

Part A

Theory of Passive Solar
Greenhouses for Cold
Areas

THE PASSIVE SOLAR GREENHOUSE CONCEPT

The amount of solar radiation that reaches any particular point on the earth's surface during an average day depends on a number of factors including the length of the day, the height of the sun in the sky, the amount of cloud, the elevation of the site, the angle of the site with respect to the sun, and the presence of objects (like hills, trees, or buildings) that cast shadow. A solar greenhouse aims to trap and intensify the heating effect of solar radiation and thus enable plants to be grown that cannot be grown under the normal (outside) ambient conditions. Thus solar greenhouses are particularly useful in areas like the trans-Himalayas where there is a lot of sunshine in winter, but the air is too cold for growing crops.

There are four main factors that work together to make a solar greenhouse (or any other building) an efficient user of the available energy (Figure 4).

- Collection of the maximum amount of solar radiation during the day (1)
- Efficient storage of the heat collected from the sun radiation during the day (2)
- Release of this heat to the interior of the building during the night (3)
- Reduction of heat losses by insulation of the whole greenhouse (4)

Collection and Storage of Radiation

One of the major factors affecting the amount of solar radiation entering a greenhouse is the position of the sun in sky. The sun moves across the sky from east to west, it rises in the morning to the east, reaches its highest position at midday to the south, and sets in the evening to the west; and it rises higher in the sky in the summer than in winter (Figure 5).

In the trans-Himalayas, passive solar greenhouses are of most use during winter when growing vegetables is impossible outside; thus they are designed to absorb the maximum amount of solar radiation possible at this time. The sides of a greenhouse exposed to the sun gain heat during the day, while the other sides, in the shade, lose heat. In the summer, when the sun is high in the sky, most of the solar radiation enters the greenhouse through the roof or any other horizontal part, but in the winter, when the sun is low, the maximum radiation enters from the south side: the sun warms the east face during the morning, the south face at midday, and the west face in the afternoon and evening. The north face is always in the shade. Thus an efficient passive solar greenhouse should be designed along an east-west axis (Figure 6),

