass frames or shutters. Sun window on south and double-glass frames. Curtain windows.	Double ceiling (and insulation). Avoid that water seeps into walls from roof. Avoid open staircases from ground floor to first storey.	Cover cement floors with thick grass mats, wooden floor or carpets. Houses on humid soil, place plastic foil for humidity blockage under ground floor and along foundation.
New house with sun in the winter.	Various sizes of windows can be made.	Wall does not have to be plastered as this will be covered up.	Sun-side windows oriented to allow for passive solar energy.	Very important with GI sheet roofing.	
New house in windy areas.	With insulation GI shutter or BACIP blanket.	Smooth plaster on exterior wall on the windy sides.	Create anterooms to block draft. No doors in the wind direction. Use shutters.	Draft-free double ceiling with insulation.	Make sure the foundation does not absorb water.
New house with cement block walls.		Very important, use of light, straw-filled cavity walls on the inside.	The larger the windows, the more effective is the insulation.	Avoid that walls absorb rain water. Good drainage of water away from the roof.	Avoid that walls absorbs humidity from the ground.
New house in traditional 18" two-stone.		Long support pegs to be masoned into wall during construction.	Windows on the sun side large with single and double glass. Glass to be kept clean.	Waterproof roof with suspended ceiling.	
New house with flat roof traditional room.	Important to place roof- hatch window over central hole.			Allow roof to become future floor of second storey.	
Existing traditional house with central hole.	Important to place roof -hatch window over central hole.	Insulation of outside walls first, then wall of side stores.	Double-glass frames or shutters in/on existing window openings.	Suspended ceiling, also dust free and dry. Waterproofing.	Wooden floor cover or carpets over grass mats.

FIGURE 4. ROOF-HATCH WINDOW IS THE BEST ENERGY SAVER, FOLLOWED BY WALL INSULATION

First the Roof-Hatch Window

In analysing the various options for thermal insulation, the installation of the roof-hatch window proved to be the most effective. Although the realisation of wall insulation in the central living room would result in firewood savings of between 30% and 40%, the roof-hatch window alone produces firewood savings of 50% or more. For this reason it is recommended that the roof-hatch window be realised first, followed by the wall insulation[3].

Levels of Energy Conservation

Although many people believe that more efficient heating devices or more fuel efficient cooking stoves is the solution to saving biomass consumption, this is ***only the case in hot climates*** where firewood is used solely for cooking. For colder climates, all international energy saving measurements ***first focus on house insulation*** as this will generate the highest environmental benefits.

In situations where an open fire is being used, firewood can be saved with the introduction of enclosed stoves. However, where the villagers already use an enclosed *buchari* (stove), making that stove more firewood efficient is rather difficult. In the poorly insulated houses the stoves need to emit large amounts of heat during the winter. Thus, making them more fuel efficient does not serve the objective of the people; insulation does, and moreover it strongly reduces firewood consumption.

Effects of Increased Thermal Insulation

The various house insulation techniques being introduced by BACIP will save firewood for room heating purposes. There are several benefits from this insulation:

- Saving of actual amount of firewood used, 50% and more.
- Saving substantial time in collecting and chopping firewood, and fuelling the stove.
- Considerable less space requirement for firewood storage.
- Less smoke due to less firewood used (this can also be reduced through better stoves).
- Reduction in requirement for dung cakes, thus increased possibility for fertiliser use.
- Less chronic cold diseases and related under nourishment.
- For an increasing number of people, lower expenses for purchasing firewood.
- Possibility to use better insulated and fuel efficient (tile) stoves that have less side radiation.
- Due to better insulated (tile) stoves, firewood savings realised also during the summer time.

[3] For more technical details about the roof-hatch window, refer to the BACIP publication entitled *Research Report on the Roof-Hatch Window*, (May 2000).

"Dinar is a *parchoon* shopkeeper. He has a BACIP demo wall insulation…The insulation has cut down on timber use, by how much, he cannot say, but it is quite a lot. By the look on his face, his 14-year-old nephew, Karamat Ali, wants to say something. I asked him how the insulation has benefited him. He says that apart from keeping him warm, it saves him time and effort because it is him, among others, who brings the timber from the *nulla*…The *nulla* is six hours both ways and you can get only one *maund* (30 kg) per day. This is done one day a week in summer and for one whole month every day in winter. Now with the insulation, the firewood collection exercise for winter would last less than 15 days. This makes him very happy."[4]

Actual Saving of Firewood and Forestry

The Northern Areas has over 100,000 families. When the insulation measurements become common practice and applied in most villages, the annual savings of dry biomass will be in the order of 100,000 to 150,000 tons per year, as compared with the current use of firewood. This is equivalent to more than 150,000 large trees per year. This also means that trees can be let to grow for construction wood.

Stoves with Terracotta Tiles for Cooking and Heating

As additional heat must be generated in the winter, the cooking *buchari* is usually placed in the central living and sleeping area. Before and after the actual cooking period, the fire is kept going to provide additional room heating. For this reason the all metal cooking *buchari* is preferred in the entire region, although individual preference as to the shape of *buchari* varies per valley.

With the improved insulation, it is possible to keep the house at an adequate temperature. The all metal *buchari* emits large amounts of heat through the sides, not only in the winter, but in the summer as well. To reduce the heat radiation through the sides and thereby reduce the firewood consumption, the BACIP *buchari* has been fitted with terracotta tiles inside along the metal walls of the stove. The tiles can be easily removed during the coldest period of winter to allow for full heat radiation.

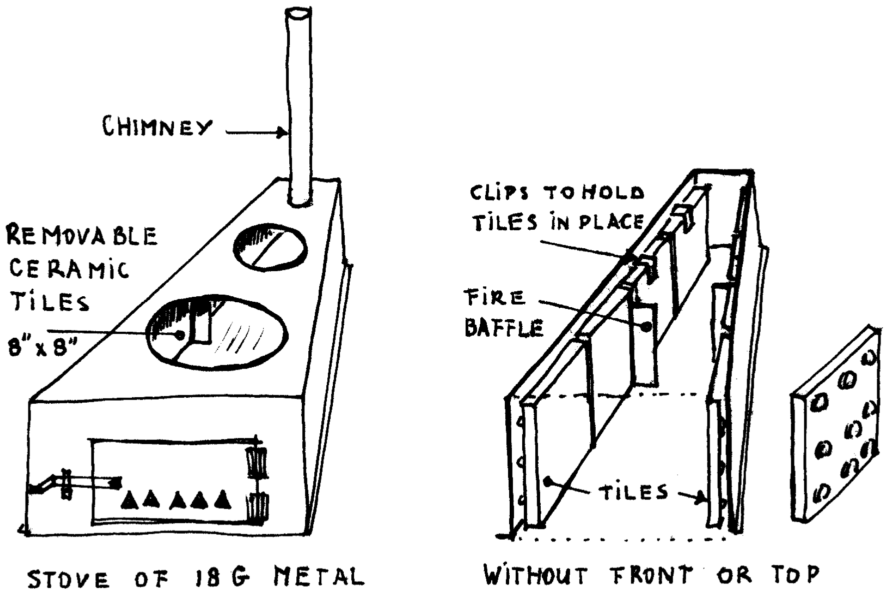

FIGURE 5. BACIP-DESIGNED COOKING *BUCHARI* WITH REMOVABLE TERRACOTTA TILES

[4] Experience of Mr. Arif Hasan, Architect and Planning Consultant, Karachi, during a field visit to Gindai village on 11 July 2000.

2. THEORY OF THE CHOSEN WALL INSULATION METHOD

Each type of wall insulation should be based on the specific thermal characteristics of the region and consider the following elements:

- **Seasonal fluctuations**. In the Northern Areas thermal insulation is needed more in the winter than insulation from heat in the summer. Only in cases where solid concrete roofs exist, special heat and cold insulation measurements have to be taken.
- **Differences between day and night temperatures.** In the Northern Areas, the difference between day and night temperatures is more than 10° Celsius. While summer nights may bring some cooling, the nights in winter are substantially colder than the daytime temperatures and houses require effective thermal insulation.
- **Air humidity.** Although air humidity in the Northern Areas is comfortable in summer and low in winter, the air humidity inside the highly populated sleeping quarters can be very high, especially if cooking is also done in the same area. This causes extensive condensation on the cold stone walls. Thermal insulation measurements must therefore prevent this condensation.
- **Daily sunshine or shading behind mountains**. Some valleys are largely or even entirely shaded in the winter. These areas are cold to very cold in the winter because the sun does not warm up the buildings.
- **Different altitudes.** The higher the village, the colder and longer the winters are. In some of the highest areas, the almost permanent winter clouds further reduce possible heating of the walls or the use of passive solar energy.
- **Wind causing additional chilling**. Orientation of the house, surface texture of the exterior walls and the use of storerooms on the cold side of the building have an important effect on the energy requirements.
- **Space use.** In some buildings the occupation is intermittent and therefore require only warmth during the period of occupation. In these cases the night-time temperature can also be lower.

Insulation on the Inside of the Walls

When the exterior walls of the house are cold and have a large mass, the thermal insulation should be placed on the inner side of the wall, or on the same side as the heat source. When it is colder outside, due to higher altitudes or shaded valleys, the wall insulation should be thicker. BACIP recommends the following:

- ◊ 2" for altitudes between 5000 ft. and 6000 ft. Cavities 1" or larger must have straw filling[5].
- ◊ 2.5" to 3" for altitudes between 7000 ft. and 8000 ft. Also here a cavity filling must be applied.
- ◊ 3" to 4" for 8000 ft. and higher and extreme cold areas. With filling of straw.
- ◊ Walls on the windy side must be soil-cement plastered on the outside to make then smooth.
- ◊ Windows on the windy side should preferably have good closing shutters.

Note: Wall insulation more than 3" thick is not practical when no other insulation measures are taken in respect to roof, doors, windows and floors.

[5] Other types of cavity fillers are possible such as rock-wool, sheep wool, wood shavings, polystyrene, etc.

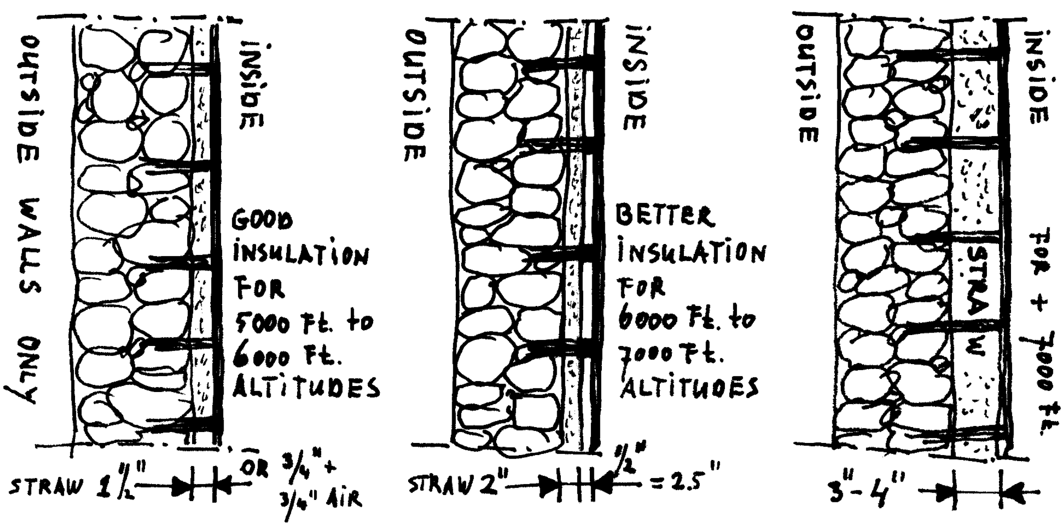

FIGURE 6. GENERAL INSULATION ADVICE

Low Weight of the Insulation or Cavity Wall

Considering earthquake requirements, the mass of the construction (or added insulation on the inside of the wall) should be as small as possible. Most insulation techniques comply with this requirement as these are mainly created by air fixing layers. All highly effective insulation materials are composed of very light materials containing locked-up air.

Air is easily heated and it is the air that transfers the warmth to the surrounding wall construction. If this wall material is heavy, the construction will absorb a lot of the heat (disadvantage) before the room reaches the desired temperature. The advantage of a heavy wall is that the warmed up wall construction will maintain a stable room temperature, even when the room is ventilated. This may be a particular advantage when the rooms are permanently occupied and need a relatively high, as well as constant, temperature. Such is the case with clinics.

For rural housing where people are active during the day and constantly going in and out of the room, heating is only required when the family sits down to eat or goes to sleep. In this case the wall insulation should not absorb large amounts of heat and must be as light as possible. This also applies to schools where the classrooms need only to be heated for a short period during the day. When only the outside walls of the house or school are insulated, the inside walls and materials of the house will contribute to the stabilisation of the inside air temperature.

