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March 26th to
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Passive Solar Architecture

In Ladakh

Training document

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Contents

Introduction

What is Passive Solar Architecture?

Passive Solar Architecture is a way of designing buildings that takes advantage of the benefits of the local environment (such as sunlight), while minimising the adverse impacts of the climate (such as cold night time temperatures) on the **comfort level** of the building.

Why do we need to heat our homes?

The human body has an interior temperature of 37^{o}C. If our body temperature falls we feel cold, and if it rises we feel hot. We keep our body temperature at the point where we feel comfortable in a number of ways. These include eating food, wearing clothing, and by heating our homes.

The comfort level of a building is the interior temperature at which you feel comfortable without needing lots of extra clothing or blankets to maintain your temperature. Providing additional heating from a stove or a heater is one way of increasing the comfort level of a house or building.

Environmental Considerations

Domestic and Industrial buildings currently use around **50%** of all the energy used in the world. Some of the energy is used in processing raw materials into construction materials like bricks and glass, but most is used in heating, cooling and lighting buildings once they are constructed.

In cold climates, the amount of energy required to heat buildings is far greater than in buildings located in warmer parts of the world.

In the Himalayas, energy for heating usually comes from **biomass** fuels. These include wood, bushes and dried animal dung. In many areas, including Ladakh and Mustang, these fuels are becoming increasingly difficult to find, and collecting fuel takes up a lot of **time** each day, as well as degrading the local environment.

Alternative sources of energy can also be used for heating. These are usually **fossil fuels**. Fossil fuels are so-called because they are essentially 'stored sunlight' that has been converted into another form by deep burial in the earths crust. High temperatures and pressures under the surface of the earth convert organic materials like wood and other organic material into **coal**, **natural gas**, and **oil**.

Coal and gas can be burnt directly to provide heat, but oil is usually refined into different forms, including **petrol**, **diesel**, and **kerosene**.
Fossil fuels such as kerosene are often used in mountain areas, but they are expensive, and require special stoves and lanterns to use the fuel efficiently.

Biomass and fossil fuels all release **gasses** and **particulates** when they burn. Gasses are usually invisible, and include carbon dioxide, which has impacts on the global environment by accelerating global warming. Other gasses, like carbon monoxide, have impacts within the home, by affecting breathing and reducing the oxygen content of the blood. Particulates, like smoke and soot, make homes dirty, but most importantly give people very bad coughs and sore eyes.

Why use Passive Solar Architecture to heat homes?

Passive solar heating provides a way of reducing the amount of energy needed to heat buildings to a useful comfort level, by replacing some of the heat derived from biomass or fossil fuels with heat derived from sunlight. Sunlight is free, and has none of the negative financial, environmental or health effects of biomass and fossil fuel use.

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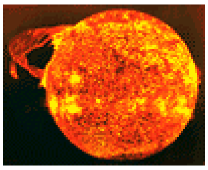
I. Passive Solar Basics

I.A. Solar Radiation

The Sun

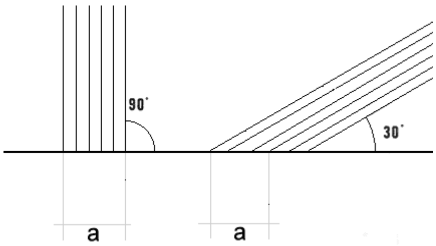


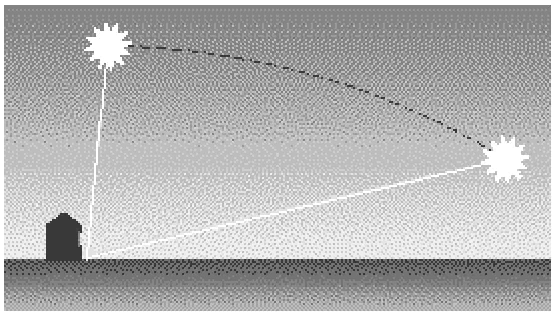
The sun is a huge sphere of luminous gas 1,392,000 km (864,950 miles) in diameter. The mass of the sun is about 330,000 times the mass of the Earth and it is located, on average, 149,600,000 km (92,957,000 miles) away from the earth. The sun generates energy by nuclear fusion reactions in its core. The energy produced in these reactions is emitted mainly as visible light and infrared radiation, which we feel as **heat**. On earth, this radiation provides light and heat, which provides the energy necessary for all life on earth.

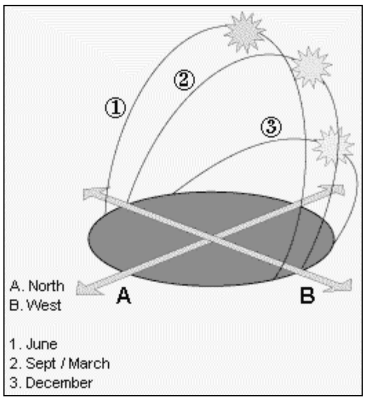
Because the earth orbits around the sun slightly elliptically, the amount of solar energy intercepted by the Earth steadily rises and falls by +/-3.4 percent throughout the year, peaking on January 3 when the Earth is closest to the sun. Around 31 percent of the suns radiation that reaches the earth, is scattered back to space by clouds and atmospheric particles.

Energy Receipt

Surfaces that are exactly at right angles (**90^{o} or perpendicular**) to the sun receive the most heat. However, because the earth is spherical, most surfaces are not perpendicular to the sun, and the energy they receive depends on the angle of the sun relative to the ground (see below).

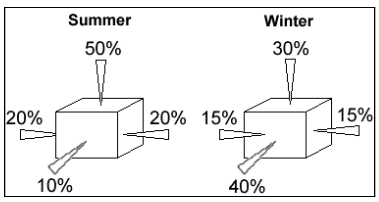






This angle changes systematically with latitude, the time of year, and the time of day. At midday, the sun is perpendicular to the ground, which is why midday is the hottest part of the day. When the sun has a lower elevation angle, the solar energy is less intense because it is spread out over a larger area.
In Ladakh, the sun is higher in the sky in summer than in winter. We can predict the position of the sun by using a solar diagram. Solar diagrams are produced for a variety of latitudes and copies of the solar diagrams for Ladakh and Mustang can be found at the back this document. They are a useful tool for predicting the intensity of radiation at given latitudes throughout the year.

Because the suns position in the sky varies throughout the year, different parts of a building will receive more or less radiation throughout the year. In summer, the roof and the east and west facing walls receive the most sunlight. In winter, the south facing walls catch the most sunlight. In winter, 90 % of the suns energy on the south face is received between 9am and 3pm.



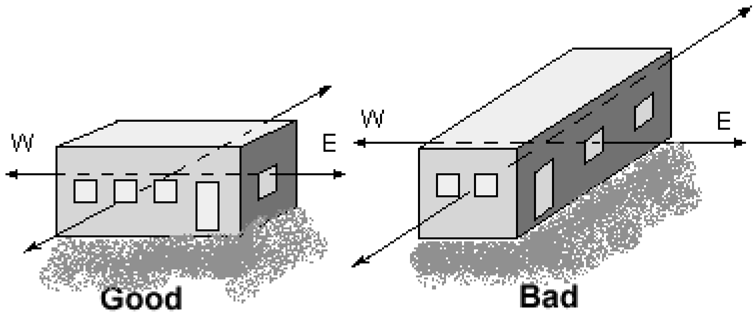
I.B. Passive Solar Building Configurations

Orientation

The aim of a passive solar building is to **absorb** (in winter) the maximum amount of radiation from the sun during the day, and to utilise this heat to warm the interior.

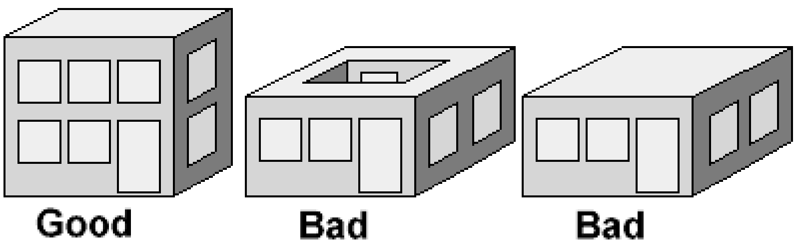
The sides of the buildings exposed to the sun gain heat during the day, while the other sides, in the shade, lose heat. This helps to avoid overheating during the summer.

To maximise the amount of radiation received, passive solar buildings are designed along an east-west axis, and the south facing walls are increased to present the largest possible **surface area** to the sun. The east and west-facing walls, which are less exposed to sun, are reduced as much as possible to minimise heat-loss.



Buildings should be aligned along an East-West axis, to maximise the surface area facing south.

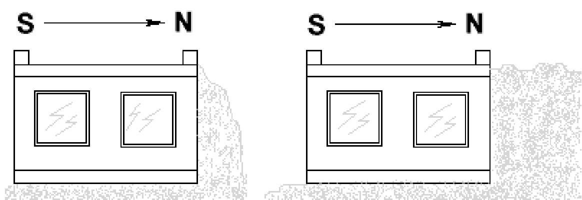
As the overall shape of the building determines the heat exchange with the exterior, it is also important to minimise the area / volume ratio so as to limit the heat loss: compact buildings with several storeys are more efficient.



The area to volume ratio should be minimised as much as possible:
compact buildings with a large surface area are more efficient.

The rooms to be heated are positioned on the side of the building, which is the most exposed to the sun: the south face. The rooms which are used the least (such as storage rooms, toilets etc) are placed on the north face, in the shade.

The surfaces in the shade, such as the north wall, or those exposed to severe conditions must be kept to a minimum. They can be underground or adjacent to an earth bank.



Heat loss from north-facing walls can be minimised by embedding
the building in an earth bank, or burying the north wall into the hillside.

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I.C. Passive Solar Concepts

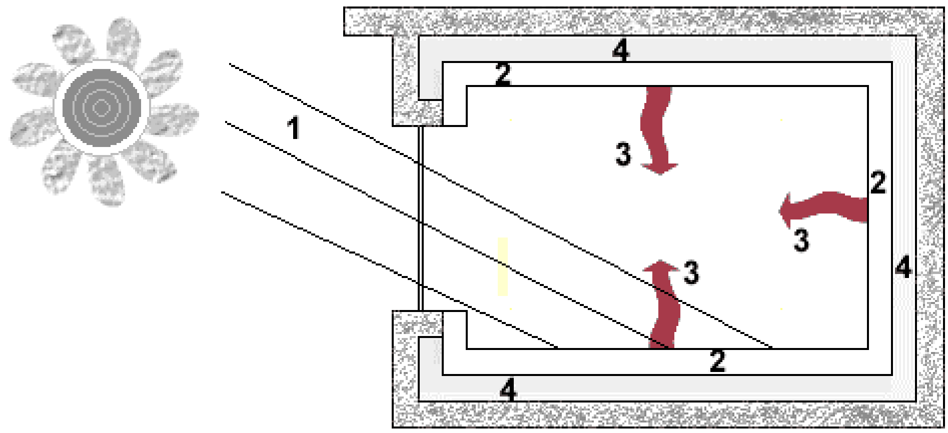
There are four inter-related components in passive solar buildings, which work together to make the buildings efficient utilisers of energy:

1 **Collection** and absorption of the maximum amount of solar radiation during the day