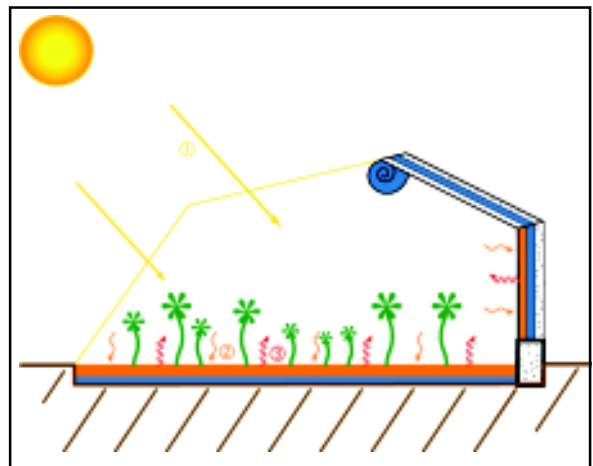


Figure 4: Passive solar concept in a greenhouse

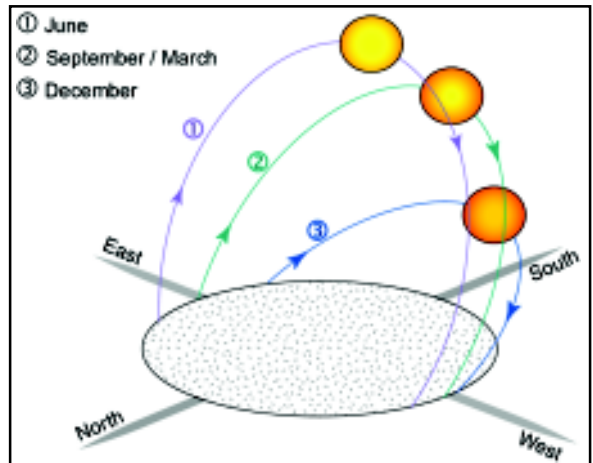


Figure 5: Seasonal variation of solar radiation

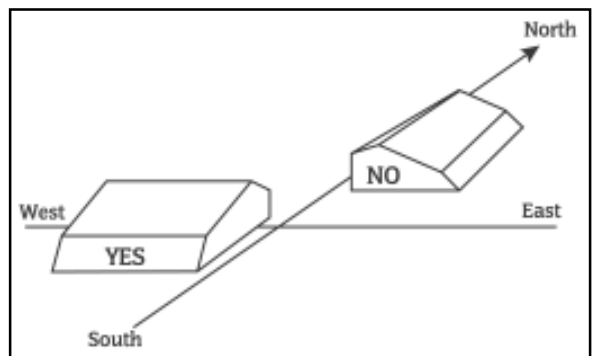


Figure 6: Configuration and orientation of a greenhouse

with the length of the south face increased and angled to present the largest possible surface area to the sun, the size of the east and west facing walls reduced to minimise heat loss and shade inside the greenhouse, and the north wall heavily insulated.

Storage, Release and Containment of Heat: the Thermal Properties of Materials

Different materials are selected for different parts of the greenhouse construction according to their primary function: transmission of radiation, heat storage and release, insulation, and building support. These different properties are summarised below.

Opaque materials

These materials block solar radiation but they can allow transfer of energy by heat conduction. There are two main types.

Dense materials (brick, stone, cement) can conduct and store heat. Except for metals, heavier materials generally store more energy and absorb it faster. In a greenhouse, dense materials are used to provide thermal mass and as load-bearing materials to form the wall supporting the polythene frame and roof.

Low density materials (light materials like straw, sawdust, wood shavings, dry leaves, and dry grass) are poor conductors and storers of heat and are thus good insulators: they help retain the heat inside the greenhouse. These materials are filled into the cavity between the load-bearing wall and the thermal mass wall.

Transparent materials

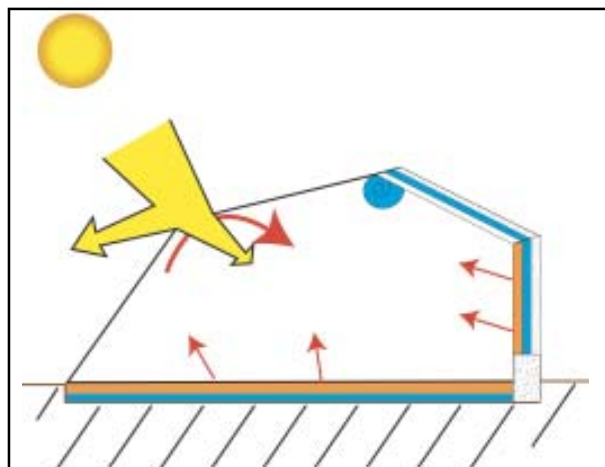


Figure 7: The greenhouse effect

Transparent materials like glass and transparent polythene allow radiation to pass through and are used to transmit radiation from the surface to the inner space of the greenhouse. Transmittance is high when the sun is perpendicular to the surface and up to an angle of about 30°, but decreases strongly at angles above 50°. Transmission is higher through glass (maximum 90%) than through polythene (maximum 80%).

An important characteristic of transparent materials is the **greenhouse effect** (Figure 7), which results from the fact that the transparency depends on the radiation wavelength. Materials can be transparent to solar radiation but not to heat radiation, whose wavelength is infra-red. The majority of **incident** solar radiation is transmitted through the material; this radiation heats the inside surfaces; these release radiative heat which is reflected back into the greenhouse by the transparent material. In other words, the radiation that enters the greenhouse is trapped inside, and heat losses only take place by conduction. The greenhouse effect is strong for glass, but 50% less efficient with

polythene. However, it is much cheaper to cover a greenhouse with polythene. If polythene is used, additional insulation can be added at night to reduce heat loss.