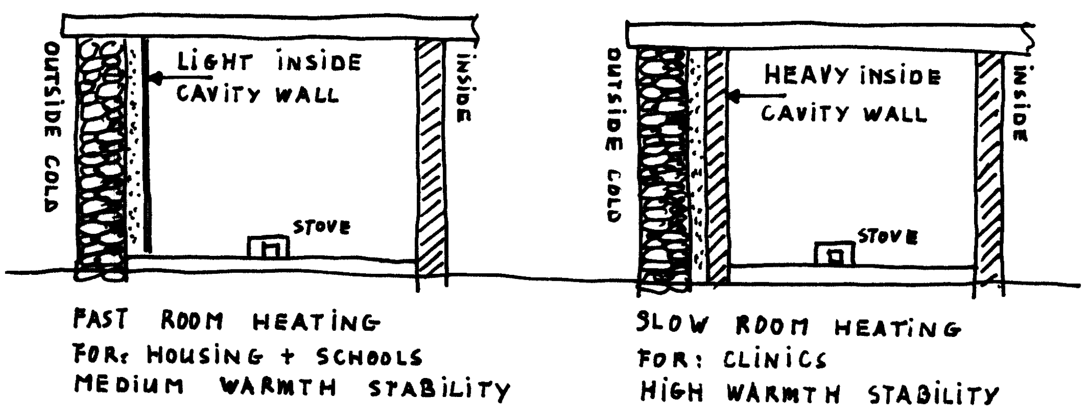

FIGURE 7. EFFECT OF LIGHT OR HEAVY INSIDE INSULATION WALLS

Reduce Humidity Transport

As only the central room in the traditional house is heated, all family members live, cook, eat and sleep in that room. The colder the region, the smaller the room and the larger the number of people huddling together. All these people and the cooking process produces humidity that normally condenses on and inside the walls. In traditional houses the thick soil-plaster walls absorb a fair amount of condensation water. In addition there is an open roof hole that provides plenty of ventilation. The main disadvantage of a wet wall is that it increases its heat transmission; thereby reducing its insulation capacity.

With a better insulated wall (on the inside face), the room humidity will now condense onto the much colder stone outside wall behind the insulation. Actually the amount of condensation will be increased as compared to the previous condensation on the plaster of the traditional wall. When the stone wall becomes wet, the insulation value will be lower as compared with a dry wall. To avoid condensation on the inner face of the stone wall, the humidity transport from the room towards the cold outside wall must be stopped or reduced. To greatly reduce the humidity passage, BACIP advises to place a plastic foil on the warm side of the insulating layer, directly behind the plaster.

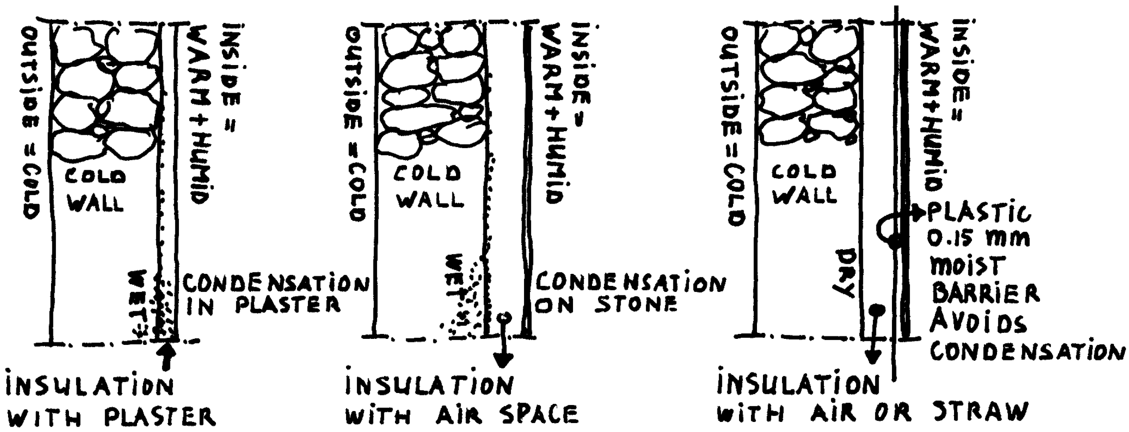

FIGURE 8. CONDENSATION ON COLD STONE OR CEMENT BLOCK WALLS

The moisture barrier should always be on the warm side of the room.

One of the side effects of the moisture barrier is that natural ventilation in a room will strongly reduce. When a room has a wood fired stove, such a stove will force some ventilation due to the chimney exhaust and with that renew the air inside the room.

When a room only has a kerosene or gas heater, without taking care of ventilation, the kerosene or gas heaters will emit large quantities of moisture into the air and burn up the oxygen.
Three problems will occur:

- The moisture in the air will be increased due to the burned gas.
- The oxygen in the air will be reduced and may cause drowsiness.
- CO may be produced with insufficient oxygen making people sleepy and eventually die.

When the insulation behind the plastic is insufficient, plywood, hardboard and gypsum board panelling may become moist an develop fungus. Plywood, when of poor quality may separate its layers. Hardboard will expand and get an uneven surface, while ceilings start sagging.

3. BACIP WORKING METHODOLOGY

The wall insulation techniques developed by BACIP are based on the simple technology of creating an insulating air layer on the inside of the exterior building walls. As the cold winter air will chill the outer surface of massive stone walls, it is uneconomical to heat those large masses of stones or cement block walls. The house is mainly heated during the cooking periods. In between the cooking periods the house cools off. With good internal wall insulation, this cooling off period will take longer and the re-heating period of the internal air and space is shortened.

Demonstrations in Village Houses

BACIP has placed demonstration models of the designed house improvements in several houses in selected villages, a different improvement in each house. In doing so, BACIP staff could:

- Spread the expenses of the villager's participation for the installation of the model improvements over a number of villagers from different villages.
- Analyse the effect of a single improvement on the habits of the family or living circumstances.
- Compare similar improvements between villages at different attitudes.
- Obtain measurable and comparative data about the house improvements.
- Modify the house improvement depending on the observations of the house owner.
- Avoid that a single household becomes a major beneficiary of several improvements.
- Organise geographically the spreading of the different house improvements for future demonstration to other villagers (exchange visits).

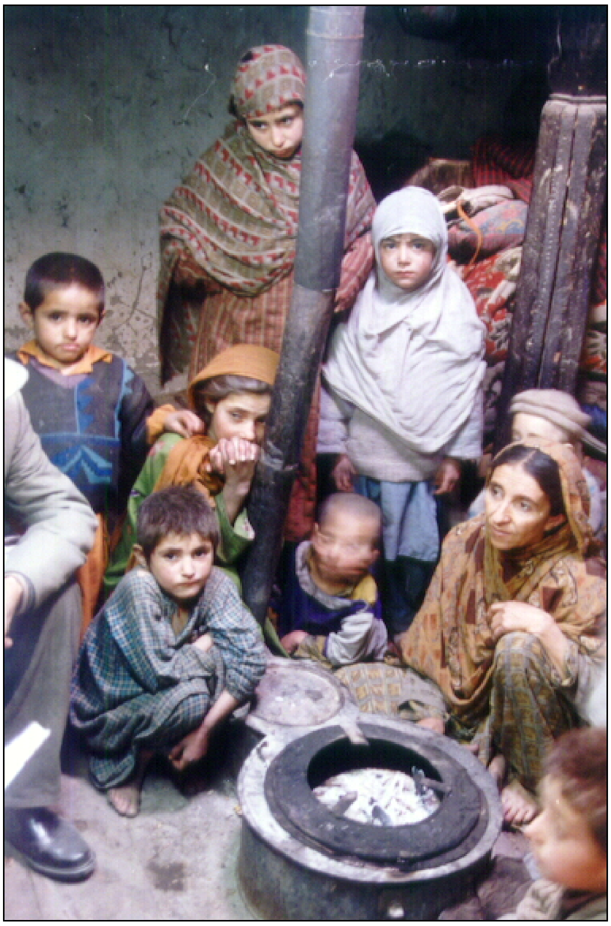

FIGURE 9. THE FAMILY USUALLY HUDDLES AROUND THE WARMTH OF THE STOVE

Reactions from the Villagers
Very positive reactions have been received from all recipients of the demonstration wall insulation techniques applied in various houses of more than 20 villages.

> *"Since we have the wall insulation, we have spent only half of the firewood this season."*
>
> *"The children do not sit on top of the stove anymore but are more lively and walk all over the house because now it is warm everywhere."*
>
> *"In the past I was using three quilts and I did not get really warm. Now I sleep with only one quilt and in the morning the house is still warm."*
>
> *"With the wall insulation, I only use the stove for cooking and then the room is warm."*

Both the positive reactions and the negative reactions are registered and problems have been solved when possible. Sometimes the comments are rather funny.

> *"The house is now very warm and I use less firewood, but sometimes I cannot sleep."*
> *"Why can't you sleep now?"*
> *"Because some mice are walking inside the wall right next to my head."*

Due to the pure silence in the rural villages, all tiny new sounds are immediately noticed. The occupation of mice inside the walls was an expected phenomena, as this also occurred in Europe when cavity walls were introduced in the late 19th century[6]. An active reduction of mice is necessary in the rural areas, especially by means of controlling the food stock. For this purpose, the BACIP programme has designed mice-proof food storage containers. In addition BACIP has rat traps available, but these only work if a group action is realised in the entire village.

The expanded metal used in the wall insulation to hold the plaster has a very fine mesh that is too small for mice to pass through. Thus mice making their way in through holes and spaces of the stone outside wall of the house will not be able to get inside the rooms.

The user satisfaction of the suggested house improvements is very important as it is the user that will eventually promote the house improvements to their neighbours. Therefore close attention must be given to all complaints, investigated and adjusted wherever possible.

A sample is of the problems and solutions encountered with applied insulation methods are given below.

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[6] Light cavity walls were made by means of a wooden latticework on which jute cloth was nailed. The jute was pasted over with wallpaper. Tens of millions houses had this system in the 19th and 20th centuries.

Problem	Possible Cause	Solution
Mice/rats inside the walls. They are noisy.	Availability of food near the houses. Open stone foundations.	– Expanded metal with small holes (six holes per five inches, all models). – Provision of mice-proof food storage containers of ferro-cement (optional improvement). – Pointing of stone foundations (expensive).
Mice/rats eat the plastic on the inside of the walls.	It is not clear if this is actually the case or only assumed by the people.	– If some of the plastic is destroyed by mice making holes, the effect of the plastic over the whole wall will remain intact.
How to avoid that mice/rats are going to live inside the cavity wall.	A 2"-3" cavity is wide enough for nests.	– When constructing a new cavity wall, the first foot of the lower wall can be insulated with rock wool or glass wool. This inert, sharp material gets into the fur and lungs of the animals when walking through it. Subsequently they die or leave. The rock wool or glass wool is an additional cost (Rs.15/sq. ft.)
How to remove mice/rats from the cavity walls.	The animals have found a nice warm nesting place.	– Reduce access to food. – Place rat traps. – Punch small holes in the plaster above the floor and spray insecticide inside the cavity and plug up the holes.
The soil-cement plaster is damaged.	People are sitting against the lower part of the wall or throwing heavy quilts against the wall. The expanded metal was not primed with cement slurry before application of the soil plaster.	– For lower wall sections that are subject to mechanical impact, additional peg supports need to be placed in the wall. – An additional (second) expanded metal layer and plaster should be applied to strengthen the lower wall section (3 ft. high). – A stronger cement mortar (1:8) can be applied on the double expanded metal. – A reed mat can be placed against the wall. Recommended is the 3 ft. high *chattai*.
The soil-cement plaster rubs off on the clothes.	This is similar to what is happening in traditional houses with soil-plastered walls.	– A reed mat (*chattai*) can be placed against the wall. – A cloth can be fixed at a height of 3 ft. – A stronger cement mortar can be applied or a lime plaster coat. – The plastered surface can be bonded with an oil-based or washable paint.
The surface is not flat or straight enough.	People want a straight wall. An uneven wall may result when the expanded metal is applied directly onto the pegs and/or due to insufficient skill of the craftsmen applying the plaster.	– A 3 ft. long wooden guide has been provided for the mason. By holding the guide against the uneven wall, the pegs can be cut off to provide a flat surface. – For new walls, the guide assists in placing the pegs in the right position. – When wooden strips are fixed, it is easier to make the wall flat. – It is easier to make a flat wall with the stiff expanded metal than with loose chicken wire-mesh.

Problem	Possible Cause	Solution
The plaster on the cavity wall can be damaged by school children.	Without proper education and explanations, school children can damage everything.	– For schools both the double expanded metal and cement plaster is recommended. – For schools a plank is fixed to the plaster at the height of the tables and chairs. – Children should be educated not to damage their school, be it the walls, doors, windows or furniture. – A maintenance/damage instruction should be developed for the schools.
Existing wall is too weak for applying pegs or nails.	Old loosely masoned wall. Round stones. No cement bonding.	– Reconstruct the wall. Do not attempt to hammer pegs into a weak wall. It is safer to reconstruct the wall. – A fee-standing wattle wall is possible.
Pegs become loose after awhile.	The tapering of the pegs is too much. The pegs were made of wet wood that dried and shrunk. The pegs were too short.	– Pegs should be long. When hammered into the wall, smaller splints may be needed to tighten them into the wall. – Do not use very fresh wood. – When pegs are inserted into a wet wall apply paint or preservative first.
Wire-mesh (expanded) metal rusts.	Non-galvanised or poorly galvanised metal has been used.	– Expanded metal needs to be primed first with cement slurry (1:1). This will reduce rusting and enhance adherence.
The freshly cement plastered wall is cold for one week.	To cure the cement plaster, the wall needs to be kept moist for at least one week.	– The plastic foil directly behind the plaster will reduce evaporation towards the back and assist in the curing. – Application of the cement-based wall plaster needs one to two weeks to cure.
Some cracks appear in the plaster after awhile.	The cement ratio was too high and causes shrinkage. Too much clay or silt in the soil causes shrinkage. Too much water in the mix causes shrinkage.	– The recommended ratio of soil : cement is 10:1. With additional water or lots of silt in the soil, shrinkage can occur. Per village the right soil-cement composition must be determined.
The plaster is dark and makes the house dark.	Unfinished surface with cement plaster is dark of texture.	– After hardening, the wall surface can be plastered with a thin coat of white lime plaster. Eventual shrinkage cracks will then disappear. – The recently plastered surface can be white-washed (cheaper).
The making of the plaster is too much work.	The plaster has to be done in several phases. Pegs, expanded metal, priming, first coat and second coat.	– As an alternative a plywood cavity wall can be realised. The plywood is more expensive in terms of material, but faster in application. In addition it can easily be applied in an existing situation and does not need hardening.
The roof started leaking.	Condensation occurs on the ceiling instead of on the walls.	– Assure that the roof is waterproof. – Apply a double or suspended ceiling. – Increase room ventilation.