2 **Storage** of the heat collected from the suns radiation during the day

3 **Release** of this heat into the interior of the building during the night

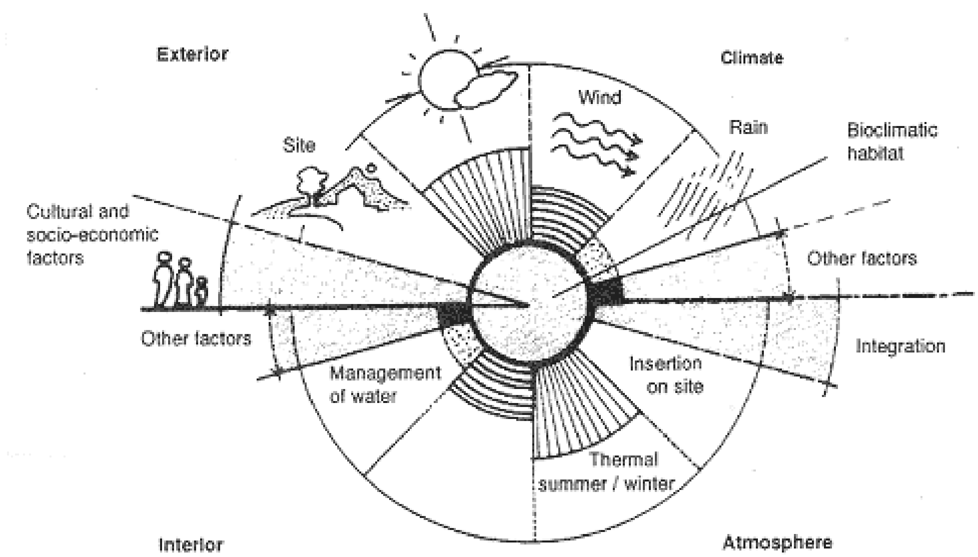
4 **Insulation** of the whole building to **retain** as much of the heat as possible inside the building



Bioclimatic Design

The passive solar concepts described above all work in conjunction, and are themselves influenced by a wide variety of external factors.

The term **bioclimatic** design refers to the interrelationship between the four concepts above, and the rest of the environment. Bioclimatic influences are complex, and are summarised below:



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I.D. Specification And Usage Of A Building

The first stage of the design process of a passive solar building is determining the **specification** and the **schedule**.

Specifications

The **specifications** of the building are defined by the proposed use of the building

The specifications are the **physical parameters** that influence the design of any building, not just passive solar ones. They include:

- Proposed number of rooms
- Proposed number of storeys
- Desired area of each room
- Number of doors

Schedule

The **schedule** of the building is also defined by the proposed use of the building, but the term refers specifically to the proposed **usage** of the building. These include:

- The purpose of the building (domestic house, office, store room etc)
- Whether the building will be for winter or summer use, or all year round
- Whether the building will be used during the day, the night, or all day
- The number of persons who will be using the building

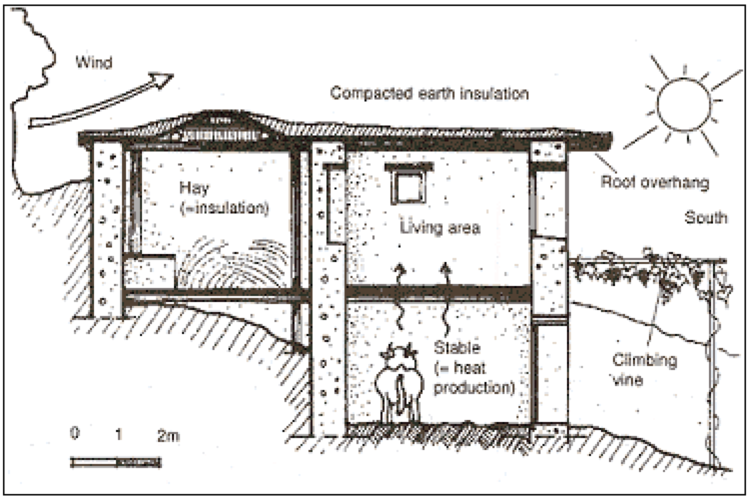
The schedule helps designers to plan the position of each room in the building to maximise the benefit of the passive solar heating system to the occupants. The schedule also defines the type of passive solar technology that is used.

General Rules

It is possible to formulate a number of general rules for the design of passive solar buildings, according to three common building configurations:

In multi-storey buildings, the following design guidelines should be followed:

- The ground floor should be used for cattle and livestock
- The first floor should be used for rooms that are used mainly during the winter
- The second floor should be used for rooms that are used mainly during the summer



An example of a building that uses a stable on the ground floor to provide additional heating.

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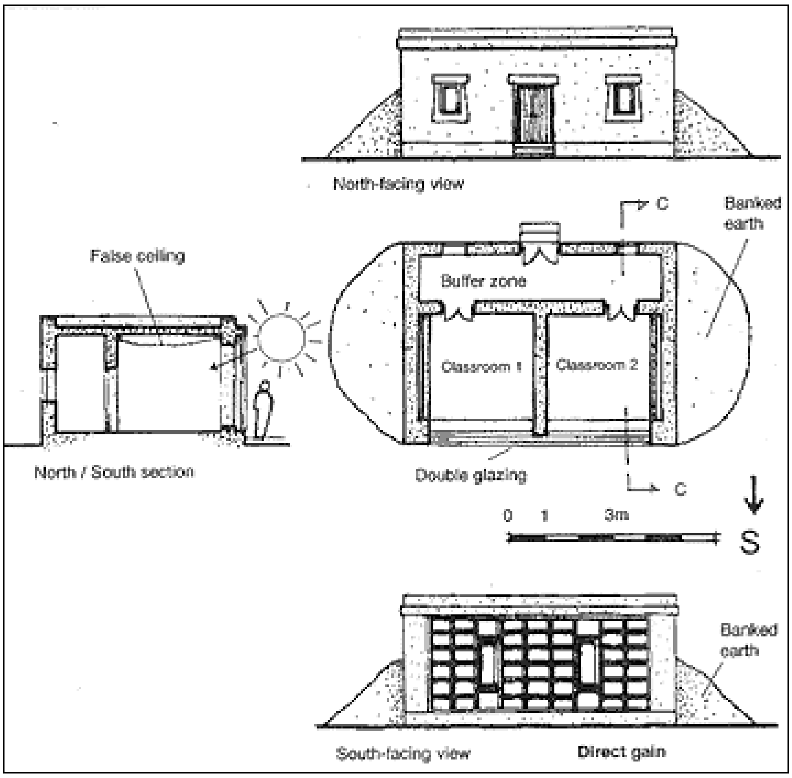
For single-storey buildings, the following design guidelines should be followed:

- The north-facing side should be used for storerooms and other little used areas, to create a **buffer zone.**

- The south-facing side should contain the most commonly used rooms, including the living room, the kitchen, and the bedrooms.

- The east-facing side of the building should contain rooms that are used mainly in the morning.

- The west-facing side should contain rooms that are used mainly in the evening.



A building that demonstrates the idea of using a Buffer Zone, situated on the north-facing side, to help insulate the building

For individual rooms, where possible, the following design guidelines should be followed:

- Glaze the south-facing walls

- Reduce as much as possible the window area on the east and west facing walls

- Avoid glazing on the north-facing side.

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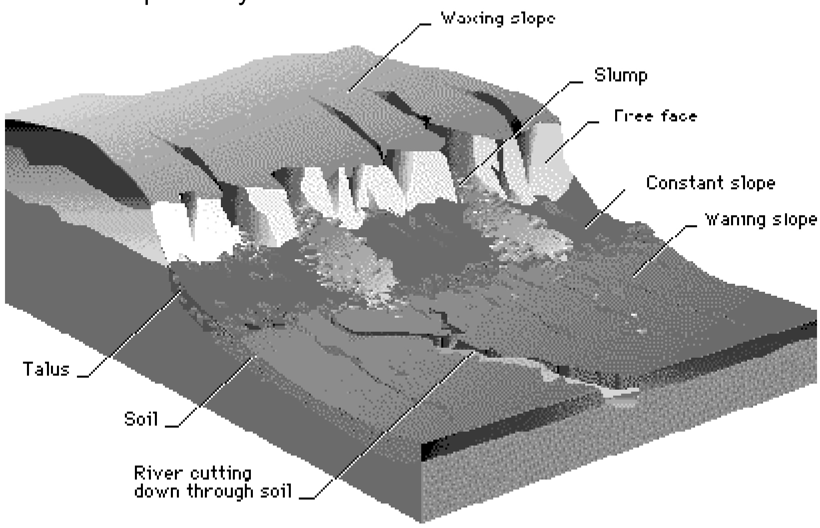
II Site Selection

A site is selected taking into account two main criteria: the **natural risks** and the amount of natural and man-made objects that influence the **shading** of the proposed building.

II.A. Natural Risks

All landscapes are subject to natural processes such as **erosion** by water and wind, and by **precipitation** (rain and snow).

In certain locations, erosion may be unusually fast, either because the **slope** of the land is very steep, the natural binding effect of tree and plant roots is absent, or the area is subject to heavy precipitation or is in close proximity to rivers and streams which overflow their banks.



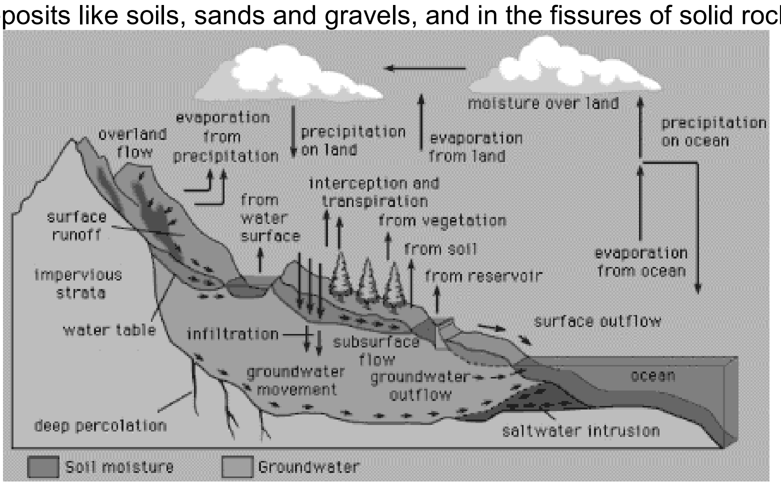
Common Slope Development Processes.

A site is safe for construction purposes if there is no risk of:

- Floods
- Landslips
- Landslides

Groundwater

Groundwater is water found below the surface of the land. Such water exists in pores between sedimentary deposits like soils, sands and gravels, and in the fissures of solid rock.



Before commencing construction, make sure that the ground is dry, and that the **water table** is at least 8 feet beneath the surface. This will ensure that the building **foundations** remain dry, and the building does not suffer from **damp**. Take care in villages near to large rivers such as the Shey in Ladakh, and the Gandaki, in Mustang.