Table 2: Advantages and disadvantages of glass and polythene

	Glass	Polythene
Advantages	<ul style="list-style-type: none"> • higher transmission • less heat loss 	<ul style="list-style-type: none"> • cheap • easy to carry • easy to repair
Disadvantages	<ul style="list-style-type: none"> • expensive • replacement if breakage • difficult to carry 	<ul style="list-style-type: none"> • less efficient • short life (especially windy area) • not biodegradable

Wall colour

The amount of solar energy **absorbed** by a material is linked to its colour (Figure 8). White surfaces reflect most of the sun's radiation, whereas black surfaces absorb most of the radiation. The proportion of the sun's radiation absorbed by a specific colour is called the absorptance.

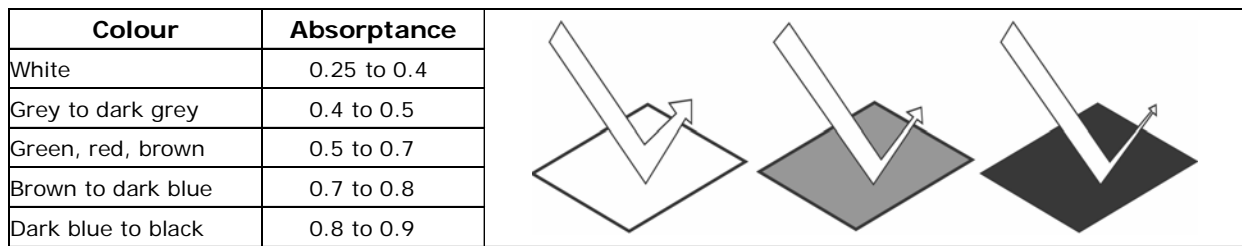


Figure 8: Absorptance related to the colour

PRINCIPLES OF SOLAR GREENHOUSE DESIGN

A passive solar greenhouse is designed to trap enough solar radiation for the photosynthesis process and to provide the interior climatic conditions required for growing vegetables all year round. When the outside conditions are very cold, heat is stored during the day in the ground and walls of the greenhouse and released during the night to keep the greenhouse air warm. During winter, the greenhouse traps enough energy during the day to ensure that the vegetables do not freeze at night. The temperature variation between day and night should be minimised to reduce thermal stress to the plants. Overheating during the day can be prevented using natural ventilation for cooling, regulated by manually operated shutters. Ventilation also regulates the humidity and thus helps to limit diseases and pests.



Figure 9: Inside views of a greenhouse in Ladakh

A passive solar greenhouse

- ❖ picks up solar radiation
- ❖ stores this radiation as heat in the mass of the walls and the ground during the day
- ❖ releases this heat during the night to warm the interior space
- ❖ is insulated to retain this heat
- ❖ can be ventilated to avoid overheating



Figures 10,11,12: Greenhouse structure

The passive solar greenhouse for cold areas described in this manual has three main components, which together ensure that these requirements are met.

- **Walls on the east, west, and north sides** where the amount of incident solar energy is limited. These walls are either buried into a hillside or insulated to limit heat loss and increase thermal storage (Figure 10).
- **A polythene sheet on the south side**, which picks up the largest amount of solar energy. The polythene transmits the majority of incident solar radiation into the greenhouse. This warms the interior space and is absorbed by the vegetables, the ground, and the walls. The sheet can be covered with a moveable layer of insulation like a curtain, cloth, or mat after sunset to reduce night time heat loss. The polythene sheet is set at an angle and supported by a wooden frame (Figure 11).
- **A (solid) roof on the north side** to limit heat loss. The roof is tilted to avoid shading in winter and reduce the interior volume (Figure 12).

Collection of Solar Radiation

Solar radiation is taken up through a transparent polythene sheet covering the south face of the greenhouse. The angle of the polythene is calculated so that the maximum amount of solar radiation is transmitted into the interior. The angle of the lower section of the polythene is 50° or more (measured from the horizontal) – the best angle to transmit solar radiation in the early morning or late afternoon when the sun is low in the sky. The angle of the upper section is 25° or more (measured from the horizontal) – the best angle to transmit the mid-day solar radiation and allow small amounts of snow to slide off.