4. CHOICE OF TECHNOLOGY

The choice of technology depends on the following aspects:
- Existing wall construction or choice of new wall construction (stone, cement block, adobe).
- Climatic situation (cold, colder, coldest).
- Available skills of local craftsmen (high skill, low skill, do-it-yourself).
- Available time for installation (summer, winter, while living in the house).
- Available materials or finance for labour and materials (soil, cement, plywood, rock/glass wool).
- Desired final effect of the wall (flat, smooth, slightly uneven).
- Prevention of damage to the construction (double expanded metal, stronger plaster, plank).
- Future prevention of mice (rock/glass wool).

Existing and New Houses

The existing walls of the surveyed houses were mostly of 18" two-stone dry masonry work. Some of the more modern houses were built from cement blocks. In the dry-stone masonry work, wooden pegs could be inserted easily by hammering them in between two or three stones until they jammed tightly. On these pegs the wall insulation could be fixed at a distance from the wall.

For houses built of cement blocks, it was difficult to hammer the thick wooden pegs in between the cement blocks as these would crumble (often of very poor quality), or the cement blocks would be hammered loose from the construction (this happened in one of the test rooms). For these constructions BACIP suggested to fix first wooden strips on the walls with steel nails and then apply the insulation onto the wooden strips.

Walls should be strong enough to permit hammering wooden pegs into it. Hammering pegs into weak walls or applying wall insulation on weak walls should be avoided. These walls should first be reconstructed. It is possible to make free-standing wattle walls, or other types of free-standing walls, and fill the back with straw.

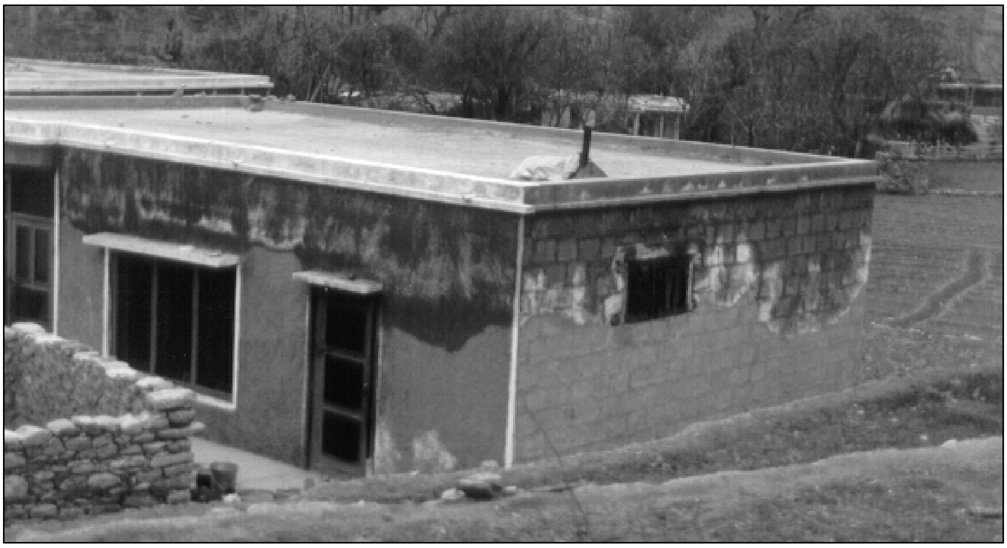

FIGURE 10. WET WALLS (FROM FOUNDATION OR ROOF) NEED TO BE TREATED SO THEY BECOME DRY

Wall Insulation Options

The following table provides some insulation options for various wall constructions:

Type of Wall Construction	18" Two-Stone Wall of Strong Construction	8" - 12" Cement Block Wall	Adobe or Soil Block Wall
When wall is going to be wet by water from the roof.	First fix 0.15 mm plastic foil directly onto the wall. Then apply pegs with preservative.	First fix 0.15 mm plastic foil and then wooden strips fixed with (steel) nails.	First fix 0.15 mm plastic foil and then wooden strips fixed with 6" normal nails.
Dry wall.	Cut holes between stones at regular 1-2 ft. intervals and hammer wooden pegs into the holes until jammed. Cut pegs off at desired length (1" or 1.5") using a straight guide.	Fix high wooden strips with steel nails. The wooden strips are the height of the cavity, 1" or 2".	Fix high wooden strips with 6" ordinary nails. The height of the wooden strips are the thickness of the cavity.
On the pegs or wooden strips.	Plastic and expanded metal. Plastic and plywood. Plastic and *chattai* mat (for high wall sections). Plastic and wattle wall. Plastic and a profiled support strip for fibre-cement panels[7].	Plastic and expanded metal. Plastic and plywood. Plastic and *chattai* mat (for high wall sections). Plastic and wattle wall. Plastic and a profiled support strip for fibre-cement panels.	Plastic and expanded metal. Plastic and plywood. Plastic and *chattai* mat (for high wall sections). Plastic and wattle wall. Plastic and a profiled support strip for fibre-cement panels.
Straw filling[8].	Between rough wall and plastic apply straw when cavity is 1" or larger.	Between rough wall and plastic apply straw when cavity is 1" or larger.	Between rough wall and plastic apply straw when cavity is 1" or larger.
Up to 7000 ft. in altitude.	Plan for a minimal cavity of 2" with plastic foil on the warm side of the wall before applying finish. Fill cavity with straw.	Plan for 2"-3" cavity with plastic in the middle or on the warm side of the wall before applying finish. Fill cavity with straw.	Plan for 2" cavity, plastic on the strips before applying finish. Fill cavity with straw.
7000 ft. to 8000 ft. in altitude.	Recommended 3" cavity in two sections and fill with straw.	3" to 4" cavity in two sections and fill with straw.	3" cavity in two sections and fill with straw.
Extreme cold or over 8000 ft. in altitude and for areas shaded in the winter.	Recommended 4" cavity and fill with straw. Other measurements should also be taken.	4" cavity and fill with straw. Other measurements should also be taken.	3" to 4" cavity and fill with straw. Other measurements should also be taken.
For high wind areas.	Make sure outside walls on the windy side are smooth.	Make sure outside walls on the windy side are smooth.	Make sure outside walls on the windy side are smooth.

In figure 11 an overview of the various wall insulation options is illustrated. From left to right the effectiveness of the insulation method is indicated. From top the bottom the cost of the insulation method increases.

[7] The design with the fibre cement panels has not been tested and is therefore not further mentioned in this report.
[8] Straw is an agricultural by-product that is abundantly collected in the second half of the summer.

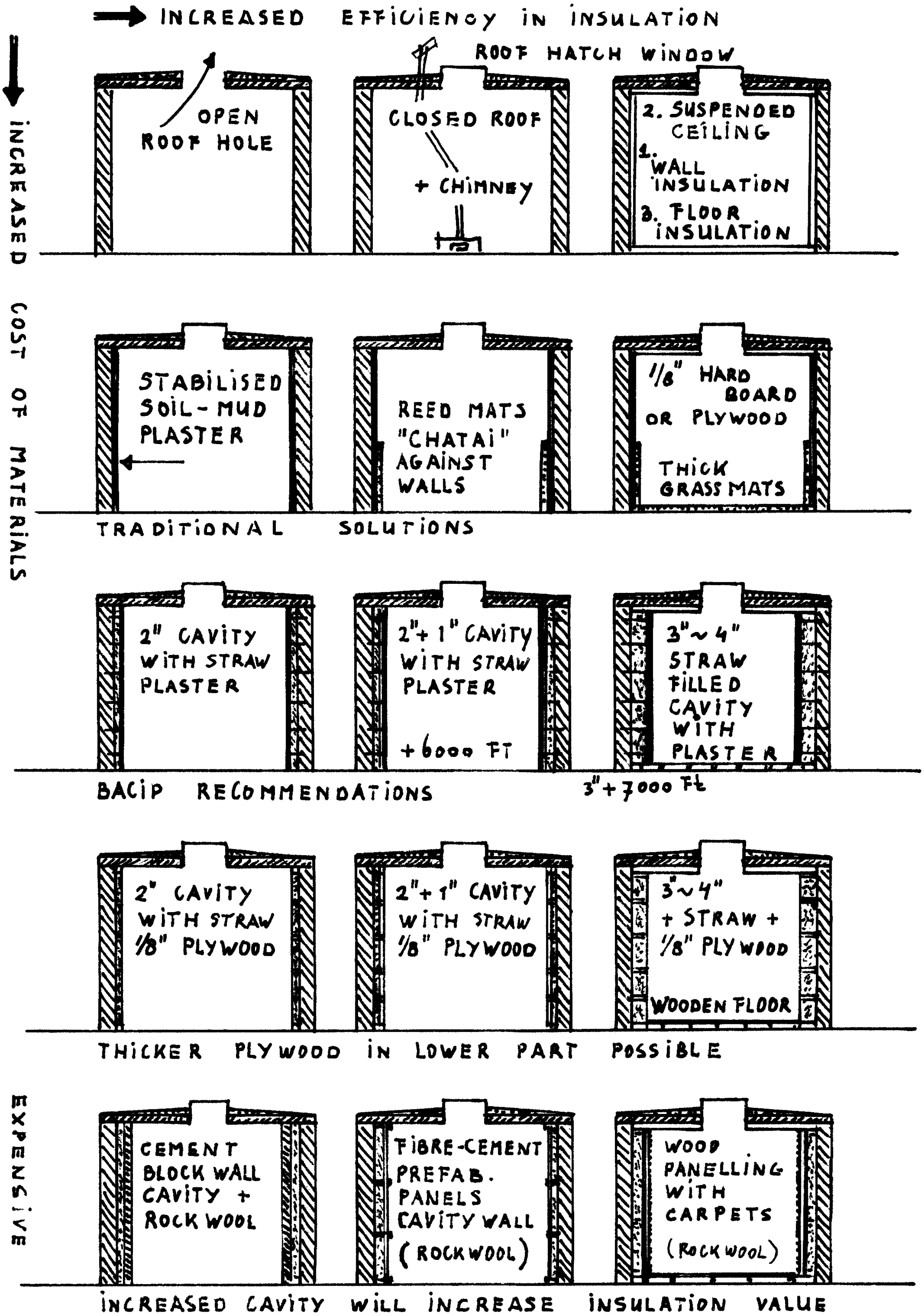

FIGURE 11. OVERVIEW DRAWING OF INSULATION OPTIONS

How to Choose the Best Design for Your Situation

A. Type of wall:

- Existing strongly built stone wall. Apply pegs into wall.
- Existing weakly built stone or cement block wall. Reconstruct wall.
- Existing strongly built cement block wall. Nail strips to the wall.

B. Thickness of cavity wall related to altitude and sun:

- 5000 ft. - 6000 ft, with sun; minimum cavity 2" (1"+1" air or 2" with straw).
- 5000 ft. - 6000 ft. without sun or 6000 ft. - 7000 ft. with sun; minimum cavity 2.5".
- 6000 ft. - 7000 ft. without sun or 7000 ft. - 8000 ft. with sun; minimum cavity 3".
- 7000 ft. - higher without sun or 8000 ft. and higher; minimum cavity 3" - 4" depending on other measurements taken in the same building.
- Walls on the windy side with smooth external plaster.
- Pegs extend 4" - 6" inside the wall and 1" or more outside. When the pegs are sticking 1" out of the wall, first apply plastic foil and then 1" thick horizontal strips. This creates a 1"+1" cavity. When the pegs extend more than 1" outside the wall, the created cavity should be filled with straw or other airy material.

C. Cost of the construction:

- House owner realises activity **without labour expenses**, from cheap to expensive:

Pegs, plastic, wattle panel wall, 10:1 soil-cement plaster (Rs.10/ft²).
Pegs/strips, straw, plastic, 1/8" plywood (Rs.13/ft²).
Pegs/strips, straw, plastic, expanded metal[9] + 10:1 soil-cement plaster (Rs.13/ft²).
Pegs/strips, straw, plastic, expanded metal + 10:1 sand-cement plaster (Rs.15/ft²).
Pegs/strips, straw, plastic, 3/8" plywood (Rs.18/ft²).
GI wire anchors, rock wool, plastic, 4" cement block cavity wall (Rs.23/ft²).
Pegs/strips, rock wool, plastic, wood panelling (Rs.25/ft²).

- House owner needs **to buy all local materials and pay labour expenses**. The plywood cavity wall construction is the fastest application method, thus reducing the (skilled) labour time to one day per room. Plaster can be done in two to three days (without curing).