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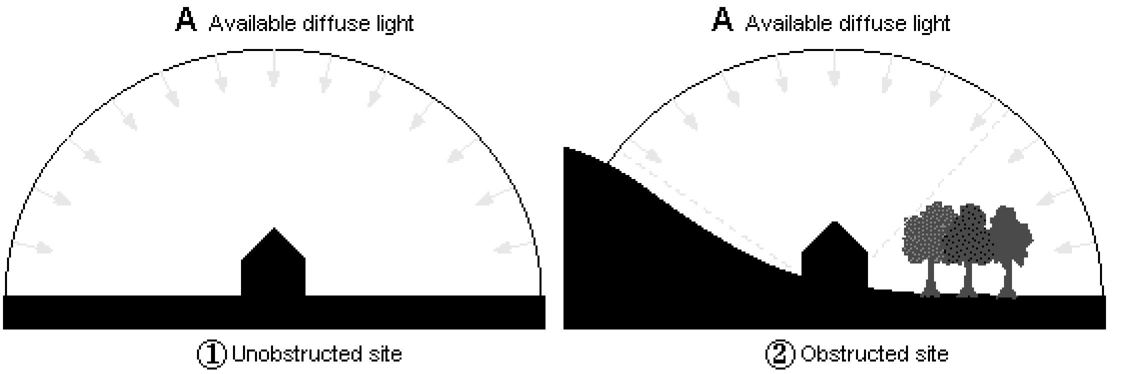
II.B. Additional Influences of Local Site Conditions

The amount of sunlight available to a building during the day is dependent on a number of factors.

- The presence or absence of obstructions that **shade** the building from the sun
- The **slope** and **orientation** of the site
- The **reflectivity** of surfaces next to the building

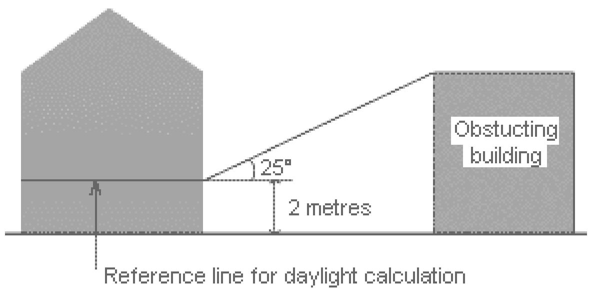
Shading

The presence of large obstructions, such as hills, trees, mountains, and neighbouring buildings can significantly reduce the amount of sunlight reaching a building.



In addition, the presence of neighbouring buildings or obstructions, even those to the north of the building, can reduce the amount of **diffuse** sunlight (indirect sun) that reaches the site.

There is a quick way of checking whether a neighbouring obstruction will have a significant effect on the amount of sunlight reaching a building.



First, measure up to a point 2 metres from the ground on the building you wish to fit passive solar components to (or fix a piece of wood at the same height, if the building has yet to be constructed). Then, estimate the angle of an imaginary line stretching from the reference line to the top of the obstruction. If the angle is more than 25°, not enough light will reach the proposed building (you can check this more accurately using a **clinometer**). In some cases, even if the angle is more than 25°, it will still be possible to construct a successful passive solar building - if the width of the obstruction is small enough to allow sufficient sunlight around its sides (a tree, for example).

Shading Survey In The Peak Of Winter

There are three hard and fast rules that can be applied in selecting a site for a passive solar building. Conducting the following **observations** during mid-winter will give a very clear idea of whether the proposed site is free from **adverse** shading conditions.

- **Sunrise** is before 9am, the **sunset** is after 3pm, and the sun is not shaded during the day.
- The land is suitable to passive solar building if the **sunrise** is before 10am and the **sunset** happens after 2pm, and the sun is not shaded during the day.
- <u>DO NOT</u> select a site where the **sunrise** is after 11am or the sunset is before 1 pm, or the sun is shaded for more than 2 hours between 10am and 2pm.

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Slope

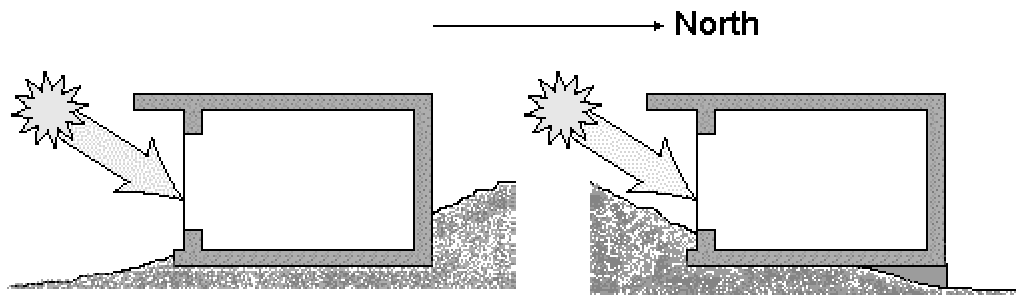
The **slope** of the land influences the amount of sunlight received on the surface. **Horizontal** (flat) surfaces receive more radiation in summer than in winter. Vertical surfaces receive more or less radiation according to the time of day – in other words, the angle of the sun in the sky.

Proportionately, a horizontal window (a skylight) will collect three times as much sunlight as a vertical window. It also distributes light into the inside of the building more evenly than a vertical window. However, because the sun is higher in the sky during the summer months, a horizontal window collects too much heat and light during the summer, which can make the building too hot. By making sure windows are completely vertical, the maximal amount of sunlight can still be collected during the winter, when the sun is lower in the sky.

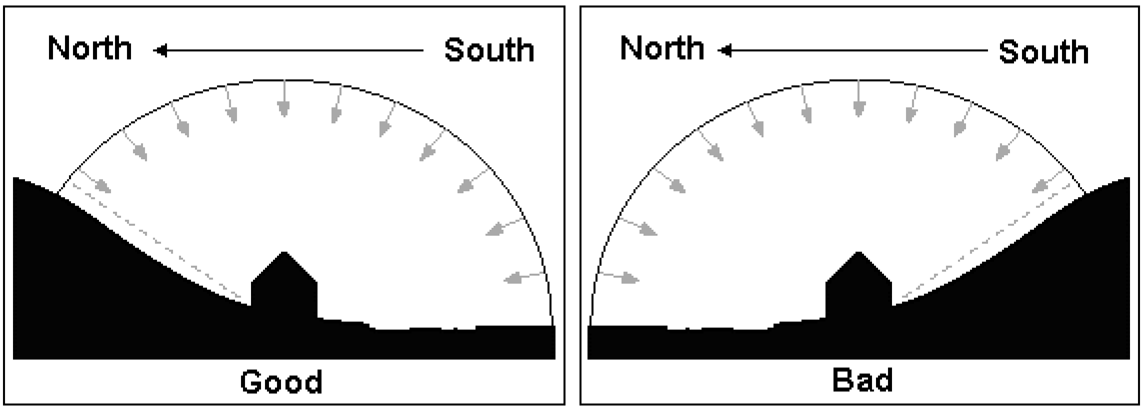
To ensure the window area is as vertical as possible, buildings constructed on a slope should be built in the following ways:

• If the upward slope is north-facing:
Dig the building into the northern part of the earth, so that a part of the north wall is underground.

• If the upward slope is south-facing:
Dig the building into the southern part of the earth, and elevate the northern side.



A site where the upward slope is north-facing is more suitable than one where the upward slope is south-facing, because a slope that rises to the south will reduce (**attenuate**) the amount of sunlight received by the building:



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III. The Thermal Properties Of Materials

III.A. Three Fundamental Modes Of Heat Transfer

Materials are able to exchange energy in different ways:

- **Conduction**: heat transfer through a material

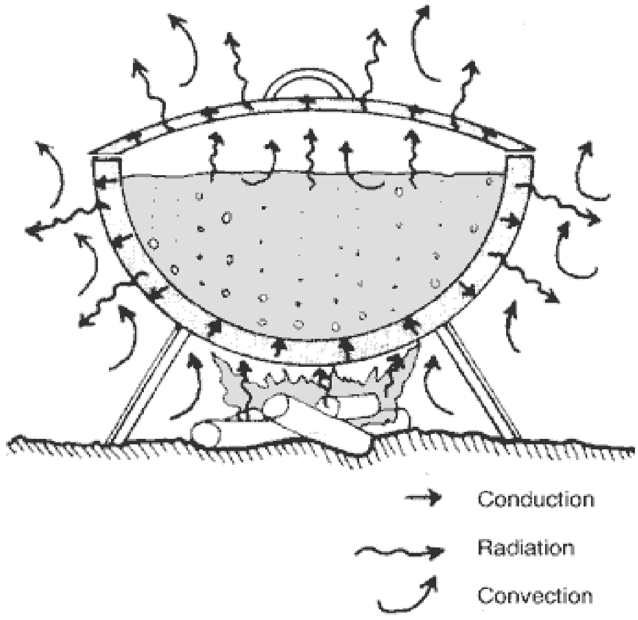
For example, in winter, the external air is colder than the internal air of a house. Some heat goes out through the wall of the house by conduction.

- **Convection**: heat exchange between the surface of a material and the air

For example, the hot surface of a bukhari heats the surrounding air by convection.

- **Radiation**: energy (heat) exchange through the air by radiation between two surfaces

For example, warmth you feel from fire, the sun, and the bukhari, is radiation.



III.B. The Thermal Behaviour Of Materials In Construction

Opaque materials

These are materials that only allow the transfer of energy through them by conduction.

Examples of these materials are brick, straw, stone.

The **conductivity** (ability to transmit heat) of a material increases with its **density** (density is a measure of the weight per unit of volume).

For example, if 100 units of heat are conducted through a 40cm thickness of stone, only 4 units will be transmitted through the same thickness of straw, because straw is considerably less **dense** than stone.

The are two distinct types of material in passive solar building:

- Dense materials (brick, stone), which can **conduct** and **store** heat

- Low-density (light weight) materials which do not conduct heat (**insulators)**, but which also can not store the heat.

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Dense materials

The dense materials are also the **load-bearing** materials in construction – they can support the **load** (weight) of roofs and walls. Dense materials can *usually* support more load than less dense materials. However, the denser the material, the quicker the conduction of heat will be through the material.

Since we know that denser materials are better conductors of heat, we can make informed choices about which type of materials will be better for use in a passive solar building.

For example, because stone is denser than mud-brick, we know that mud-brick buildings will be warmer than stone buildings, because the heat is **conducted** more rapidly through stone, and is therefore **re-radiated** (in effect lost) into the outside environment more quickly.

Energy (in this case, heat) takes a certain amount of time to be transmitted from one side of a wall to the other. This is known as the **lag time**.

For example, it takes 12 hours for heat to be conducted through a 35 cm thick mud-brick wall. The **lag time** is therefore 12 hours.

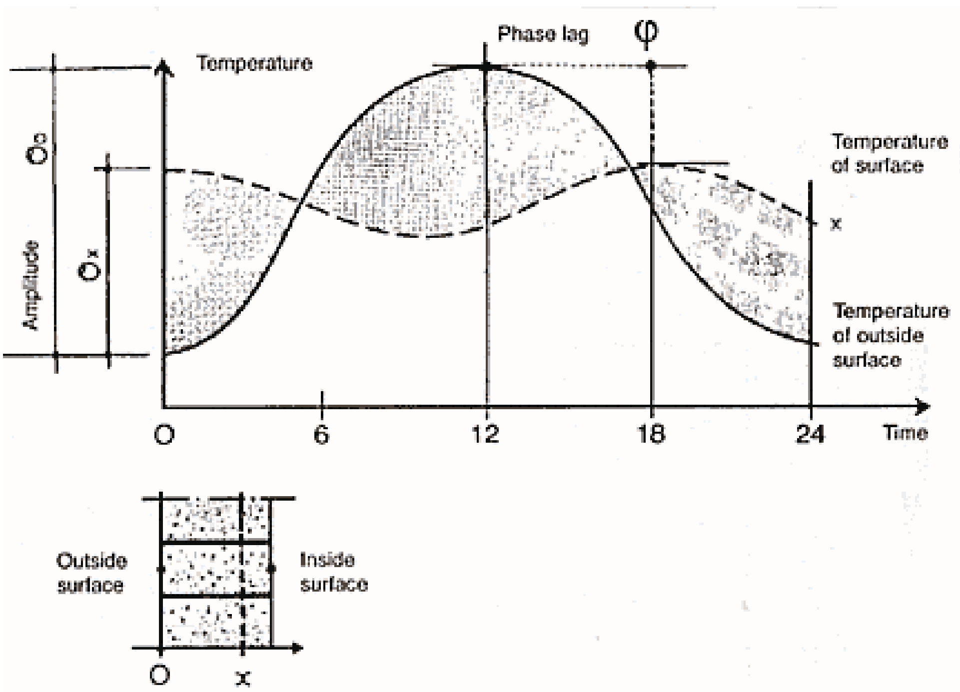

Diagram illustrating the lag time and the changes in wall temperature over a 24 hour period

This makes mud-bricks an ideal choice for passive solar buildings, because it means the cold of the night reaches the inside rooms during the day, and the heat of the day reaches the inside rooms during the night. The room temperate is therefore maintained at a comfortable level throughout a 24-hour period.