Moveable insulation (parachute, cloth) is used as a curtain below the polythene after sunset to reduce heat loss; it is removed after sunrise. Moveable insulation can increase the ground and interior temperature at night by up to 5°C. At high altitudes, a double polythene layer can be used to reduce heat loss; it can also increase the interior temperature by up to 4°C at night.

Thermal Storage and Insulation

Several components are used in the design to increase thermal storage and reduce heat loss.

Double wall

The walls are composed of three layers: an **outer load-bearing wall** built with mud brick, rammed earth, or stone; an **inner wall** used to store heat during the day and release it at night, also built with mud brick, rammed earth, or stone; and an **insulating layer** of materials like straw, sawdust, wood shavings, dry leaves, dry grass, or wild bush cuttings pressed between the two.

Colour

The inner side of the west wall is painted white (whitewash) to reflect the morning solar radiation after the coldness of the night; the inner side of the east wall is painted black to absorb and store the afternoon solar radiation, which is then released at night to heat the interior space; and the bottom two feet of the inner side of the north wall are whitewashed and the upper part painted black for similar reasons.

Roof

The fixed roof is sloped (to the north) at an angle of 35° . In winter, when the sun has a low elevation angle, this angle optimises the solar radiation absorption on the inside surface. During summer, when the sun is high in the sky, the roof partly shades the greenhouse and reduces the risk of overheating. The roof is covered with a layer of insulation (straw, or similar); a piece of white cloth or parachute material can be added below it to improve the insulation and reflect solar radiation onto the vegetables. The shape of the roof reduces the interior volume compared to traditional greenhouses, thus increasing the interior temperature.

Ground

The greenhouse floor is dug out so that it lies 6" (15 cm) below the outside surface level. This improves plant growth as the dip acts as a trap for carbon dioxide, as well as providing additional thermal insulation. In extremely cold climates, a 2" layer of dung should be laid four inches below the surface to insulate the ground and increase the thermal mass efficiency. Horse or donkey dung are the most suitable as they contain straw, but yak or cow dung can also be used.

Door

The door is located on the wall opposite to the side from which the prevailing wind blows (the lee side) to reduce infiltration of cold air.



Figure 13: Greenhouse under construction (view of the double walls and the structure of the roof)

Ventilation

On sunny days, the air in the greenhouse can become very warm. Overheating (over 30°C) can damage the vegetables and encourage diseases and pests. Manually operated openings (ventilators) are provided in the lower part of both sides (door, wall shutter) and in the roof. The warm air rises and leaves the greenhouse through the roof ventilator, drawing in the cooler ambient outer air through the lower ventilators (Figures 14 & 15).

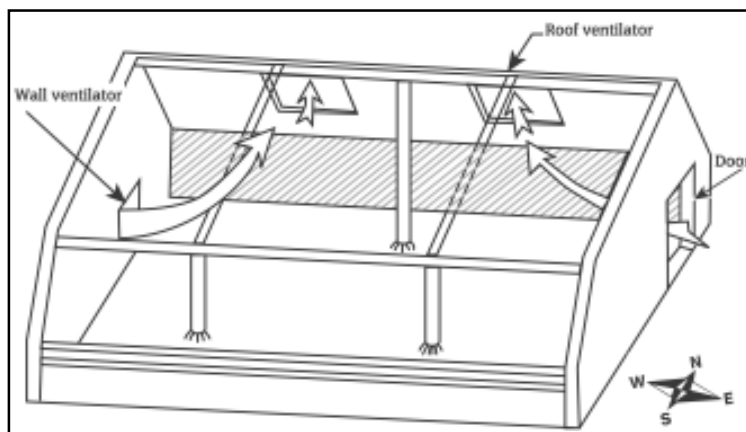


Figure 14: Air circulation in a greenhouse



Figure 15: Opening the roof ventilator

PRINCIPLES OF SITE SELECTION

Characteristics of a Suitable Location

Water supply

Vegetables require water to grow. During the cold winter period, the greenhouse requires less ventilation, evaporation is lower, and more moisture is retained inside, thus only a small amount of water is required. But in spring and summer, the greenhouse is ventilated during daytime to avoid overheating, evaporation is higher, and moisture is lost with the ventilated air, so that a larger amount of water must be given.