  Pegs/strips, straw, plastic, 1/8" plywood (Rs.20/ft²).
  Pegs/strips, straw, plastic, expanded metal + 10:1 soil-cement plaster (Rs.20/ft²).
  Pegs/strips, straw, plastic, expanded metal + 10:1 sand-cement plaster (Rs.22/ft²).
  Pegs/strips, straw, plastic, 3/8" plywood (Rs.25/ft²).
  Pegs, straw, plastic, wattle panel wall[10], 10:1 soil-cement plaster (Rs.25/ft²).
  GI wire anchors, rock wool, plastic, 4" cement block cavity wall (Rs.28/ft²).
  Pegs/strips, rock wool, plastic, wood panelling (Rs.30/ft²).

D. When is the construction to be realised?

- The application of the insulation on the inside of the exterior walls requires that those rooms or room areas need to be vacated for the duration of the construction period. The construction requires room to work and for laying the materials around and causes noise.
- Cement-plastered constructions should not be done in the winter period, unless it can be assured that the room is kept well above the freezing point.

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[9] It is recommended to use working gloves for applying the expanded metal as it has sharp edges. The expanded metal of 26 gauge (6 holes per five inches) costs about Rs.3 per square foot.
[10] Buying the wattle panels may be expensive in certain areas. These need to be bought well in advance.

- When cement-plastered walls are realised, these need to be kept moist for at least one week for curing. This not only creates a mess in the house as everything will be wet, but the wet wall will remain cold for at least another week. When the inside room temperature is below 10° Celsius, curing will take two weeks. The drying of the wall after curing may take another week.
- When the inside plastered wall is realised with soil-lime plaster, it is recommended to mix 20% (by volume) chopped straw into the soil. The mixed soil and lime-water (40 kg lime per 200 litre water) should soak for at least one day before application. The lime-stabilised soil plaster can dry immediately and does not require curing with water. Also here no freezing should occur.
- When the plastered wall or the soil-lime plastered walls are dry, it may be necessary to apply a thin lime-coat onto the wall a month later (mixture of 4 kg lime to 12 litre water). This will smoothen the surface and make the room light.

E. Visual presentation of the completed construction method:

- When applying pegs in a new wall, the extended ends should all be exactly in line so the future wall insulation will be flat.
- When pegs are applied in an existing wall, a guide should be used to make sure that the pegs are all cut off at the same distance from the wall. This will make the future wall flat.
- The application of expanded metal on wooden strips is easier to make flat than expanded metal on pegs only.
- A thick layer of plaster can be made flatter than a thin layer of plaster.
- When the plaster is slightly uneven, it is called "rustic" and appreciated by some people. Others consider very flat surfaces fashionable. This a matter of taste and should be considered before the application of a certain technique.
- The application of plywood is flatter than expanded metal.
- The application of 3/8" plywood panels is flatter than thin 1/8" plywood. The 3/8" plywood can be used in the lower part of the wall for added strength.
- After completion, the cemented walls can be plastered with a very thin lime plaster. This will make them smoother and the room lighter.
- After completion, the cemented or lime plastered walls can be whitewashed annually.
- The plywood panel walls need to be painted or whitewashed.
- For areas where people lean or rub against the wall and the wall may easily get dirty, the application of washable oil-based paint is recommended.

F. Additional strength or protection of the wall on the lower side:

- For schools and housing, a second layer of expanded metal with plaster is recommended up to 3 ft. This strengthens the wall against impact or pressure from leaning against the wall.
- For schools, a horizontal plank is recommended at the level of the tables. The plank is fitted flat against the double reinforced plastered wall.
- In some cases it is recommended to make the lower panel from thicker plywood (3/8") for added strength.
- For housing, additional pegs need to be placed in the lower part of the wall at intervals of one foot to provide additional support for the expanded metal or the strips.
- For housing, it is recommended to place *chattai* reed mats (3 ft. in height) against the wall where people sit, particularly if soil-cement plaster is applied.
- For housing, wood panelling (2 ft. in height) can be applied against the lower portion of the wall where people sit or sleep.
- For housing, a suspended cloth or carpet can be fixed against the wall where people sit against the wall. The upper side of the cloth can be held with a thin wooden strip.

G. **Control of mice and rats:**

- Mice cannot pass through the 26-gauge expanded metal with six holes per five inches. The expanded metal, however, should be well closed around the entire wall.
- The outside of the house walls should be pointed with cement mortar if holes between the stones allow access by mice.
- Rock wool or glass wool blankets can be inserted in the lower part of the cavity of the wall during construction. The glass wool and/or rock wool is an effective remedy against mice (Rs.15/ft^2). Gloves should be worn when working with this material.
- Perforating holes in the lower wall and spraying insecticide inside helps to reduce all vermin. The small holes should be plastered up afterwards.
- Fight mice and rats with good food storage and rat traps. Cats do keep some of the mice away but also require food.
- Straw can be best applied in bags. Polypropylene (PP) fibre agricultural bags are available second hand and can be stuffed with long fibre straw.
- For each bag a cup of dry construction lime should be added. This dry hydraulic lime will reduce insect and mice infestation.

FIGURE 12. CEMENT BLOCK WALL WITH STRAW INSULATION AND PLASTE

ALL PEGS SHOULD BE PAINTED WITH RED OXIDE TO AVOID ROT (NOT SHOWN).

5. INSULATION DETAILS

The location of the internal cavity wall insulation depends on the overall design of the house and where people need it to be warm. The best way to protect the house from the cold is to insulate only the external walls of the house.

Houses constructed in cold regions should have the central living room surrounded by entrance rooms and stores. These rooms act as a buffer against the very low outside temperatures. Here a choice has to be made, either to insulate both the outside walls and the inside living room walls with an average insulation each or to insulate only the inner room walls with a thicker insulation. Insulating only the inner room is less expensive as much less surface needs to be treated. Consequently, though, the outer entrance rooms and storerooms will become very cold, almost as cold as the outside average daytime temperature.

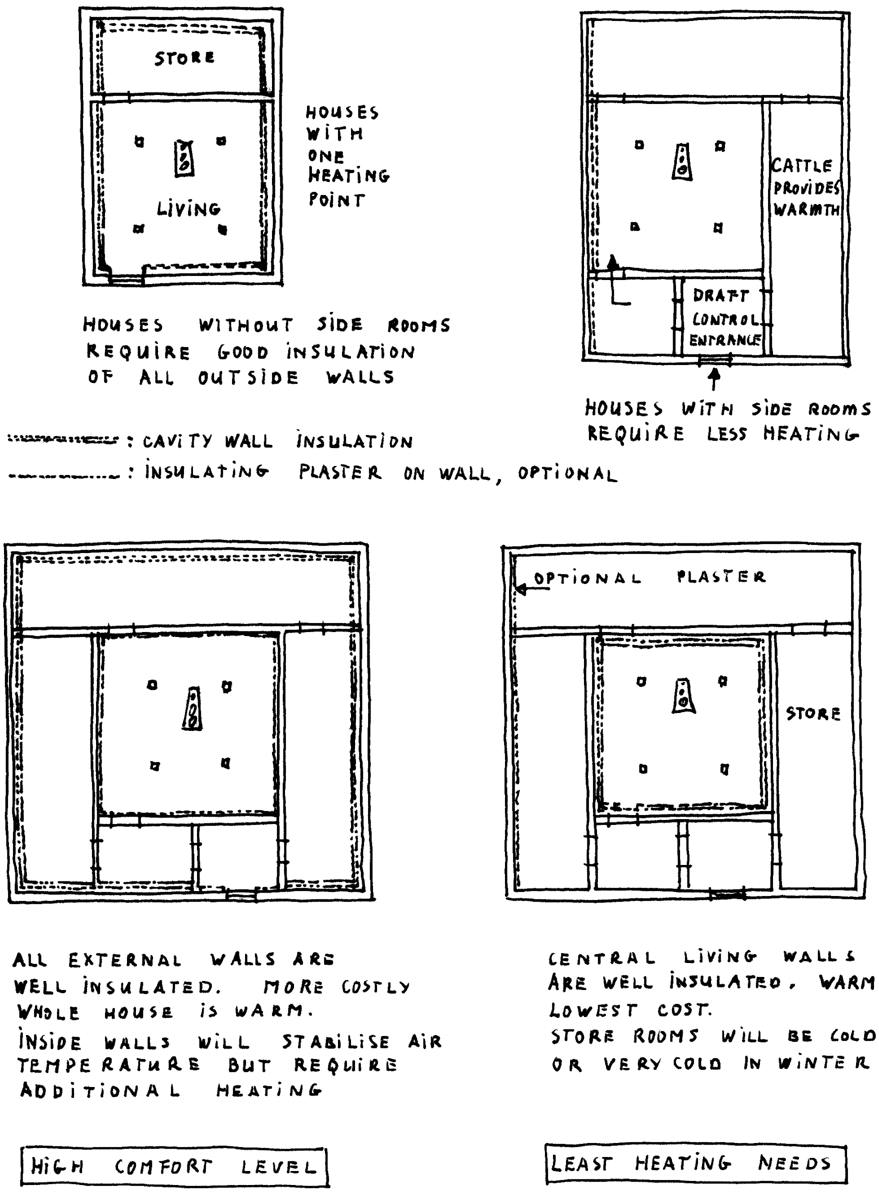


FIGURE 13. PLANNING OF INSULATION OPTIONS DEPENDING ON THE ROOM LOCATION

Indoor bathrooms or bathrooms attached to the house should be fully insulated, taking particular care to ensure that the water piping or water storage is on the inner side of the insulation. For bathrooms the better type of cement plaster cavity wall needs to be realised as the walls will get wet.

If the temperature of a storeroom should not fall below the freezing point, then a cavity wall needs to be fitted on the inner side of the external walls of the store to provide insulation.

Condensation on Windows

Humid air inside the house will always condense on the coldest surface. If a room is well insulated, condensation will no longer occur on the cavity wall. It is possible, though, that excessive condensation will occur on the windows. It is therefore advisable to ensure that condensation water can drain directly to the outside of the wall. To reduce condensation on the windows, double-glass or curtained windows can be realised. The curtained window will be most effective if the curtain closes all around the window, creating a standing layer of air between the window and the curtain.

Double-glass windows can be custom made for any planned or existing window opening. For existing windows, double-glass windows can be made by fitting another glass frame onto the outside of the existing single-glass window frame. A shuttered window can be made by adding a double-sided galvanised sheet shutter on the outside.

Condensation on Ceiling

Condensation occurring on the ceiling or inside the roof can cause dripping, with the droplets often mixed with the accumulated soot from the ceiling. Although some villagers thought that their roof had started to leak, this was not the case. The droplets formed because after the walls had been insulated, the roof became the coldest surface in the room and condensation formed.

The realisation of improved roof insulation will help to reduce the condensation and the fitting of a suspended ceiling will most probably eliminate the condensation entirely. Increased ventilation will also reduce or eliminate inside condensation. Improved roof insulation should be done in conjunction with roof waterproofing and the reduction of the weight of the roof construction. The realisation of the suspended ceiling under the roof should only be done if the roof has been upgraded with good roof waterproofing that also keeps the walls dry.

FIGURE 14. WOODEN GRAIN STORAGE BOXES AGAINST THE WALL ARE EXCELLENT INSULATORS

Detailed Designs of the Wall Insulation Constructions

The following four drawings provide detailed designs of the cavity wall insulation constructions for new walls. The same wall insulation designs can be applied to existing walls; the difference being that the pointed pegs need to be inserted (hammered) into the existing walls. This should not be attempted with weak constructions.

A. *Wall with Straw and Wattle Panels – Code 5.6.1.N*

This design is particularly useful for either free-standing wall sections or places where 3"- 4" thick wall insulation needs to be applied. The design is very cheap in all areas where wattle from the willow trees is a local product and the panels can be manufactured by the village population. In Baltistan the use of entire wattle panel walls is very common and many houses built in the past century used this method. Currently wattle is widely used for making baskets, as well as drying panels (shields) that are used for drying vegetables and fruits on the roofs.

A contract for making wattle panels can be made with the villages where the willow trees grow and the villagers have expertise in weaving the panels. When a sufficient number of panels has been collected, the construction can be realised per wall section.

If there is a regular demand for the wattle panels, this will encourage villagers to grow more willow trees, resulting in a wider availability of wattle in the future. In low altitude regions where no willow trees are grown, the buying of wattle mats may be expensive.

Panels can be made in various sizes, but it is recommended to make panels 3 ft. x 8 ft. (room height). By doing so, horizontal joints are avoided. The joints of the panels should be tightly bound together with galvanised wire to prevent any movement; thereby reducing the risk of cracks appearing in the wall.