In other words, the heat of the days sunshine is **stored** in the walls while they are heated by the sun. This heat is then released into the interior during the night.

MATERIAL	**Heat transferred in comparison with stone for the same thickness**	**Thickness required for an equivalent insulating effect**	**Thickness required for a 12 hour lag-time**
Stone	100	1m	50cm
Concrete	48	48cm	45cm
Mud bricks	28	28cm	35cm
Wood	8	8cm	-
Straw	4	4cm	-

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Transparent materials

These are materials that **transmit** solar radiation, in other words they allow radiation to pass through them. Examples of materials that transmit solar radiation are glass and **transparent** polyethylene.

Transparent materials are characterised by their **transmittance** (τ), which is the level of transmission of **incident radiation**, i.e. the amount of sunlight that passes through the transparent material:

τ glazing = 0.9
τ polyethylene = 0.8

The transmittance is high when the sun is perpendicular (or up to a angle of 30°) but decreases strongly when the angle is over 50°.

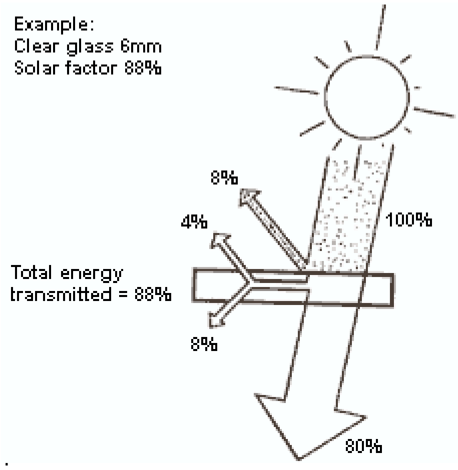
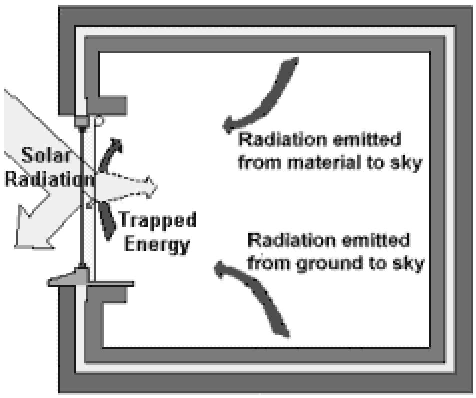


Diagram illustrating the transmittance of sunlight through glass.

The Greenhouse Effect

This important characteristic of glass makes it a basic material for the majority of solar systems. The majority of **incident** solar radiation is transmitted through a pane of glass. This radiation heats the inside surfaces of the glazed room.



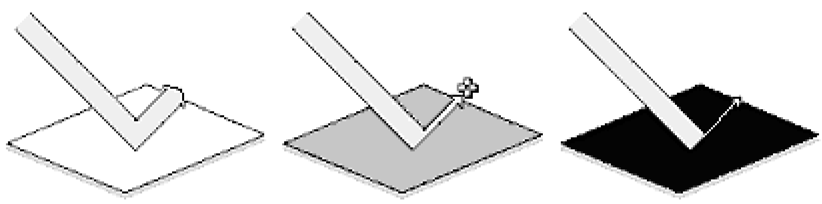
The inside temperature rises because the radiative heat losses from the inner surfaces to the outside environment are re-reflected into the room by the glass. Therefore, once solar radiation has been transmitted through the glass it cannot be transmitted back through the glass. This is because the wavelength of the radiation is changed during its passage through the glass.

The greenhouse effect works with polythene, but the process is 50 % less efficient than with a glass cover.

III.C. Absorption

The amount of solar energy **absorbed** by a material is linked with its colour. The colour white reflects most of the suns radiation, while black absorbs most of it.

The proportion of the sun radiation absorbed by a specific colour is called absorbivity.



COLOUR	ABSORBIVITY
White	0.25 to 0.4
Grey to dark grey	0.4 to 0.5
Green, red, brown	0.5 to 0.7
Brown to dark blue	0.7 to 0.8
Dark blue to black	0.8 to 0.9

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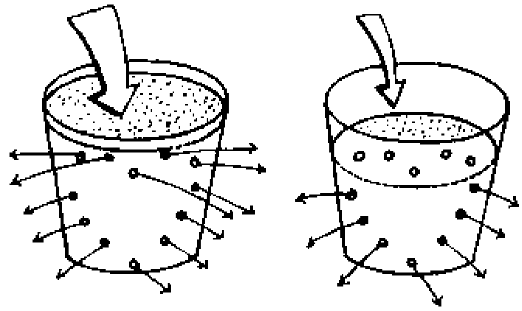
India

IV Insulation

In theory, to increase the interior temperature of a building all that is needed is a sufficient increase in the size of the solar collection area (e.g. the amount of glass). Theoretically, this should provide sufficient heat for storage within the walls, thus maintaining interior temperature over a long period. However, because of the way materials behave, this premise is false, because heat is continually lost from the building, through convection and conduction, to the outside environment.

To minimise these losses, another basic parameter comes into play, particularly at night or during cloudy days: **insulation**.

Insulation helps to keep the warmth inside by limiting the heat losses. Those losses are caused by conduction through walls or glazing, or by the infiltration of air between the inside and the outside of the building, which removes heat through convection.



The analogy of the leaking bucket is very relevant to explain the theory of insulation. In the analogy, the energy in the building is the amount of water in the bucket.
If there are no holes in the buckets, the water level is maintained: so the amount of energy inside the building does not decrease.

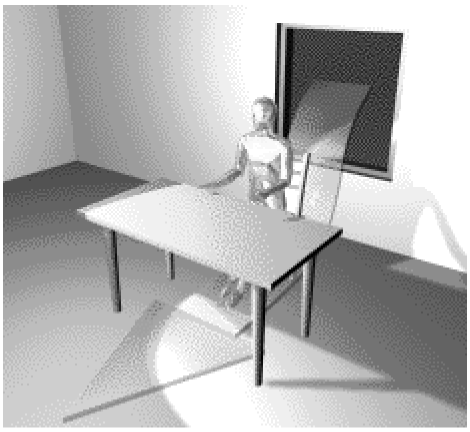
But if the bucket leaks, the water drains out, and the heat drains out the building, so the temperature decreases. The slower the bucket leaks, the less the water level drops, and the heat losses are less important (in other words, the insulation is more efficient), and the temperature remains higher.

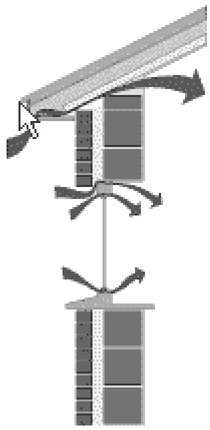
There are several measures that limit heat losses from a building:
- Controlling air **infiltration**
- Thermal insulation of glazing
- Wall and ceiling insulation

IV.A. Infiltration

Infiltration refers to the air **exchange** between the inside and the outside of the building: the cool external air enters into the room, **displacing** the warm air inside, and therefore reduces the interior temperature.

Cold air can also infiltrate through doors, and through door and window frames. However, a tightly sealed building does not maintain enough clean oxygen-rich air inside and the inhabitants will not feel comfortable.





Key sources of infiltration loss.

Infiltration is caused by air leakage between:

1. Glazing and wood frames
2. Wood frames and walls
3. Leakage in the door openings
4. Doors and wooden door frames

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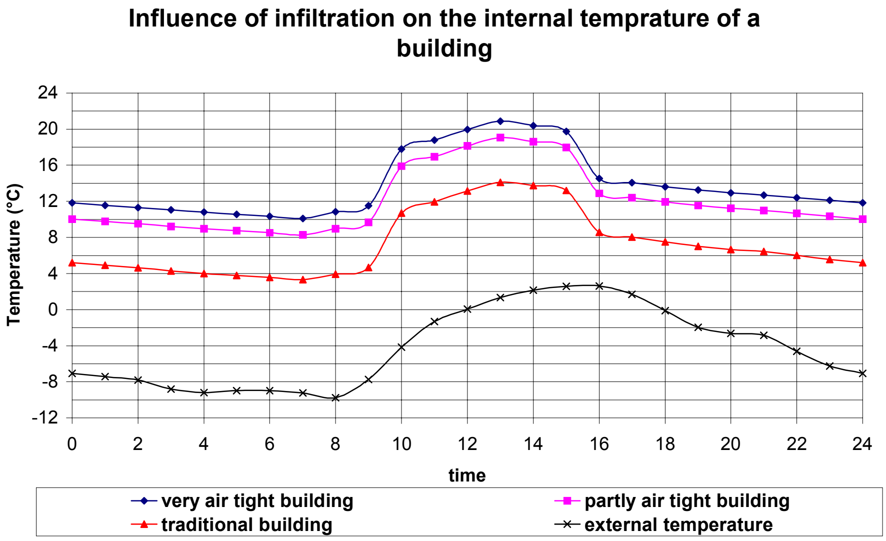
User behaviour has a great effect on the size of the losses caused by air replacement, and leaving a door partly open causes rapid drops in interior temperature. In general, users have a poor understanding or sensitivity to this problem and this, coupled with rapid ageing of doors and windows, give rise to relatively high infiltration losses in passive solar buildings in the Himalaya.

The infiltration rate depends directly on the quality of fixtures like doors and windows. If the carpenters and masons are skilled and aware of infiltration losses, the heat losses can be limited. It is easy and cheap to reduce infiltration heat losses.

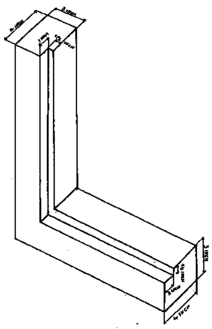
In Ladakh, because of the quality of construction and the behaviour of the inhabitants (the door is often opened), the heat losses due to air infiltration are very important factor in the



temperature of the building.