During winter and spring, many streams and springs are frozen; it is necessary to ensure that there is a source of running water located close enough to the greenhouse that transportation is not so difficult as to discourage the farmer from operating the greenhouse.

The crucial period is spring, when more water is required than in winter but static sources may still be frozen. The distance to the nearest running water has to be acceptable during this period.

The maximum distance that a farmer can be expected to carry water without it becoming a disincentive is about 600 feet (200m) in winter and 300 feet (100m) in spring and summer.

Solar radiation

Solar radiation is required both for photosynthesis and to heat the greenhouse. If the sunrise is too late or the sunset too early, the greenhouse remains cold for longer and vegetable production is reduced. Nearby obstacles can also shade the greenhouse.

Sunrise must be before 9:30 am and sunset later than 3:00 pm.

Slope and type of land

The slope of the land influences the amount of solar radiation collected, the ground temperature, and the heat loss through the walls.

A site is **suitable** if

- the land is flat and dry
- the land is on a south-facing slope: the amount of solar radiation is increased by the ground reflection, at the same time, the greenhouse is partly underground, the ground is warmer than the ambient air, and heat loss through the walls is reduced
- the land backs on to a south-facing terrace (the drop down from one terrace to the next forms the back of the site): the terrace wall can be used as the back wall of the greenhouse and may support the roof; the benefits are a lower investment cost, warmer ground, and a larger thermal mass if the step is built up using stone masonry

A site is **rejected** if

- the land is on a north-facing slope the amount of solar radiation is decreased
- the land is against a north-facing terrace: the greenhouse has to be oriented towards the north and the benefits will be limited
- the land is marshy: the ground freezes easily in winter and the vegetables may also freeze
- the site is not on agricultural land (stone, sand, or similar)

Site Characteristics that Affect the Design

Wind

If the door of the greenhouse is exposed to wind, infiltration of cold ambient air will lower the inner temperature of the greenhouse.

The door must always be located on the opposite side from the prevailing wind.

Climate (Altitude)

Temperature decreases with altitude, thus a similar greenhouse will be more efficient at lower altitudes than on the high plateau. The design can be adapted to colder climates by increasing the thermal mass and ground insulation and reducing the width, among others.

The greenhouse design should take into account the normal lowest winter temperatures at the site.

Snow

Heavy snowfall can damage the polythene laid over the greenhouse if a considerable weight of snow remains on it. In snowy areas, the polythene needs to slope more steeply so that the snow slips off.

The polythene sheet must slope more steeply in areas with high snowfall.

Selecting the Best Site

A site is suitable for a greenhouse project if all the criteria shown in Table 3 are fulfilled.

Table 4: Criteria marking system

Characteristic	Points	Characteristic	Points
Distance to running water in winter		Sunrise in January	
less than 50 feet	5	Before 7:30 am	8
less than 100 feet	4	8:00 am	6
less than 200 feet	3	8:30 am	4
less than 300 feet	1	9:00 am	2
less than 600 feet	0	9:30 am	0
Distance to running water in the spring		Sunset in January	
less than 50 feet	6	After 5:00 pm	6
less than 100 feet	5	4:30 pm	5
less than 200 feet	2	4:00 pm	4
less than 300 feet	0	3:30 pm	2
Slope			
Site adjacent to a south-facing terrace (terrace wall is between 1.5 and 4 feet high)	5		
South-facing slope	3		
Flat	2		

We have developed a simple selection tool that weights these different factors and provides an easy way of comparing the advantages and disadvantages of different possible sites using the criteria listed above. The different site characteristics are allotted marks according to the list shown in Table 4, and the number of marks filled out in the form shown as Table 5. The total number of marks is calculated; the site with the highest number is the most suitable based on these criteria. Similar sites can then be further differentiated on the basis of other criteria of more specific interest like accessibility, security, distance to workforce, and so on.