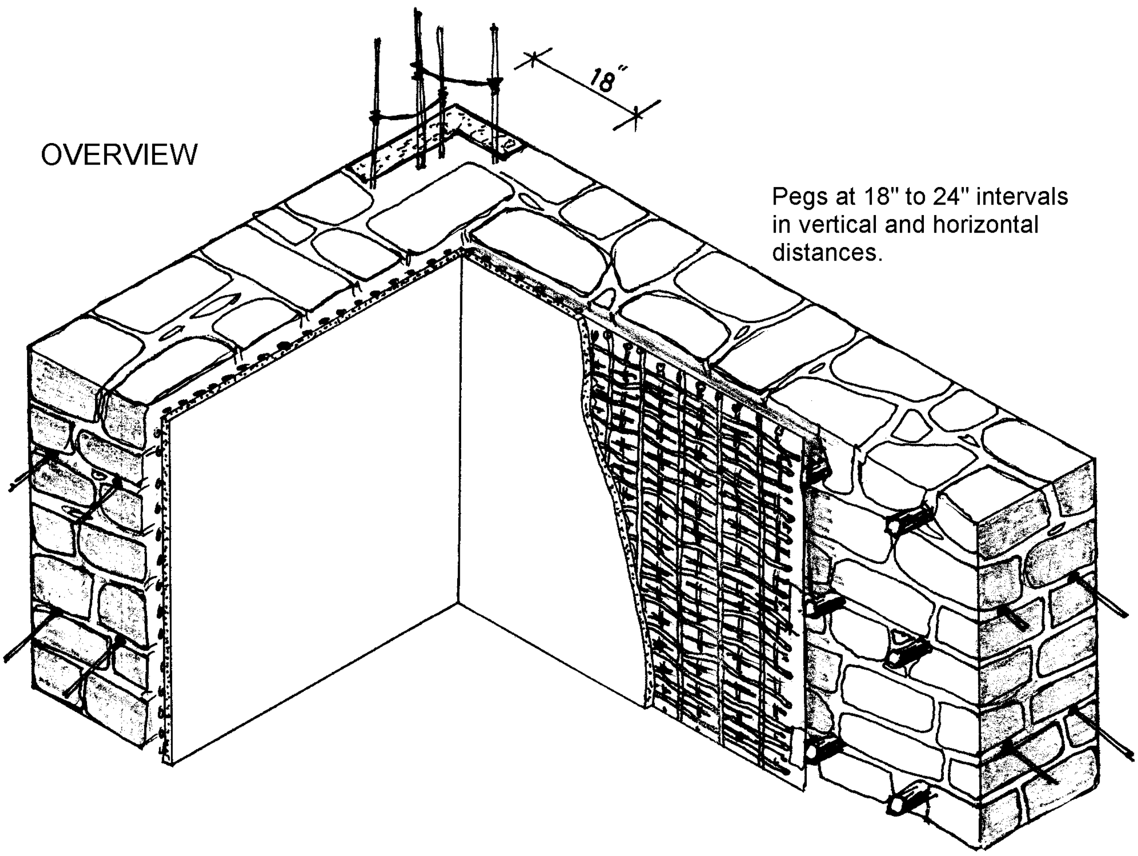
For a second storey, it is possible to place inside and outside wattle panels. The outside panel can be plastered with a stronger sand-cement plaster. The two panels will create a very light wall construction.

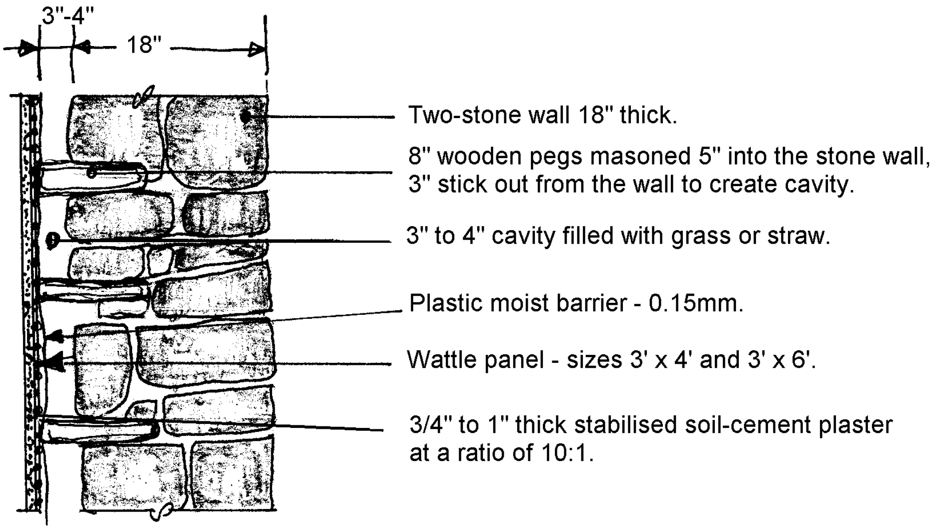
FIGURE 15. CAVITY WALL WITH WATTLE PANEL (THIS WALL IS NOT FINISHED ABOVE THE PLASTIC)

BACIP WALL INSULATION TECHNIQUE ON NEW WALL - 5.6.1.N

BACIP wall insulation technique applied to new 18" two-stone wall with 3" to 4" cavity filled with straw and 3/4" thick plaster on wattle panel. Total wall size = 23".
The stabilised plaster is applied at a ratio of 10:1 (10 soil+sand to 1 cement).

OVERVIEW





DETAIL OF WALL SECTION

FIGURE 16. DESIGN CODE 5.6.1.N – PEGS, STRAW, PLASTIC, WATTLE PANEL, PLASTER

ALL PEGS SHOULD BE PAINTED WITH RED OXIDE TO AVOID ROT.

B. Wall with Pegs, Straw, Plastic, Wooden Strips, Expanded Metal and Plaster – Code 5.6.2.N

This is a very effective and low-cost design, giving at the same time a fairly straight wall surface. The pegs need to be cut off exactly in line using a straight guide. A layer plastic is then applied over the pegs and the cavity created filled with straw (see figure 18). Wooden strips nailed onto the pegs (over the plastic) assist in making the surface of the wall flat. Between each two horizontal strip, another layer of standing air layer is created. Plaster material that may eventually fall through the expanded metal will only fall into the first cavity, making a stiff ridge and keeping the cavity between the plastic and the wall clean.

This cavity wall design also keeps the length of the pegs short as they only protrude one inch out of the wall. When a cavity is 1" or larger, then a straw filling should be applied.

The masonry work of the inner face of the wall does not have to be very precise, thus saving labour time (and expenses). This is particularly important if the mason is to make the wall thinner (lighter) than the common two-stone walls which they are accustomed to making. The making of thinner stone walls usually causes the wall to become slightly irregular on one side. That is not a problem at all with this cavity wall design.

The special benefit of this cavity wall design is that the stone wall does not have to be plastered. The amount of plaster usually applied on the rough stone wall is equivalent to the amount of plaster needed to be put on the expanded metal. In the financial calculation for a new wall construction, only one plaster surface needs to be considered.

When applying the soil-cement or sand-cement plaster, the composition should be 10:1. During the testing period a mixture of 15:1 was tried with various soil types, but in several occasions the soil-cement plaster started to crack or crumble after some time. For the lower parts of the walls that have to be stronger, a plaster of 8:1 can be used.

BACIP also tested using galvanised chicken wire-mesh with small holes (22 gauge). The flexibility of the chicken wire-mesh was too great and necessitated the use of numerous wooden strips to keep the distance between the wooden support strips short. In addition the chicken wire-mesh tended to rust when soil-cement plaster was applied, despite the galvanisation. The expanded metal is stiffer and remains flatter during application of the mortar[11]. To enhance the adherence between the expanded metal and the plaster, the expanded metal needs to be sprayed/splashed with a wet cement slurry (1:1) before applying the soil-cement plaster.

A possible disadvantage of the cement-plastered cavity wall design is the need for curing. Curing with water is necessary for at least one week to ensure that the cement is adequately hardened. It is possible that after some time small cracks will appear in the plaster due to shrinkage of the plaster, especially when the soil contains too much silt or clay. Also when the plaster has been applied too wet, or too much cement has been added (to make it strong), shrinkage can occur. Walls that have these cracks are best treated with a thin coat of lime plaster.

[11] It is recommended to wear leather working gloves when handling the expanded metal.

BACIP WALL INSULATION TECHNIQUE ON NEW WALL - 5.6.2.N

BACIP wall insulation technique applied to new 18" two-stone wall with 3" cavity and 3/4" thick plaster on expanded metal. Total wall size = 22".
The stabilised plaster is applied at a ratio of 10:1 (10 soil+sand to 1 cement).

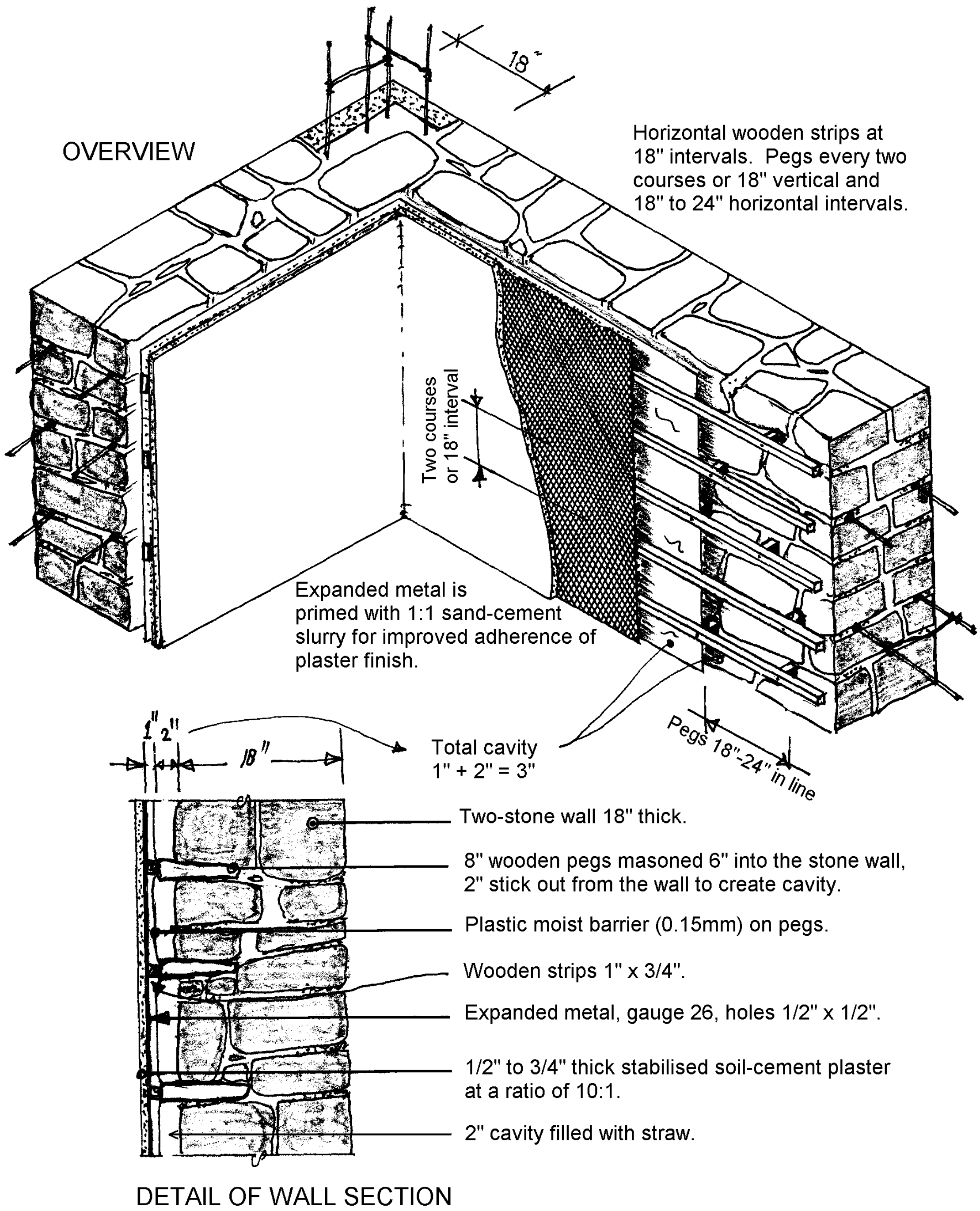


FIGURE 17. DESIGN CODE 5.6.2.N – PEGS, STRAW, PLASTIC, WOODEN STRIPS, EXPANDED METAL, PLASTER

ALL PEGS SHOULD BE PAINTED WITH RED OXIDE TO AVOID ROT.