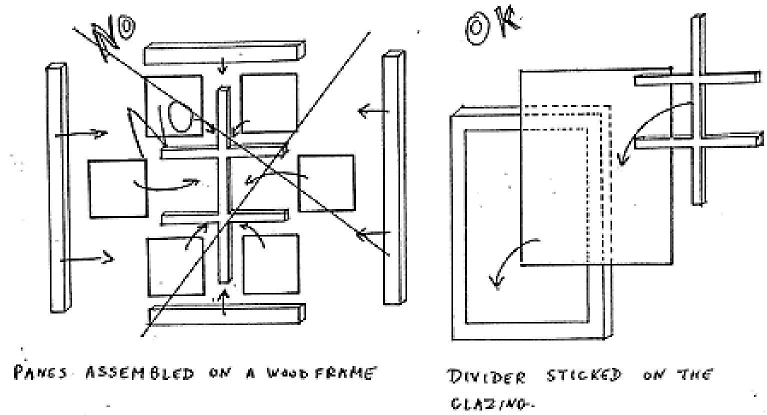
Reducing Infiltration Losses

Glazing and wooden frames



- Select a wood of good quality (Karu).
- The wooden frame section should be at least 4 inch x 3 inch, if less, the structure may bend.
- Cut a 1 inch deep and ½ inch thick band in the inner periphery of the outer side (see picture). If double-glazing is used, the size of the band is 1 ½ inch deep and ½ inch thick.
- Fill the joints between the glazing and the battens, and between the battens and the wood frame with putty.

If the glazing area is important, the infiltration will be reduced if the whole glazing is one single pane on which a divider is fastened, and not several small panes assembled in a wood frame.



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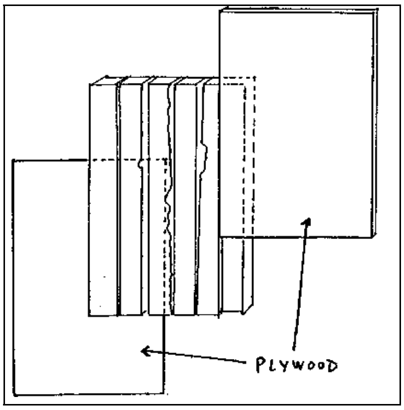
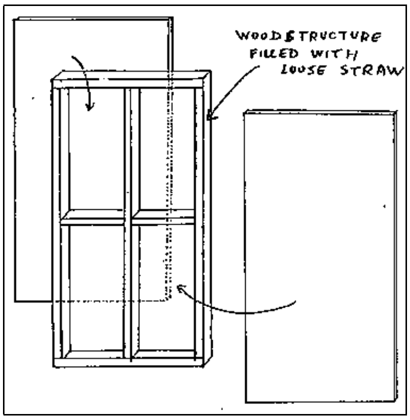
Leakage from the door

If the door is constructed with planks, the leakage between the planks increases the infiltration rate. A simple and cheap way to retrofit the door is to nail a plywood sheet on the external side of the door.





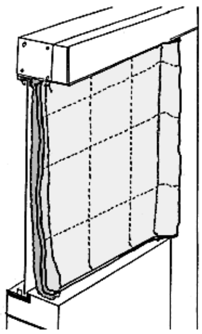
A more efficient door can be constructed in the following way:
- a plywood sheet (4mm)
- a wood structure (2 inches thick) filled with straw
- a plywood layer

IV.B. Glazing

In a insulated building, windows are one of the greatest sources of heat loss. Direct gain passive solar heating can be 100 % more effective if:

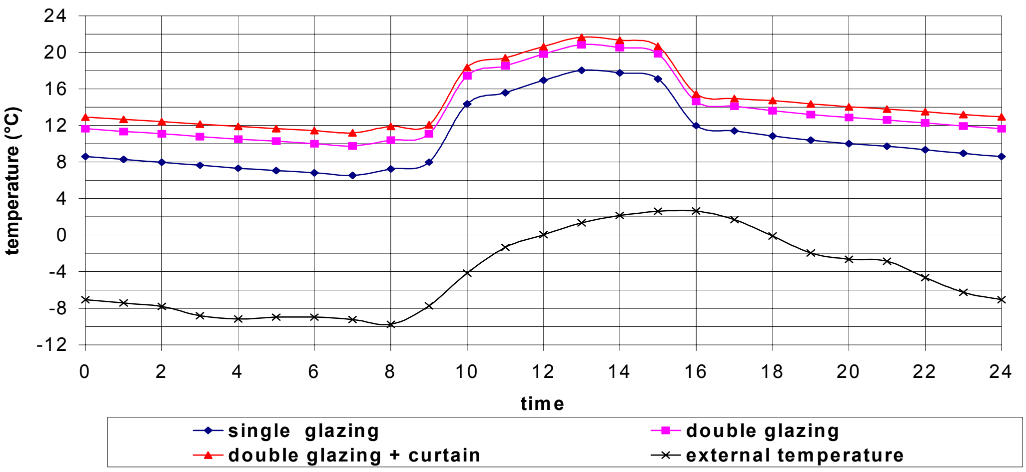
- single glazing is doubled by using polyethylene or fitting double glazing made from glass,

- night time insulation is placed in the window (curtains or blinds).



Using Glazing Successfully

The effect of different glazing types on temperatures inside the building



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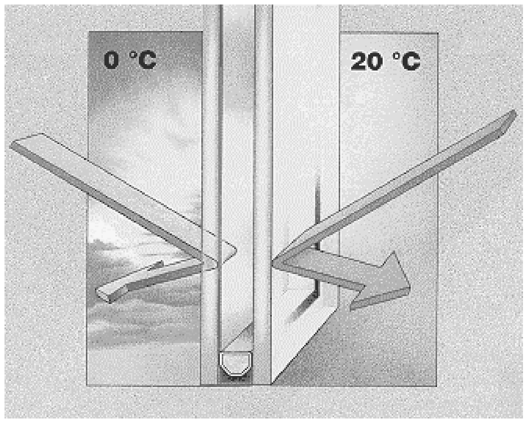
1. Double glazing (in new constructions)

- Select a wood of good quality (Karu) with a section 4 inches x 3 inches.
- Cut a 2 inch deep and ½ inch band in the inner periphery of the outer side.
- Take accurate measurements (as the glazing will expand with the heat), and reduce the length and width of the glass by 4 mm, to account for the expansion.
- Put the first layer of glass in the grooves in the wooden frame and fix it in place with wooden battens.
- Fill the joints between the glazing with putty and fasten battens to the wooden frame to hold the glass in place.
- Put the second layer of glazing on top of the wooden battens. Fix the second layer of glass with another layer of battens and fill the joints with putty.



2. Glazing doubled with polyethylene membrane (new construction or retrofitting)

- Select a good quality polyethylene, similar to the covers used in greenhouses.
- Put the polyethylene on the external side of the wood frame.
- Nail the polyethylene at the top of the wood frame.
- Tighten the polyethylene, make sure that the polyethylene is not in contact with the glazing, and nail the other sides.

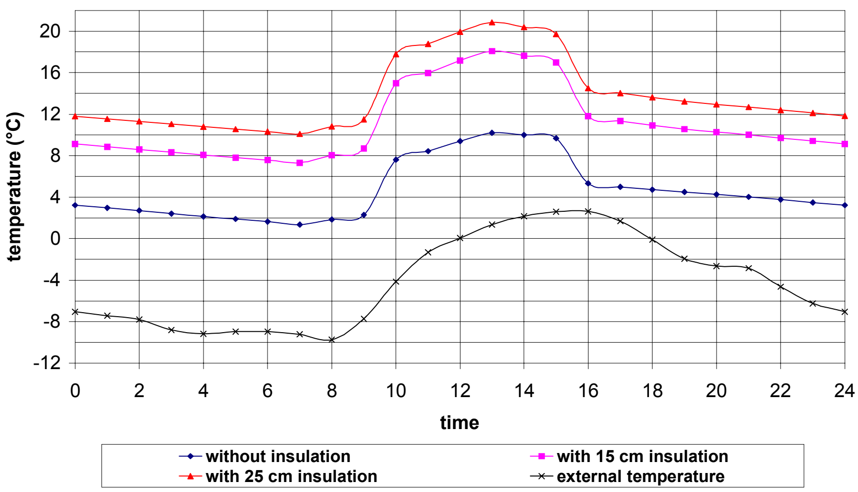
3. Night insulation

The simplest approach to moveable insulation is a curtain or blanket. Open the curtains in the morning as soon as the sun raises and close them when the sun goes down to prevent heat losses (see picture above).

Curtains can also prevent infiltration losses: make the covers oversized so they seal snugly all the way around the window. Hang curtains so they operate easily and fit tightly at the top of the window. Buttonholes can be put along the top edge for hanging and the curtain can be rolled up by fastening a cord pulley system every metre.

Make sure the curtain does not in touch the glazing: an air gap has to remain between the glazing and curtain, but the curtain should seal snugly with the walls all the way around the window.

Influence of insulation thickness on the internal temperature of a building



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IV.C. Wall And Ceiling Insulation

1. Walls

There are several distinct types of walls:

a) Partition Walls

The adjacent room is a buffer zone where the temperature level is much higher than the external temperature level. Less insulation is required.

b) The wall is buried partially underground

The ground is usually at a higher temperate than the outside air, so less insulation is required.

c) The wall is south oriented

See chapter V

d) The wall is external and east, west or north oriented

In this case, the wall has to be carefully insulated.

2. Wall insulation

a) Insulation materials

The best insulation materials are low-density materials, such as straw. The potential insulation materials in Ladakh and Mustang are:

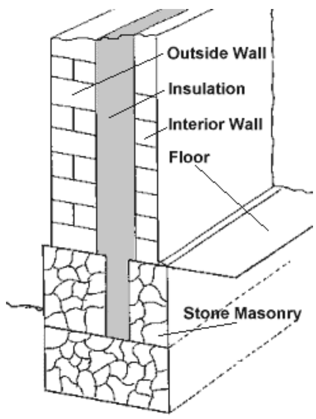
- barley and wheat straw
- mustard straw and husks
- wild bushes
- *Yagzee*
- Sawdust and wood shavings

Some of these materials are already used as animal fodder. Try to estimate if you can use them for construction without disturbing the animal fodder system. All these materials are organic, so they will rot if they become wet.

b) Wall Design

An insulated wall is composed of **three** layers:

- ❑ an external wall to protect insulation from animals and rain
- ❑ an insulation layer
- ❑ an internal wall for thermal storage



This type of wall is known as a **cavity wall**, and it is filled with insulating materials. The external wall is the load-bearing wall and protects the insulation layer from moisture and animals. The internal layer is the thermal storage layer, which stores the heat from the sun, and releases it progressively into the interior. It is constructed of materials, which allow a gradual release of heat – for example mud-bricks. The insulation layer is 15 cm thick for buildings used during the day and 30 cm for buildings used during the night. The insulation of the foundation and the lower 60 cm of the wall is a mix of the selected insulation material (2/3) and seabuckthorn (1/3) in order to protect from rats. The upper part is filled with the selected organic material packed loose, without any compression.

The first week the insulation level decreases under its own weight, so fill it again, compress it slightly by hand, and again add some insulation material until the insulation reaches the level of the top of the wall.

c) Foundations

The foundations are composed of 40 cm deep stone masonry that is 5 cm wider than the thickness of the wall to be built on top of the foundations. This part is underground. The first 50 cm of the wall above the ground is also built in stone masonry, but with a cavity. Again, the external part is 5 cm thicker on each side than the external wall and the internal part is 5 cm thicker on each side than the thermal storage wall that will be built above it. The cavity is filled with the same mix of seabuckthorn (1/3) and straw (2/3).