Table 3: Suitability of a site for the implementation of a greenhouse project

Feature	Factor	Condition	Site survey
Shade	sunrise (January)	before 09.30 am	
	sunset (January)	after 03:00 pm	
	shade from distant object (hill/mountain) between 9:30 am and 03:00 pm	none	
	shade from nearby object (trees/houses) between 9:30 am and 03:00 pm	none	
Water distance to the nearest water point	December to March	<600feet (200m)	
	April to October	<300 feet (100m)	
Site	flat		
	slope	south facing slope	
	if terraced	site adjacent to south-facing terrace	
	marshy/ dry	dry	
Final decision on suitability			YES/NO

Table 5: Site selection table

Criteria	Description	Score
Distance to water in winter		
Distance to water in spring		
Slope of site		
Sunrise		
Sunset		
TOTAL		

SELECTING THE MOST APPROPRIATE DESIGN

The design of a greenhouse for a specific location is influenced by the site characteristics, the climate, and the expected amount of snowfall. Ten different basic designs have been developed: one for each of the three main types of land in each of three different climates, and a tenth for flat land in snowy areas. Details are provided in Section B.

Essentially there are three shapes of greenhouse designed to fit the three different types of site.

- Shape A for a **flat and dry** site
- Shape B for a **south-facing slope**
- Shape C for a site **adjacent to a south-facing terrace wall**

The designs for different climates focus on reducing heat loss at the colder sites. Three designs are proposed, for cold, very cold, and extremely cold (winter) climates. The altitude range at which these designs are appropriate will differ in different areas depending on the latitude and longitude. As a guide, the climate at any given altitude will be colder in Afghanistan and Central Asia than in Ladakh, and colder in Ladakh than in Sikkim (for example, the temperatures at 2800m in Afghanistan are similar to those at 3500m in Ladakh).

- Design 1 is for sites with a **cold climate**: lowest temperature above -10°C.
Examples: Nubra (Ladakh, India), Lahaul (Himachal Pradesh, India), and Kabul (Afghanistan)
- Design 2 is for sites with a **very cold climate**: lowest temperature -10°C to -15°C.
Examples: Leh (Ladakh, India), Bamyán (Afghanistan), Qinghai (China)
 - Roof insulation layer is increased to 2"
- Design 3 is for sites with an **extremely cold climate**: lowest temperature below -15°C.
Examples: Chang Tang (Ladakh, India), Wakham (Afghanistan)
 - An inner partition is added to increase thermal mass
 - A double layer of polythene is used
 - The ground is insulated
 - Only one roof ventilator is required
- Design 4 is for **snowy areas**.
 - The slope of both roof and polythene are increased to 40° so that snow can slide off on both sides
 - A double layer of polythene is used
 - Only one roof ventilator is required

Table 6 shows a grid for selecting the appropriate design for a particular site. In all the designs the door must be constructed on the wall opposite to the prevailing wind to limit infiltration of cold air. Details of the designs and how to construct the greenhouses are provided in Part B.

Table 6: Select the appropriate design				
Site	Climate			
	Cold min. > -10°C	Very Cold min. -10°C to -15°C	Extremely Cold min. < -15°C	Snowy
Flat	Design 1A	Design 2A	Design 3A	Design 4
South-facing slope	Design 1B	Design 2B	Design 3B	-
Adjacent to south-facing terrace	Design 1C	Design 2C	Design 3C	-

Note that individual variations are possible to suit the specific location and available materials. These include, for example, extending the greenhouse along the east-west axis (as shown in Picture 2), and using different materials for the roof construction. A number of these possibilities are mentioned in the above and in the Technical Datasheets.

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