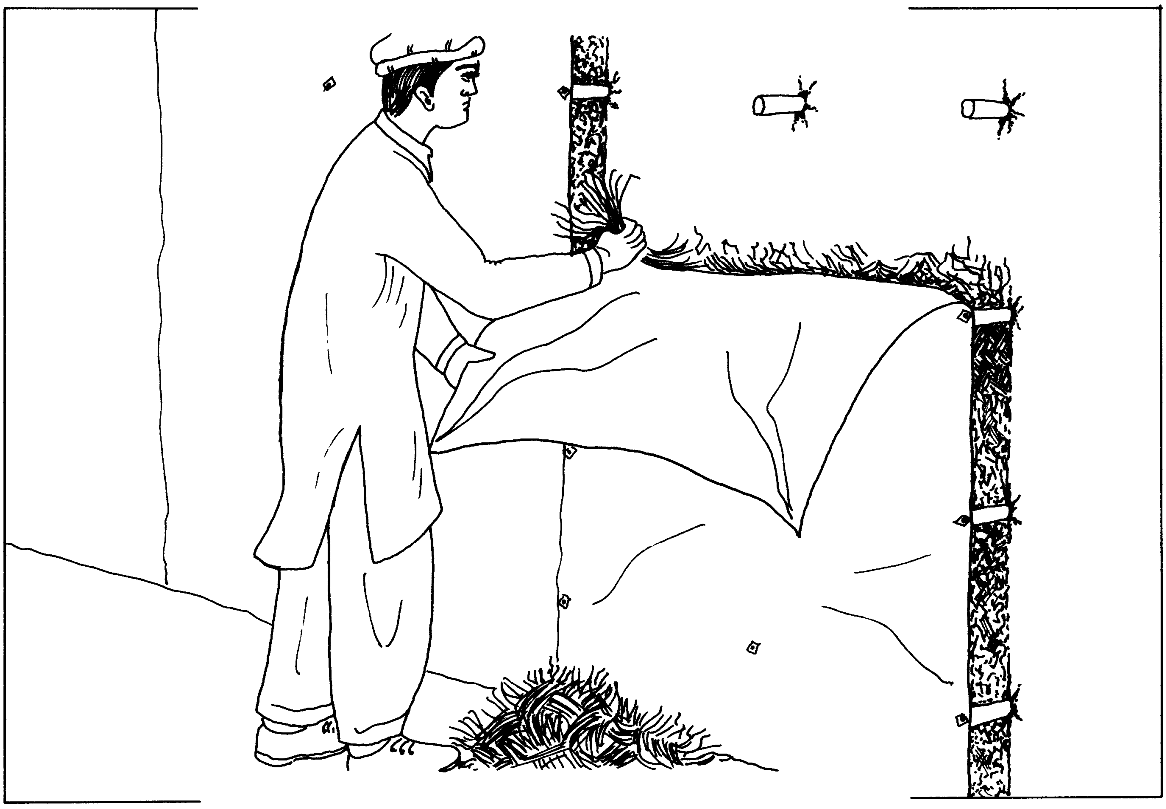


FIGURE 18. ALL CAVITIES ONE INCH OR LARGER TO BE FILLED WITH STRAW IN BAGS AND ADDED LIME.

FIGURE 19. PEGS MASONED INTO THE WALL FOR ATTACHMENT OF PLASTIC AND EXPANDED METAL.

ALL PEGS SHOULD BE PAINTED WITH RED OXIDE TO AVOID ROT.

C. ***Wall with Pegs, Straw, Plastic, Expanded Metal and Plaster – Code 5.6.3.N***

This design is highly recommended by BACIP for all areas having long, cold winters as the 2"- 3" thick straw-filled cavity insulation characteristics are the best.

If the distance between the two sides of a cavity wall becomes 1" or more, air circulation will occur between the warm and cold sides of the wall, thus reducing the insulation effect. To reduce the air circulation, loose straw or other loose airy material should be added. If coarse straw is used, filling the space behind the plastic will be easy and less chance will exist of the straw sliding down into the lower part of the cavity. Fine grass will be subject to pulverisation and settling on the bottom of the cavity. In addition the grass seeds may be an attraction for mice and/or other insects.

This wall design has the following advantages:

- The plastic is directly behind the expanded metal, reducing the possibility of too much plaster going through the expanded metal. In fact it is possible to use less plaster with this design than the design having a 1" cavity between the plastic and the plaster (Code 5.6.2.N). The thinner plaster will reduce the amount of heat the wall will absorb in order to reach room temperature.

- This design requires less amount of wood in its application due to the absence of the horizontal wooden strips.

- The plastic is behind the plaster/expanded metal and will assist in the curing, as evaporation of the water in the fresh plaster will be only towards the inside of the room.

To obtain a good result, the extended points of the pegs should all be precisely in line. This will create a flat surface for fixing the expanded metal.

The application of soil or sand plaster onto the expanded metal requires a priming of the metal with a thin sand-cement slurry of 1:1. This will enhance the adherence between the plaster and the expanded metal. The plaster is applied in two phases. First a rather dry mortar is pressed carefully halfway through the expanded metal, one trowel at the time. When this is hardened and holds firmly, a slightly thinner mortar coat is applied to smoothen out the surface.

When pressure or impact is expected in the lower part of the wall, additional pegs or a double layer of expanded metal should be applied.

The cement-plastered cavity wall designs need curing with water for at least one week to ensure that the cement is adequately hardened. It is possible that after some time small cracks will appear in and around the plastered wall due to shrinkage of the plaster, especially when the soil contains too much silt or clay. Also when the plaster has been applied too wet, or too much cement has been added (to make it strong), shrinkage can occur. Walls that have these cracks are best treated after a month with a thin coat of lime plaster (4 kg lime to 12 litre water).

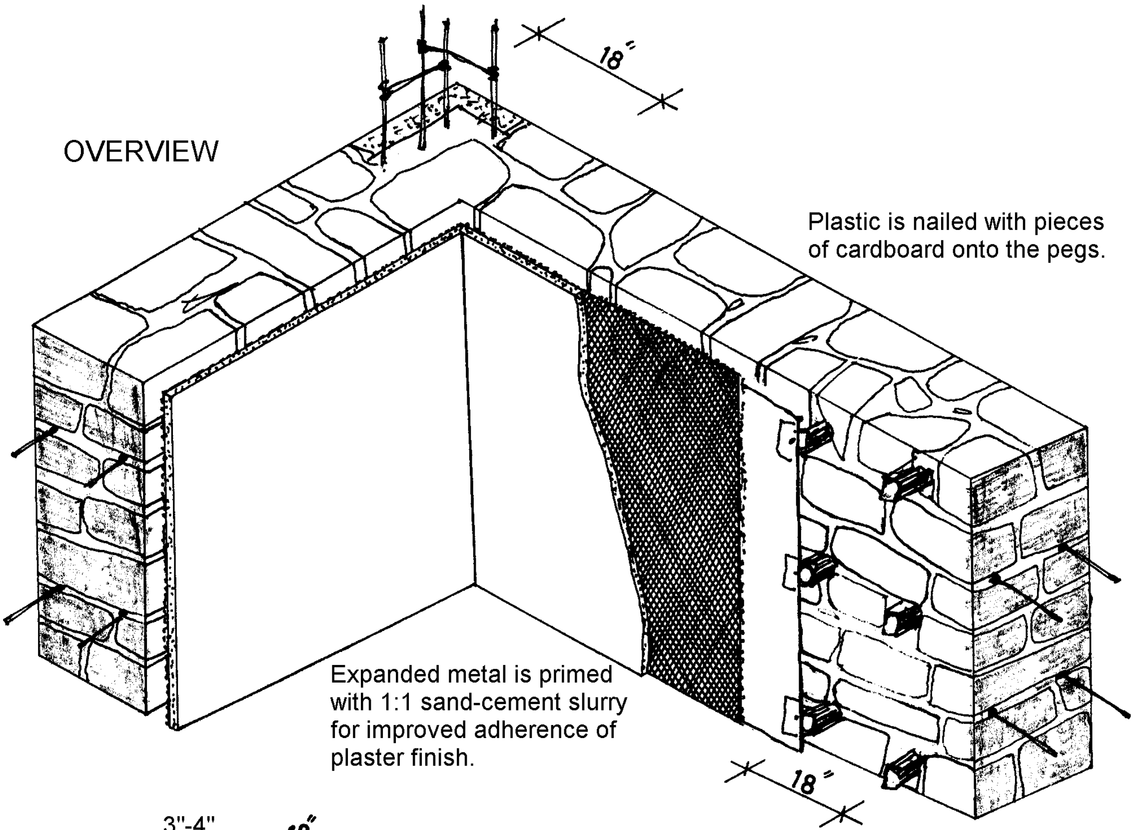
In the Northern Areas, this cavity wall design has shown to have the highest benefit ratio when applied by low-cost village craftsmen, considering cost, effectiveness and durability.

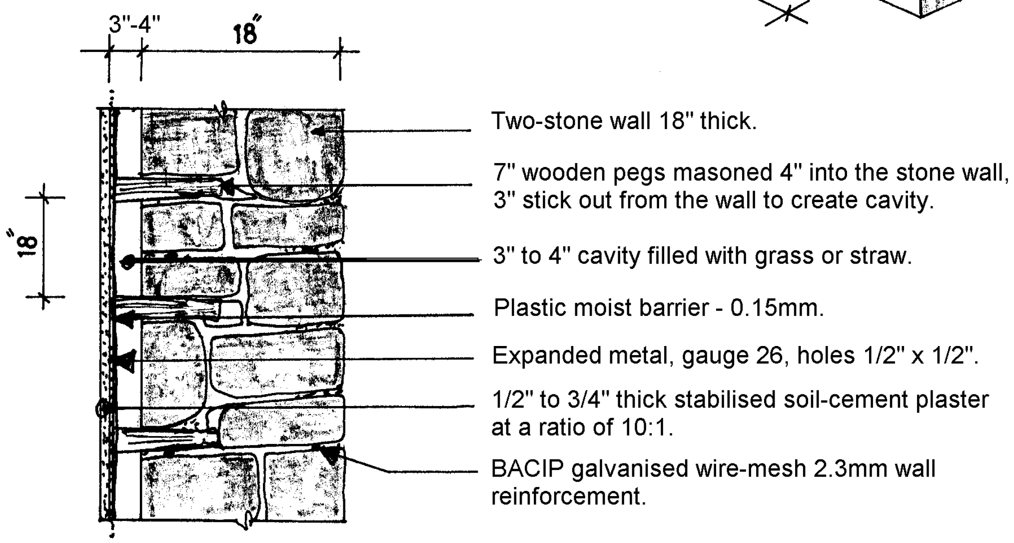
This system can be applied on both new and existing walls made from either stone or cement blocks.

BACIP WALL INSULATION TECHNIQUE ON NEW WALL - 5.6.3.N

BACIP wall insulation technique applied to new 18" two-stone wall with 3" to 4" cavity filled with straw and 3/4" thick plaster on expanded metal. Total wall size = 22".
The stabilised plaster is applied at a ratio of 10:1 (10 soil+sand to 1 cement).

OVERVIEW





DETAIL OF WALL SECTION

FIGURE 20. DESIGN CODE 5.6.3.N – PEGS, STRAW, PLASTIC, EXPANDED METAL, PLASTER

ALL PEGS SHOULD BE PAINTED WITH RED OXIDE TO AVOID ROT

D. *Wall with Wooden Strips, Straw, Plastic, and Plywood – Code 5.6.4.N*

A cavity wall can be applied onto a cement block wall by either masoning pegs into the new wall or applying wooden strips with steel nails onto the already masoned wall. If a wide cavity needs to be created, the strips can be placed in a crossed position; the first layer horizontally (or vertically), then the plastic foil, followed by the second layer vertically (or horizontally). A cavity that is 1" or wider needs a straw filling behind the plastic. Because the plywood is so light in weight, the wall absorbs very little heat and therefore the room will rapidly warm up. It can also be easily applied to existing walls.

The special advantage of the plywood construction is the speed at which the work can be realised. It requires only 1/4th the time to apply than that of the plastered wall, but the material is slightly more expensive than plaster. When no skilled mason is available, then the application of the plastered wall may be time consuming for the do-it-yourself person. For those wall sections where pressure or impact on the lower part of the plywood wall can be expected, a thicker 3/8" plywood should be applied. This, obviously, will be more expensive.

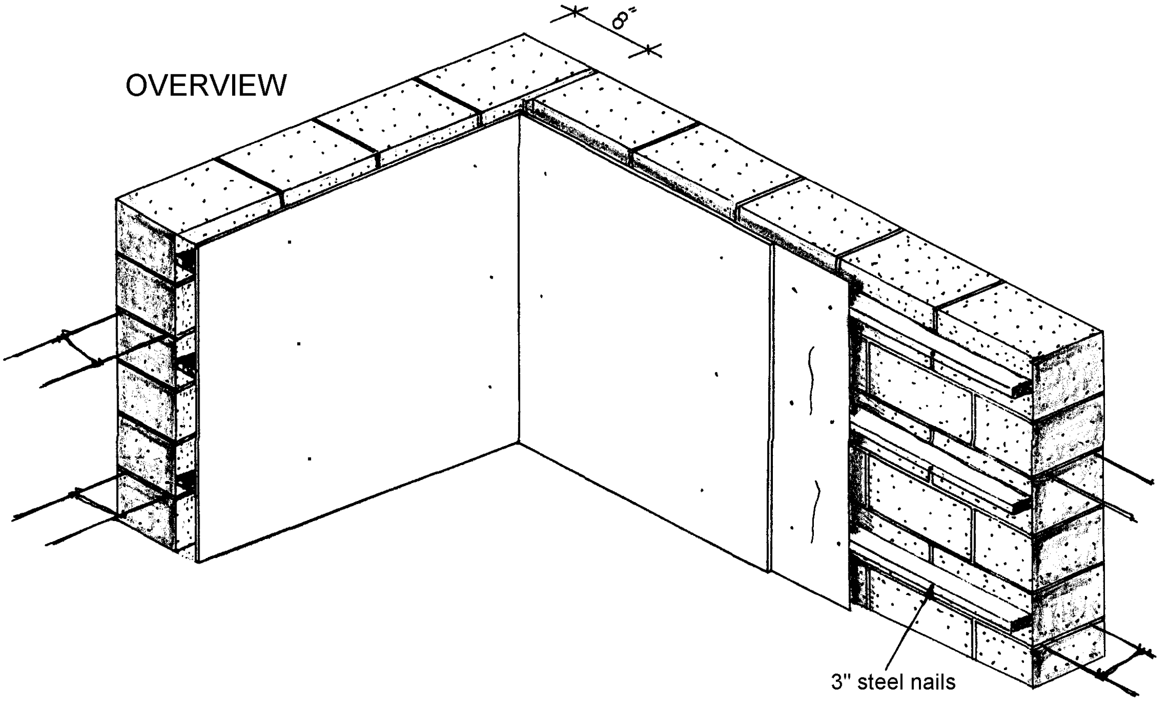
A possible disadvantage of the plywood is that it can only be applied in rooms that are totally dry. Wet areas will affect the plywood, causing it to rapidly deteriorate. Water resistant plywood does exist, but is not readily available and definitely more expensive.