3. Ceilings

A traditional roof is composed of the following materials, from top to bottom:

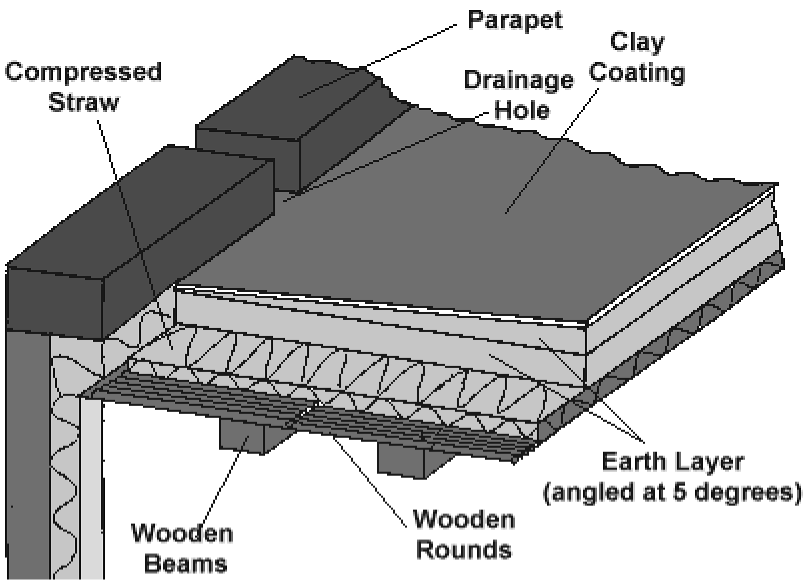
- beams
- local wooden rounds (*talboo* or *bailes)*
- straw or insulation material (except sawdust)
- earth
- a clay coating for waterproofing
- parapet around the periphery

The recommended thickness for the insulation layer is 10 cm for buildings used during the day and 20 cm for building used during the night.

This is the effective thickness of the insulation layer after compression. The compression is usually a factor of 2 but it can vary according to the material and the stem length.

The thickness of the earth layer is at least 15 cm. The layer is slightly tilted to the backside to drain out the rain so make openings in the north parapet every 1.5 metres.

The earth layer is covered by a 1-inch clay coating to protect the insulation material and the interior of the building from water infiltration.



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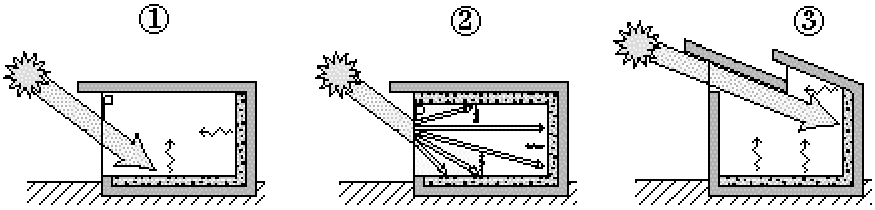
V Types of Passive Solar Installations

V.A. Direct Gain

Direct gain is a simple way to heat a building during the day.

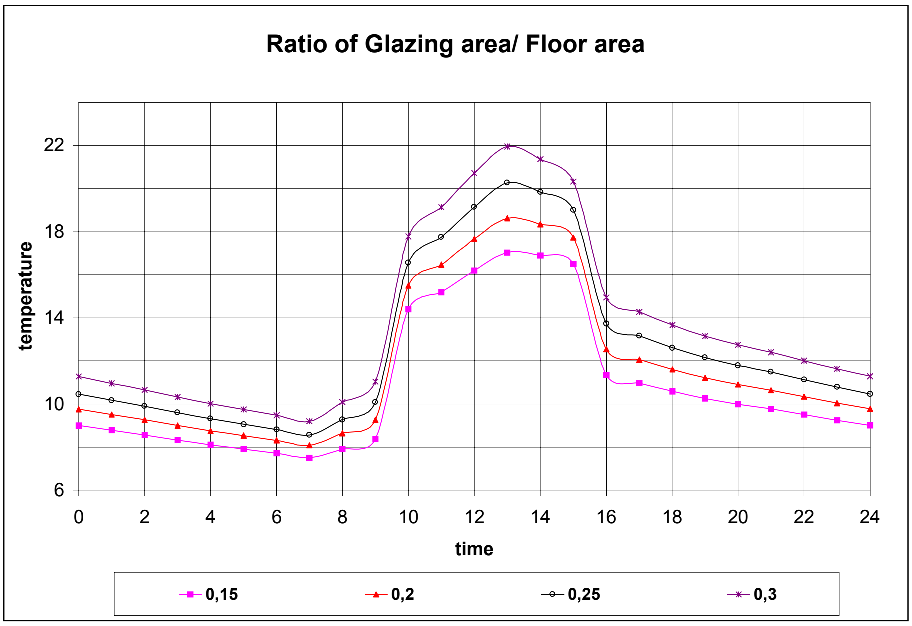
South facing windows admit the sun radiation directly into a living space.



Types of Direct Gain Buildings

Those buildings are comfortable the day but cold during the night. They are day-use buildings. The most important side of the building is the south face area – the larger the area, the hotter the building is during the day. The area is calculated according to floor area of the room.

In Leh: $\dfrac{\textit{south glazing area}}{\textit{floor area}} = 0{,}2$



The glazing area is calculated without the wooden frame and divider. If the glazing is oversized, the temperature will be too hot.
The area of window in the east and west-facing areas should be as small as possible. Avoid glazing on the north side.

Application
- day use
- evening use

Positive aspects
- cheap
- easy to construct

Negative aspects
- cold during the night
- cold during cloudy days

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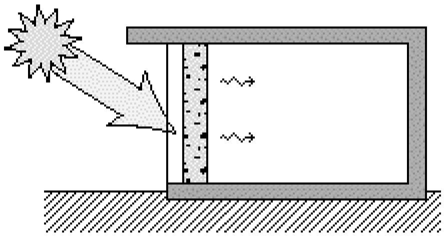
1. Thermal mass

A passive solar heated building admits the solar radiation through the glass and stores it in a dense material, the **thermal mass**, which will release it later: this reduces the temperature fluctuations of the building: the building will be less hot at midday, and more comfortable after sunset.



Thermal mass is dense material such as mud, earth and stone: it is the load bearing wall, partition and floor. The thermal mass should be well distributed throughout the building. Keep the walls clear of posters and pictures.

For each m² of south facing glass, install at least 6 m² of thermal mass.

Thermal mass, coupled with insulation, is a much more efficient way of heating a building than the simple direct gain designs.

2. Window insulation

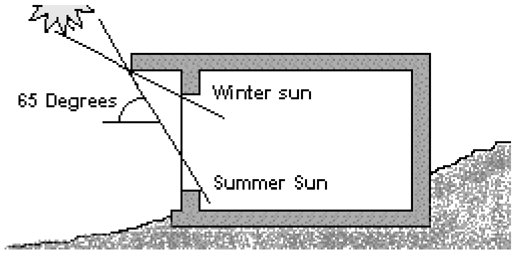
Glazing is the greatest source of heat loss in a passive solar building. The effectiveness is doubled if:

- the glazing is double or an extra polyethylene membrane covers the single glazing,
- a curtain or blanket is added during the night.

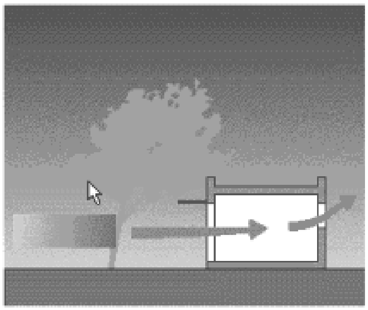
3. Cooling

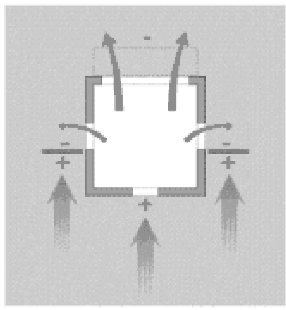
Extremely valuable in the winter, south-facing windows can overheat the building in summer time. This can be avoided if:

- a generous eave provides shading by blocking high summer sun but still admits low winter sun for heating,

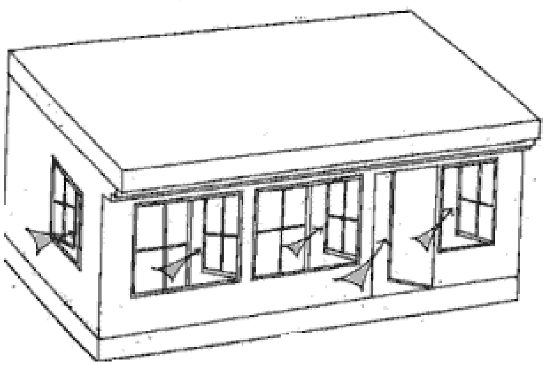


- plan enough operable windows or vents to allow cross ventilation,





- trees shade windows with their leaves in the summer and let the sun through the branches in the winter.



4. Construction

Wooden frame

- Select wood of good quality: Karu
- The section is 4 inches x 3 inches. If less, the structure may bend.
- Cut a 1 inch deep and ½ inch thick band in the inner periphery of the outer side. The glazing is pinned to the back.

If double-glazing is fitted, the size of the band is 1 ½ inch deep and ½ inch thick.

Glazing

- Take accurate measurements and, because the glazing will expand with the heat, reduce the length and width by 4 mm.
- Fix the glazing on the wood frame with wooden battens.
- Fill all the air gaps between the glazing and the battens, the battens and the wood frame with wood. The infiltration will be limited.

If the glazing area is important, the infiltration will be reduced if the whole glazing is one single pane on which a cosmetic pane divider is stuck, not traditionally with several small panes assembled in a wood frame.

V.B. Attached Greenhouse

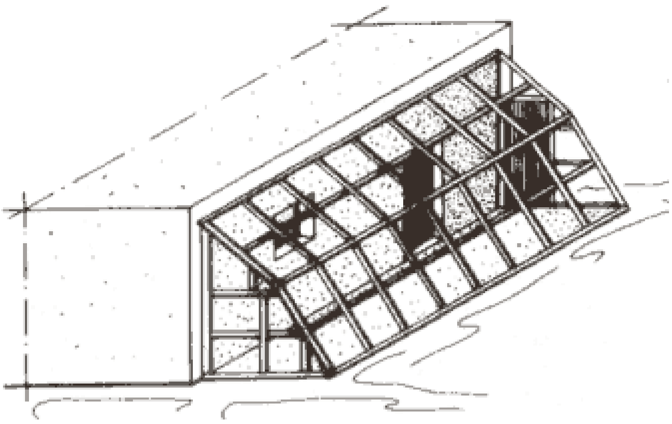
High temperatures are achieved in the greenhouse during the day.

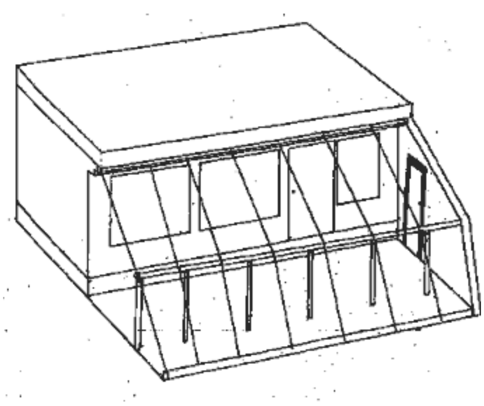
By adding openings (windows, holes) the warm air from the greenhouse is transferred to the interior through these openings. Nevertheless, it is important to cover the opening during the night because the greenhouse will be colder than the building. If not all the heat will be lost through the hole.

The dividing wall can be considered as a low efficiency solar wall so painting the external surface of this wall a dark colour is recommended.