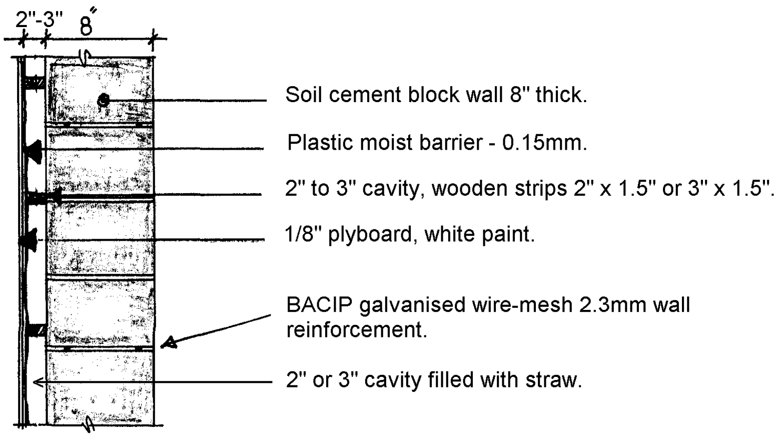
The plywood model can also be realised with chipboard or other board materials. Each board material has its advantages and disadvantages in price, transport, application and durability. The 1/8" plywood model has been chosen by BACIP because the material is very light, thus keeping transport costs low. As a future option, 4 ft. x 4 ft. fibre cement panels can be used. These panels cost at least Rs.15/ft² for 5 mm thick sheets. As this option has not yet been tested, it is not included in the present document.

FIGURE 21. APPLICATION OF 1/8" PLYWOOD ON EXISTING CEMENT BLOCK WALL CREATING AIR INSULATION

BACIP WALL INSULATION TECHNIQUE ON NEW WALL - 5.6.4.N

BACIP wall insulation technique applied to new 8" thick soil cement block wall with 2" to 3" cavity and plyboard. Total wall size = 10.5"
The plyboard is fixed with nails on top of 2" x 1.5" thick wooden strips.





DETAIL OF WALL SECTION

FIGURE 22. DESIGN CODE 5.6.4.N – WOODEN STRIPS ON CEMENT BLOCKS, STRAW, PLASTIC, PLYWOOD

TIMBER IN CONTACT WITH THE MASONRY OR STONE WALL SHOULD BE PAINTED WITH RED OXIDE.

6. THERMAL CHARACTERISTICS

The thermal characteristics of the different wall designs have been measured by BACIP by means of thermometers placed in the houses where the wall insulation was realised and by recording firewood consumption. The data was compared with temperature data from houses with similar layouts and occupation, and firewood consumption prior to the wall installation. All villagers have a good sense of the amount of firewood consumed in their houses as every piece of wood needs to be brought down from the mountains, involving many days of hard labour and travel.

> "Three years ago I spent a lot of money to build this cement block room. But from the time it was ready, I could not use it as it was too cold in the winter and too hot in the summer. During the winter I used it as a potato storeroom only. Since last winter we have the wall insulation, and now we live here as it is comfortable warm and does not need much heating". (Furfu)

The BACIP staff measured with the house owners the amount of firewood used. The reduction from previous years was between 30% and 50% over one winter season, varying among families. Results showed that the occupants of houses with the wall insulation only slightly increased their average or maximum room temperature, but that room temperature could be easily maintained for the entire day without additional heating[12]. Apart from these measured results, the satisfaction level of the house owners is one of the most important indicators as it is the house owners who eventually need to promote the wall insulation techniques to their neighbours.

The data presented in this report give an indication of the different insulation values of the various wall designs by calculating the resistance value (R value in M^2 K/W), as well as the time lag in hours. The calculated values are based on the available information about thermal conductivity or resistance values in building materials[13].

TABLE OF MATERIAL CHARACTERISTICS

No.	**Material** *The highest resistance (best insulator) at the beginning.*	**Density of Material in kg/m³**	**Material Specific Thermal Conductivity λ = W/m.K**	**Specific Thermal Resistance R_m= m.K/W**
1	Expanded polypropylene	20	**0.02**	50.00
2	Air, low humidity	1	0.026 - **0.023**	40
3	Rock wool/glass wool	150	**0.04**	25.00
4	Rock wool on expanded metal	200	**0.06**	16.67
5	Wood wool, loose	150	**0.064**	15.62
6	Straw or thatch	240	0.07 - **0.08**	13.33
7	Wood shavings, loosely packed	250	**0.08**	12.50
8	Sawdust, loose	270	**0.085**	11.76
9	Softboard, low density	300	**0.10**	10.00
10	Plywood, multiplex	530	0.138 - **0.116**	8.33
11	Medium Density Fibre (MDF)	500-600	**0.14**	7.14
12	Hardboard medium quality, paper	570	0.14	7.14

[12] *Report on Thermal Performance of BACIP Wall Insulations in Northern Areas of Pakistan*, by Dr. Irshad Ahmed, National Institute of Silicon Technology (NIST), Islamabad, June 2000.
[13] The bold printed figures are standard calculation data from the *Polytechnisch Zakboekje* (European Polytechnic Information), Koninklijke PBNA, Arnhem, The Netherlands (1980).

No.	**Material** *The highest resistance (best insulator) at the beginning.*	**Density of Material in kg/m³**	**Material Specific Thermal Conductivity λ = W/m.K**	**Specific Thermal Resistance R_m= m.K/W**
13	Gypsum plaster	900-1200	0.17	5.88
14	Linoleum, PVC flooring tiles	650	**0.186**	5.38
15	Hardboard, normal hard quality	800	**0.20**	5.00
16	Wood	817	0.138 - **0.233**	4.29
17	Chipwood panels, low density	450	**0.25**	4.00
18	Fibre cement, Eternit	800	**0.30**	3.33
19	Soil-grass (dry 1:1) lime water bonded and compacted	1000	*0.35 Estimated*	2.86
20	Terrazzo floors	1500	**0.41**	2.44
21	Adobe blocks	1100	0.48	2.08
22	Water	1000	**0.58**	1.72
23	Soil-cement mortar (10:1)	1400	0.6	1.67
24	Cement blocks, solid, low quality	2000	0.65	1.54
25	Burned brick masonry, inside	1500	**0.70**	1.43
26	Soil, not compacted.	1300	0.71	1.41
27	Soil-stabilised, compacted, dry	1400	*0.75 Estimated*	1.33
28	Burned brick masonry, outside	1800	**0.87**	1.15
29	Glass	2500	1.05 - **0.814**	1.11
30	Sand-cement plaster (10:1)	1900	**1.3**	0.77
31	Two-stone wall masoned in loose soil, 30% cavity with soil fill	1600-1700	*1.5 Estimated*	0.67
32	Reinforced concrete, 5% reinforcement, vibrated	2400	**1.5**	0.67
33	Reinforced concrete, not vibrated	2300	**1.6**	0.63
34	Two-stone wall masoned in light cement mortar 30% of volume	1800-2000	*1.7 Estimated*	0.59
35	Low quality concrete, not reinforced	2100	1.7	0.56
36	Sandstone	2150	**1.745**	0.57
37	Two-stone wall, masoned in strong cement mortar (30% without holes)	2200	*2.0 Estimated*	0.50
38	Ice	950	**2.21**	0.45
39	Stone, solid granite	2500-2600	**2.8-2.9**	0.35
40	Corrugated metal sheet, steel	7800	50 - **58**	0.02

The above figures have been used for the calculations in Chapter 7. However, it must be mentioned that the calculation results are approximations only as some figures have been estimated. BACIP has made some estimations regarding the two-stone wall R factors.

During the realisation of the wall construction in the houses, other factors may be of influence, such as the wind-chill factor. The behaviour of the people and the amount of room ventilation caused by opening and closing the doors will also influence the actual firewood saving.

In the calculations of cavity walls or ceilings, the width of the cavity or the airspace between the two surfaces is important. The larger the width, the lower the insulating factor becomes due to the effect of air circulation inside the cavity. In this case, the standard air insulating factor cannot be applied.

TABLE OF RELEVANT CONDUCTIVITY FIGURES FOR CAVITIES[14]

Thickness of Air Layer in Centimetres	Thickness of Air Layer in Inches	Vertical Cavity Conductivity and Resistance		Horizontal Cavity with Warm Side Above (Hot Roofs)		Horizontal Cavity with Warm Side Below (Warm Rooms)	
		λ = W/m.K	**R_m= m.K/W**	**λ = W/m.K**	**R_m= m.K/W**	**λ = W/m.K**	**R_m= m.K/W**
1	1/2"	**0.065**	15.38	**0.064**	15.63	**0.066**	15.15
2	3/4"	**0.115**	8.69	**0.106**	9.43	**0.131**	7.63
4	1-1/2"	**0.221**	4.52	**0.187**	5.35	**0.252**	3.97
8	3- 1/8"	**0.448**	2.23	**0.350**	2.85	**0.492**	2.04
10	4"	**0.564**	1.77	**0.430**	2.33	**0.616**	1.62
15	6"	**0.861**	1.16	**0.632**	1.58	**0.913**	1.10
20	8"	**1.163**	0.86	**0.837**	1.19	**1.210**	0.826

The above table shows that an air cavity of larger than 3/4" (λ = 0.115) will be far less effective than when the same space is filled with wood shavings (λ = 0.08) or straw (λ = 0.07).
Also, an air space of about 3" has about the same conductivity as adobe (λ = 0.45).
This means that when an air space is 1" or larger, it is essential to fill the cavity up with loose straw.
In the first tests, several walls were made with a 2" cavity between the rough stone wall and the plastered expanded metal. This is not a very effective use of the space.

IMPORTANT:
Cavity walls with a cavity opening of one inch or wider should always be filled with loose straw or have separated air spaces, each not wider than 3/4 inch (2 cm).

The total R value (total thermal resistance of the wall) can be calculated by adding the various thermal resistance values of each wall element (or cavity) together. The thermal resistance of each wall element is the R_m value multiplied by the thickness in meters of that wall element. In addition the transfer resistance must be added **between the outside air and the wall** (R_{so} = variable) and the transfer resistance **between the inside air and the wall** (fixed R_{si} = 0.11).

VALUES FOR R_{SO} WITH RESPECT TO WIND SPEED AND BUILDING LOCATION[15]

Source	Exposure	Wind Speed in Meters per Second	Conductivity U Value = W/m²K	Insulation Value R_{so} = m²K/W
Roof	Sheltered	1.0	09.90	0.07
	Normal	3.0	18.1	0.045
	Severe	9.0	42.7	0.020
Walls	Sheltered	0.7	08.70	0.08
	Normal	2.0	14.0	0.055
	Severe	6.0	30.4	0.03

[14] Cavity walls are very common in cold climates, but need to be filled with a light material. These figures are standard calculation data obtained from the *Polytechnisch Zakboekje* (European Polytechnic Information), Koninklijke PBNA, Arnhem, The Netherlands (1980).
[15] Source: *Buildings, Climate and Energy,* T.A. Markuss and E.N. Morris, 1980, page 272.

7. WALL CALCULATIONS

Based on the data from the tables in Chapter 6, the following calculations for a 8" = 20 cm cement block wall with different types of wall insulation on the inside can be made:

λ = W/mK is the typical conductivity for a certain type of material.
R_m = Average Resistance (R) value of material type for one meter thickness (1 : λ in mK/W).
R_1 = Actual calculated R value of first material for its actual thickness (R_{sm} x thickness in meters).
R_{so} = R value of outside air film, depending on wind factor (0.03=high, 0.055=normal, 0.08=low)[16].
R_{si} = R value of inside air film (standard 0.11).
R_{vca} = R value of vertical cavities of specified thickness, see table Chapter 6.

C1. <u>Cement block wall 8" = 20 cm thick, no insulation. Measured from outside to the inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so}= 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for simple cement-block wall type 1	R_{C1}= 0.45

C2. <u>Cement block wall 8" = 20 cm thick, with 1/2" air insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 0.012 cm; R_{vca} 0.01 m = 15.38	R_{vca}= 0.185
Cement plaster 2 cm; 0.02m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 2	R_{C2} = 0.67

The added air cavity of half inch considerably increases the insulation value of the wall by R 0.22.

C3. <u>Cement block wall 8" = 20 cm thick, with 1" air insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Cement plaster 2 cm; 0.02m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 3	R_{C3} = 0.70

The added air cavity of another half inch increases the insulation value of the wall by only R 0.03.

C4. <u>Cement block wall 8" = 20 cm thick, with 2" air insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so}= 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 5 cm; R_{vca} 0.04 m = 4.52	R_{vca}= 0.226
Cement plaster 2 cm; 0.02m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 4	R_{C4}= 0.71

The one inch <u>additional</u> air cavity increases the insulation value by only about R 0.04.

[16] Source: *Buildings, Climate and Energy*, T.A. Markuss and E.N. Morris, 1980, Page 272.

C5. Cement block wall 8" = 20 cm thick, with 2 x 1" air insulation and plaster on inside.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 5	R_{C5}= 0.92

When separating the wider air cavity, it increase the insulation value by about R 0.2.
The first conclusion here is that making the cavity wider is less effective than adding cavities.

C6. Cement block wall 8" = 20 cm thick, with 3" air insulation and plaster on inside.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 7.5 cm; R_{vca} 0.08 m = 2.23	R_{vca}= 0.167
Cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 6	R_{C6}= 0.64

With further increment of one-inch air space, the incremental insulation value is now lower than with the one-inch insulation, due to internal air circulation (convection) that transmits the heat.

C7. Cement block wall 8" = 20 cm thick, with 2" + 1" = 3" air insulation and plaster on inside.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 5 cm; R_{vca} 0.04 m = 4.52	R_{vca}= 0.226
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 7	R_{C7}= 0.92

The two separated air cavities increases the insulation value considerable by about R 0.28.

Cavities with Straw Filling

When we take the above wall designs and fill the cavity with straw, the following calculation results are obtained. As an alternative for straw, rock wool can be used, but this is usually more expensive than straw. In traditional houses loose sheep wool has been used in the past; this is equally effective.

C8. Cement block wall 8" = 20 cm thick, with 1/2" straw insulation and plaster on inside.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Straw 0.012 m x (R_m= 13.33)	R_2 = 0.16
Cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for cement block and 1/2 straw wall type 8	R_{C8}= 0.64

As compared to bare wall (C1) increment of R value of 0.19.

C9. <u>Cement block wall 8" = 20 cm thick, with 1" straw insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54) R_1 = 0.308
Straw 0.025 m x (R_m= 13.33) R_2 = 0.333
Cement plaster 2 cm; 0.02m x (R_m = 1.67) R_3 = 0.033
Inside air film resistance (standard value) R_{si} = 0.11

Total R value for 1" insulated cement block wall type 9 R_{C9} = 0.81
Half inch additional straw insulation increases R value with 0.17.

C10. <u>Cement block wall 8" = 20 cm thick, with 2" straw insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54) R_1 = 0.308
Cavity 5 cm; 0.05 m x (R_m= 13.33) R_2 = 0.666
Cement plaster 2 cm; 0.02 m x (R_m = 1.67) R_3 = 0.033
Inside air film resistance (standard value) R_{si} = 0.11

Total R value for 2" straw insulated cement block wall type 10 R_{C10}= 1.15
With one inch additional loose straw in the cavity, the insulation value increases by about R 0.34.

C11. <u>Cement block wall 8" = 20 cm thick, with 3" straw insulation and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54) R_1 = 0.308
Cavity 7.5 cm; 0.075 m x (R_m= 13.33) R_2 = 1.00
Cement plaster 2 cm; 0.02 m x (R_m = 1.67) R_3 = 0.033
Inside air film resistance (standard value) R_{si} = 0.11

Total R value for 3" straw insulated cement block wall type 11 R_{C11}= 1.48
With one inch additional loose straw in the cavity, the insulation value increases again by about R 0.33.

COMPARISON TABLE OF ABOVE CEMENT BLOCK WALLS

Wall Type	R Value with Empty Air Cavity	R Value with Straw-Filled Cavity	Difference in R Value
20 cm cement block, no cavity	0.45	NA	---
20 cm cement block, 1/2" cavity	0.67 improved	0.64 reducing	Negative
20 cm cement block, 1" cavity	0.70	0.81 good	+ 0.11
20 cm cement block, 2" cavity	0.71	1.15 very good	+ 0.44
20 cm cement block, 1"+1" cavity	0.92 improved	1.15 very good	+ 0.23
20 cm cement block, 3" cavity	0.64 reducing	1.48 excellent	+ 0.84
20 cm cement block, 2"+1" cavity	0.92 not increasing	1.48 excellent	+ 0.56
Thicker insulation	Reducing	Other effects become important	

The above table illustrates that the walls that are insulated with a 2" double air cavity or a single 2" cavity filled with straw or wood shavings (rock wool) give a very good thermal insulation, useful for almost the entire Northern Areas of Pakistan.

Stone walls that are treated with the same type of 2" internal wall insulation will have the same beneficial effects as the cement block walls.

An open air cavity of three inches or more does not have a better insulating effect than an open air cavity of one inch that is either empty or straw filled. All cavities that are one inch or more need to be filled with a loose material to reduce internal airflow.

Making the insulation thicker than three inches is not very useful as other aspects, such as cold roofs and floors or poorly insulated windows, become dominant. Also the much needed ventilation then becomes the most dominant factor of heat loss from the room.

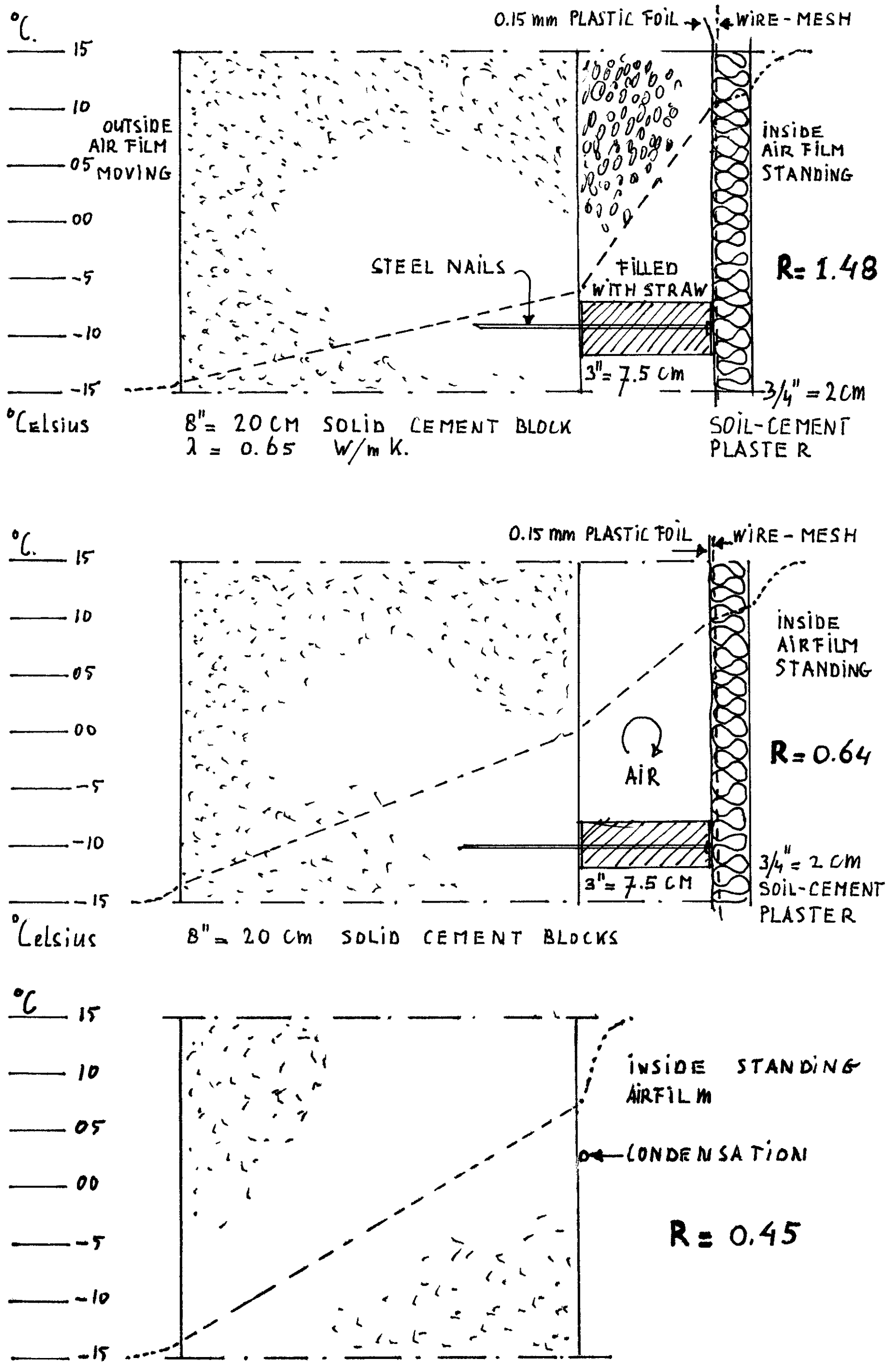


FIGURE 23. CALCULATIONS OF R VALUE FOR C11, C6, AND C1

8. TESTED AND APPLIED BACIP WALL INSULATION DESIGNS

The following calculations are made for the BACIP wall designs as indicated in above wall design drawings.

Code 5.6.1 <u>Two-stone wall: 18" = 44 cm thick with cavity, plastic, wattle panel and 3/4" soil-cement plaster on the inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Two-stone wall, masoned; 0.44 m x (R_m = 0.59)	R_4 = 0.26
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Wattle panel 1 cm; 0.01 m x (R_m = 5)	R_5 = 0.05
Soil-cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for 1" air insulated wall type 5.6.1	R_{w1} = 0.70
R for same design with 1"+1" air cavity	R_{w1} = 0.92
R for same design with 2" straw-filled cavity	R_{w1} = 1.15
R for same design with 2.5" straw-filled cavity	R_{w1} = 1.28
R for same design with total 3" straw-filled cavity (R_{vca}= 1)	R_{w1} = 1.5

Code 5.6.2 <u>Two-Stone wall: 18" = 44 cm thick with cavity, plastic and 3/4" soil-cement plaster on the inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Two-stone wall, masoned; 0.44 m x (R_m = 0.59)	R_4 = 0.26
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Soil-cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for 1" air insulated wall type 5.6.2	R_{w2} = 0.65
R for same design with 1"+1" air cavity	R_{w2} = 0.87
R for same design with 2" straw-filled cavity	R_{w2} = 1.10
R for same design with 2.5" straw-filled cavity	R_{w2} = 1.23
R for same design with total 3" straw-filled cavity (R_{vca}= 1)	R_{w2} = 1.45

Code 5.6.3 <u>Cement block wall 8" = 20 cm thick, with cavity and plaster on inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Cement plaster 2 cm; 0.02 m x (R_m = 1.67)	R_3 = 0.033
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for insulated cement block wall type 5	R_{w3} = 0.70
R for same design with 1"+1" air cavity	R_{w3} = 0.92
R for same design with 2" straw-filled cavity	R_{w3} = 1.15
R for same design with 2.5" straw-filled cavity	R_{w3} = 1.28
R for same design with total 3" straw-filled cavity (R_{vca}= 1)	R_{w3} = 1.5

Code 5.6.4 <u>Cement block wall 8" = 20 cm thick, with cavity and plywood on inside</u>.

The highest wind cooling factor is considered: Outside air film	R_{so} = 0.03
Cement block wall 0.2 m x (R_m = 1.54)	R_1 = 0.308
Cavity 2.5 cm; R_{vca} 0.02 m = 8.69	R_{vca}= 0.217
Plywood 1/8" panels 3 mm; 0.003 m x (R_m = 8.33)	R_6 = 0.025
Inside air film resistance (standard value)	R_{si} = 0.11

Total R value for 1" insulated cement block wall type 4	R_{w4} = 0.69
R for same design with 1"+1" air cavity	R_{w4} = 0.91
R for same design with 2" straw-filled cavity	R_{w4} = 1.14
R for same design with 2.5" straw-filled cavity	R_{w4} = 1.27
R for same design with total 3" straw-filled cavity (R_{vca}= 1)	R_{w4} = 1.49

TABLE OF ESTIMATED THERMAL RESISTANCE OF BACIP WALL DESIGNS

Description	Code 5.6.1 18" Two-Stone Wall with Cavity and Plastered Wattle Panels	Code 5.6.2 18" Two-Stone Wall with Cavity and Plaster	Code 5.6.3 8" = 20 cm Cement Block Wall, Cavity and Plaster	Code 5.6.4 8" = 20 cm Cement Block Wall, Cavity and Plywood Panels
Total R value for 1" insulated wall	R_{w1} = 0.70	R_{w2} = 0.65	R_{w3} = 0.70	R_{w4} = 0.69
R for 1"+1" air cavity	R_{w1} = 0.92	R_{w2} = 0.87	R_{w3} = 0.92	R_{w4} = 0.91
R for 2" straw- filled cavity	R_{w1} = 1.15	R_{w2} = 1.10	R_{w3} = 1.15	R_{w4} = 1.14
R for 2.5" straw- filled cavity	R_{w1} = 1.28	R_{w2} = 1.23	R_{w3} = 1.28	R_{w4} = 1.27
R for 3" straw- filled cavity	R_{w1} = 1.5	R_{w2} = 1.45	R_{w3} = 1.5	R_{w4} = 1.49

<u>Recommendation of R values for the Northern Areas[17].</u>

For the Northern Areas, the following **minimum** outside wall insulation values are recommended for buildings that have in the winter daily sun for more than four hours:

R = 0.8 to 0.9 for the lowest areas between 5000 ft. - 6000 ft.
R = 0.9 to 1.0 to for areas from 6000 ft. - 7000 ft.
R = 1.0 to 1.1 for areas from 7000 ft. - 8000 ft.
R = 1.2 for areas over 8000 ft.
For permanently shadowed areas, BACIP recommends to add at least 0.2 to the R value.

Further increasing the R value of the walls is only useful if attention has been given to other insulation aspects of the house, such as the roof, windows, floor and space planning.

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[17] If standard codes do exist about the thermal resistance of walls and roofs, these will have only a relative and time-bound value. When the energy expenses rise, the codes need to be adapted to meet the future higher energy costs. Current building practice should focus on the future economic situation.