The greenhouse can be used during the day and the adjacent rooms remain comfortable during the day and night. Vegetables can not be grown in an attached greenhouse. The moisture emitted by the crops would damage the building.

The attached greenhouse can be built in two configurations:





- with glazing and a wooden frame, the greenhouse is fixed all year,
- with polyethylene the greenhouse can be dismantled in spring.

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The second option is cheaper. However, the life of polyethylene is only four years and then it has to be replaced.

Application:

- greenhouse: day use
- adjacent room: day and night use

Positive aspects:

- cheap
- easy to construct or retrofit

Negative aspects:

- fragile
- short life (4 years).

Construction of an attached polyethylene greenhouse

The wind, blowing from the west, can damage the polysheet. To reduce the risk of damage, the east and west sides of the greenhouse are constructed with mud bricks. The door is built in the east wall. The plastic cover is a single sheet. It is a supported in the middle by a wood beam. The upper angle is around 50 – 60 ° and the lower angle is around 70 – 80 °.
The wood beam is polished or covered by cloth in order to not damage the plastic cover.

Side Walls

For a durable solar greenhouse, it is best to have solid mud or stone side-walls on the east and west sides of the greenhouse. This adds strength, particularly in strong winds. It also adds to the thermal mass of the greenhouse so that it will remain warmer after sunset.
The negative effect of solid side walls is that they shade the greenhouse in the morning and evening.

Doors

In Ladakh, the wind usually blows from west to east. The door should be located on the east wall to protect it from the wind. If the wind usually blows from a different direction, then the door should be moved accordingly.

Support Frame

The frame to support the polythene greenhouse should be fixed securely to the building, and all the posts should be buried in the ground to keep them in place. The posts along the front edge of the greenhouse should be spaced at approximately 1.5m intervals to give good support without wasting materials.
The frame should be in contact with the polythene at all times, if it is rough then it will very quickly damage and tear the polythene. This is because they rub against each other in the wind. This can be prevented by either by smoothing the wood of the frame or by covering it in soft material such as cloth.
It is recommended that the frame be made from wooden struts, although other materials can be used (pipe, tubes etc) if they are strong enough.

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Covering Membrane

Polythene

- Polythene should be resistant to UV radiation (so that it is not damaged by the sun). It should be thick and strong. The polythene supplied by the Horticultural Department is perfect.
- The angle of the polythene sheet is important. The angle of the sheeting should be correct or too much of the suns light will be reflected off the polythene, rather than going through. It is recommended that the lower part of the polythene is at 60° to 90° above horizontal, to catch the most sun in the morning and evening. The upper part of the polythene should be at 30° to 60° to best catch the afternoon sun.
- The polythene needs to be fixed well to the all the sides of the frame. It is important to make a close fit to avoid infiltration of air.

The upper edge of the polythene can be wrapped around a long piece of wood and then securly nailed to the building. It is important that the wood makes a good fit and that the polythene does not have nail holes on the outside. The lower edge of the polythene can be held down by bricks, stones and earth to make a good fit against the ground . It is important that the polythene is not cut by stones, so use cloth or soft earth between the sheet and the ground.

The sides of the polythene have to be attached to the side walls of the greenhouse. The best way to do this is to make a frame that fits onto the top of the sloping wall and the polythene can then be attached securely to this.

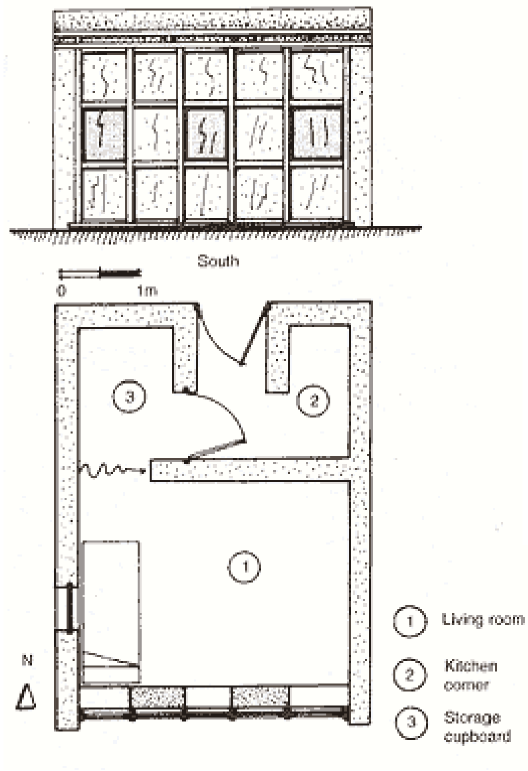
- Keep the polythene clean, both when the greenhouse is first being made, and during its life. If the polythene is dirty, sunlight cannot pass through and it will not work well.

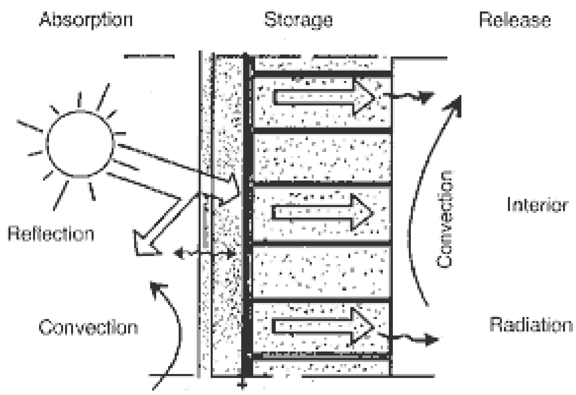
V.C. Solar Wall

A solar wall is a south oriented black painted glazed wall. The black painted wall catches the sun radiation and by the glass covering, the wall remains insulated from the climate outside so the heat is stored and migrates slowly to the inside.

Therefore, the solar wall is a system of delayed heating: the energy is stored during the day and will be released the night after a lag period. The temperature of the main room can be maintained after the daylight periods.

Direct gain panes are also included in the wall to provide enough light to the living space.





Application

- nocturnal heating
- main / bed room
- bathroom
- poultry farm with attached greenhouse

Positive aspects:

- very efficient

Negative aspect:

- unattractive
- costly
- little light enters inside the room

From inside to outside the house, the solar wall comprises:

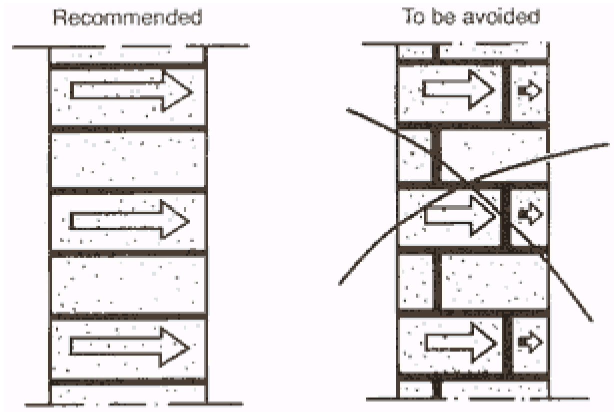
- a wall made of mud brick or stone and black painted on its outer surface
- a 5 cm x 10 cm section wooden frame, anchored in the wall. This frame forms a trellis on which the glass is placed
- glazing on the wood frame

Construction

The wall

The wall is built of dense material. The recommended thickness is:

- mud bricks 20 to 30 cm
- earth 25 to 35 cm
- stone 30 to 40 cm

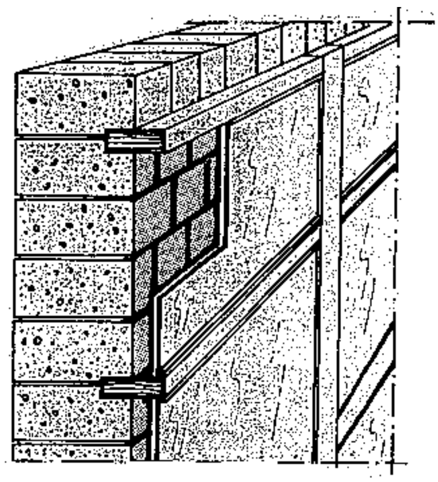


If mud bricks are selected, place them perpendicular to the wall so only one layer is used.

Avoid an air gap: the horizontal and vertical jointing is done with as thin a mortar as possible. Seal all the air gaps with mud.

Wood frame

A 5 cm x 10 cm section wood frame is anchored 5 cm deep in the wall. This frame forms a trellis. A band is cut on the inner periphery; inside which the glass will be placed.



Plaster

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The outer surface is then plastered with a traditional mud coating, or with a cement coating. The black colour can be made with commercial paint or as a hash mixed with oil.

Check the quality of the outer layer thoroughly. As the temperature amplitude is very pronounced, the coating may deteriorate, especially near to the wooden frame.

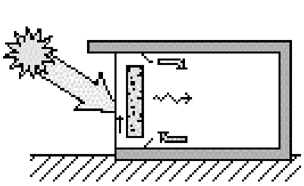
Glazing

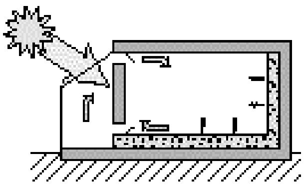
Glazing is placed on the wood frame and fixed with battens. These battens must be carefully positioned so as to form a dust-proof seal over the whole surface of the building, while leaving sufficient play (2 mm) all round the glass panes so that they do not break because of thermal expansion.

Use of an existing wall is possible if the thickness and composition are as recommended above.

V.D. Trombe Wall

A Trombe wall is a ventilated solar wall.

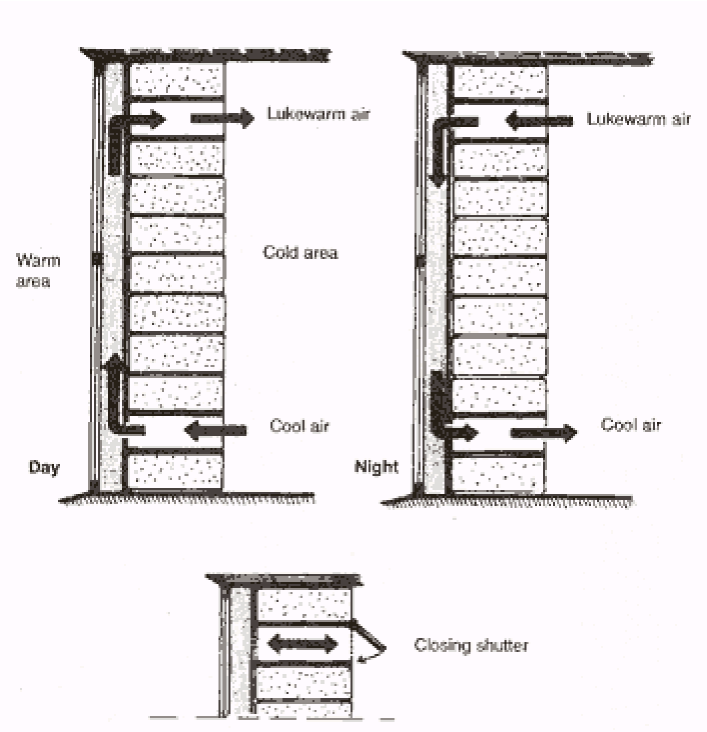




There are openings in the top and bottom of the wall.

During the day, the air trapped between the glass and the wall heats up and rises (warm air tends to go up).
This allows a **convection current** to flow: the cool air of the building is drawn into the lower part of the Trombe wall and returned to upper part of the building, with a significant increase in temperature.

The circulation is reversed during the night so the openings have to be closed after sunset until sunrise.



The convection current means that heating can be provided as soon as the sun rises in the morning, and as a result a room heated by a Trombe Wall is warmer during the day than a similar room heated by a Solar Wall. Trombe Walls are colder the night, however, overall an increase in efficiency of around 10% is obtained (as compared as Solar Wall).

Application:
- day use
- nocturnal heating
- bathrooms

Positive aspects:
- very efficient

Negative aspects:

- unattractive
- costly
- very little sunlight enters the room, so interiors can be dark
- glazing can easily become dirty because of dust carried in the convection currents

Construction

Contrary to the solar wall (where the wooden frame is built in the wall), a 5 cm air gap remains between the wall and the wood frame to allow efficient air circulation. The wooden frame is anchored in the ground and at the top of the wall.

Walls

- The construction of a Trombe Wall is very similar to that of a solar wall. See the section on solar wall construction.
- The wall should be painted black.

Wall Openings

- The main difference between a Trombe wall and a solar wall is that the trombe wall has ventilation openings to allow hot air to enter the building.

- It is recommended that the area of the ventilation holes should be approximately 2% of the total surface area of the wall.

- These openings should be placed all along the bottom and the top of the wall. Openings should be the size of one brick, (usually 30cm x 15cm). The openings at the top and bottom should be identical - therefore the total area of the ventilation holes at the top of the wall should be equal to 1% of the total area of the wall, while the holes at the base should also equal 1% of the total area of the wall.

  EXAMPLE:
  - If the wall is 3m tall and 4m long, then it has a total area of 12m².
  - The total area of the top openings should then be one percent of this, i.e. 12m² / 100 = 0.12m² = 1200 cm².
  - If one opening is 30cm x 15cm then the total area for one opening is 450cm²
  - The number of openings will be the **total area for all the openings / the area for one opening.** i.e. 1200 cm² / 450cm² = 2.6 = about 3 openings at the top.

- This will be discussed more clearly during the workshop.

- The openings should be opened during the day and closed at night.

This is because during the day the air trapped between the black wall and the glass gets hot. This hot air then rises up and into the room through the top openings. The air in the wall is then replaced by the cold air that was sitting in the bottom of the room and comes in through the openings at the bottom of the wall.

At night the air in the wall gets cold and the openings have to be closed to stop the cycle happening in reverse and cooling the room.

- The openings must be closed tightly; this can be done using cloth, shutters or a brick with cloth to close the gaps.

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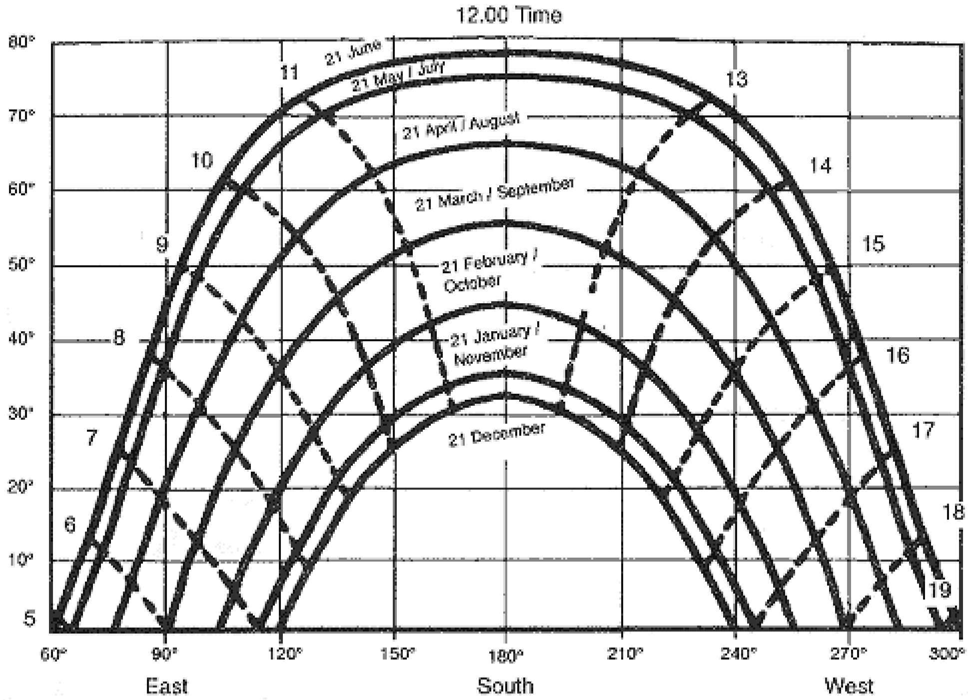
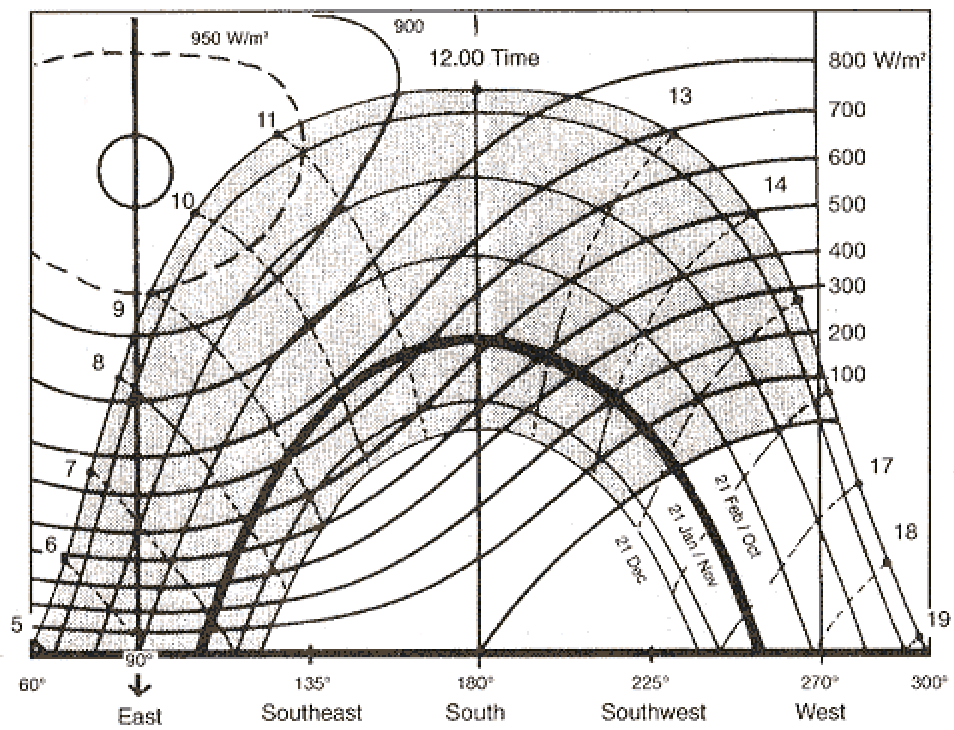
Wood Frame

- In Solar wall, the wood frame is fixed inside the wall. In Trombe wall, a gap remains between the wall and the wood frame to allow the air to circulate. The gap between the wall and the surface of the frame should be at least 5cm.
- The frame is constructed as explained in section VC. The size of the glazing pane can be 2 feet by 2 feet.
- The frame is fixed on ground, on the roof and on the sides.

Appendices – Solar Diagrams



Solar Diagram for Leh (Latitude 35^{o} North)



Solar Indicator for Leh

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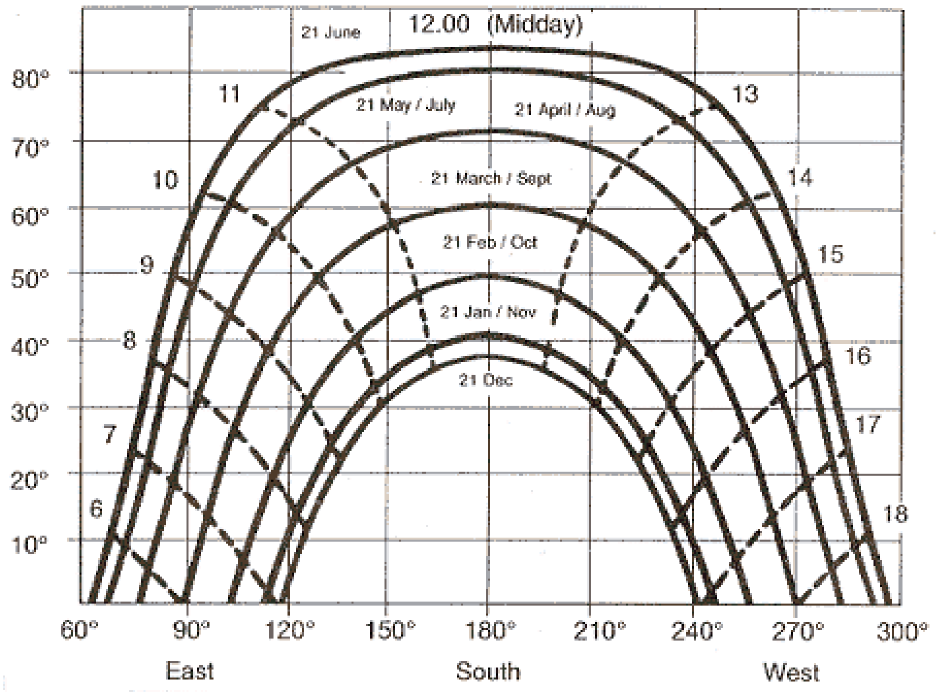
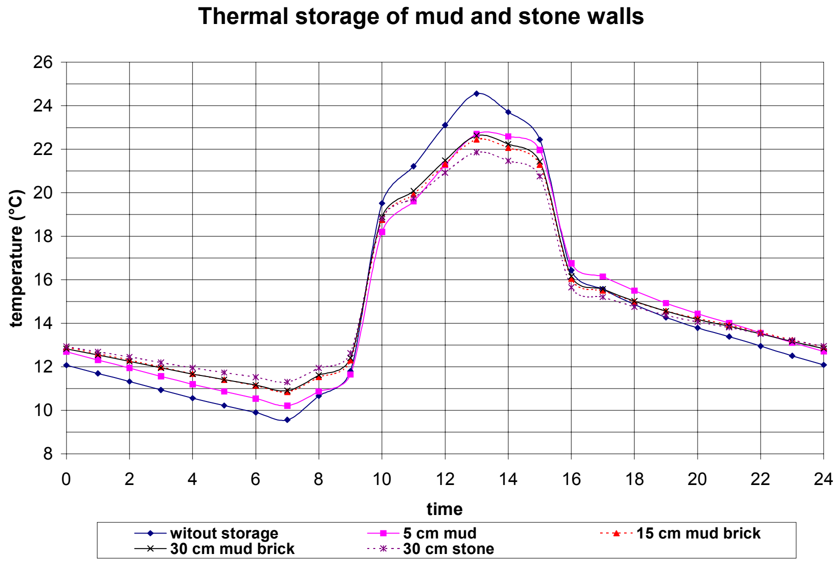


Solar Indicator diagram for 30° Latitude (Mustang lies at approximately 28° Latitude North)



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References

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Cover Photo: Andrew Webb

Textual References

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Data

Data collected on the VTC built in Chuchot by LEHO and GERES and monitored by ApTIBET and TERI during the winter 1999/2000

Thermal simulation using © TRNSYS software.

Data collected by LEDeG at the LEDeG Hostel (Leh) during the winter 1996/1997