SOLAR GREENHOUSES FOR THE TRANS-HIMALAYAS

A construction Manual

Vincent Stauffer

About the organisations

ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD) is an independent 'Mountain Learning and Knowledge Centre' serving the eight countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan – and the global mountain community. Founded in 1983, ICIMOD is based in Kathmandu, Nepal, and brings together a partnership of regional member countries, partner institutions, and donors with a commitment for development action to secure the future of the Hindu Kush-Himalayas. The primary objective of the Centre is to promote the development of economically and environmentally sound mountain ecosystems and to improve the living standards of mountain populations.

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GERES

The Renewable Energy and Environment Group (GERES) is a French NGO created in 1976. GERES works in a dozen countries in Asia and Africa promoting renewable energy resources and energy efficiency through a development process controlled by the local people. GERES encourages the use of local resources with the aim of respecting the environment and providing well-balanced development schemes.

GERES has been working for 20 years for the benefit of local development in the Hindu Kush-Himalayas (HKH), with a focus on promoting well-adapted and eco-friendly technologies. The main field activities are concerned with energy saving (passive solar buildings, improved stoves) and income generation (solar greenhouses, solar poultry farming, ecotourism, food processing, processing wool).

GERES first project in the HKH was set up in 1982 in Ladakh (India). At present, GERES supports local NGOs in India, Nepal, China, and Afghanistan in a variety of activities.
Our strategy is based on privileged partnerships with various government and non-government organisations and the participation of the local population. Our projects aim at enabling local communities to earn additional income to access modern services while preserving the fragile environment of the Hindu Kush-Himalayan region.

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Aubagne, France
April 2004

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Published by
International Centre for Integrated Mountain Development
G.P.O. Box 3226
Kathmandu, Nepal
with
GERES (Renewable Energy and Environment Group)
2, cours Foch, 13400 Aubagne, France

ISBN 92 9115 832 1

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Printed by

FOREWORD

Food security remains the major preoccupation of mountain communities in many parts of Asia, especially in the higher altitude and more remote parts of the Hindu Kush-Himalayan region. The climate in this region of the trans-Himalayas is very harsh: winter temperatures can fall below -30°C, and precipitation is low. The natural resources are limited, and farmers rely on sheep, goats, cattle and yak as their main source of survival, with limited subsistence agriculture on very small landholdings focused mainly on cereals. In the winter, snowfall blocks the high passes and roads are closed, and the population must rely almost entirely on its own resources for survival.

Mountain communities have survived for centuries in this environment, but population increases, environmental pressure, and political changes and limitations to movement are increasing the challenge. At the same time, expectations and demands are increasing, as contact with the outside world and more widespread education raise people's awareness of the possibilities and potential benefits elsewhere. The result is increased out-migration, especially of the young and strong; reduced capacity of those left behind to use the land; loss of community, culture, and the indigenous knowledge of how to survive in these harsh conditions; and an influx of people to urban areas to join the growing ranks of the poor and rootless.

The Renewable Energy and Environment Group GERES, supported by its partners in development (European Commission, French Ministry of Foreign Affairs, and others) works with mountain communities to help them establish tools and processes that strengthen and develop local potentials, improve livelihoods, and provide people with better options for remaining in their home areas. Many innovative tools have been developed, improved, and adapted for local use. GERES, working with Indian, Chinese, Nepalese, and Afghan NGOs, has focused on technologies for saving energy (passive solar buildings and improved stoves to reduce consumption of wood and other fuels), and generating income (solar greenhouses, solar poultry farming, processing of food and wool).

One of the major challenges is to help communities use the inactive winter period to increase food security and generate additional income. Fortunately, one resource that the trans-Himalayan area has in abundance is sunshine, especially in winter. Solar radiation can be used to improve the quality of life in many ways. Potential benefits include warming houses, schools, dispensaries and handicraft centres, and developing off-season agricultural activities such as composting, greenhouse production, and poultry farming.

This manual focuses on the construction of passive solar greenhouses that enable vegetables to be grown during winter in the high altitude areas of the trans-Himalayas.

The International Centre for Integrated Mountain Development (ICIMOD) works to improve the livelihoods and security of the mountain communities of the Hindu Kush-Himalayas (HKH). Improving the productivity and sustainability of mountain agriculture, reducing fuel consumption, and reducing environmental damage are central to its activities. As a part of its programme, ICIMOD has had a major focus on rural technologies and alternative energy approaches, including hosting a series of national workshops on passive solar building technologies in four of the countries of the HKH. The new Integrated Programme on Agriculture and Rural Income Diversification (ARID) focuses on high value products, rural enterprises, and renewable energy options, among others. Thus ICIMOD is delighted to have had this opportunity to support GERES in the development of this manual on solar greenhouse technology, and to be able to make this information available to a wider community.

GERES and ICIMOD both hope that this manual will prove useful to the many NGOs and other technical organisations who are working with communities and farmers in the HKH region to improve living standards and conditions, and ultimately that increased access to winter vegetables and exotic summer produce will improve the quality of life and income generation opportunities of many of the small farmers in some of the most marginalised areas of the Hindu Kush-Himalayas.

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Acknowledgements

The greenhouse design proposed in this handbook is the result of improvements made by NGOs and by farmers themselves of a design initially proposed by GERES. The main contributors to this design evolution were marginal farmers of the trans-Himalayan areas, who suggested practical improvements that reduce the investment cost and construction requirements and ensure that the design is appropriate for the resources available in these high mountain areas.

LEHO (Ladakh Health and Environment Organisation) was the first non-government organisation (NGO) to experiment with the model; this NGO did a tremendous amount of work to improve the design and to train carpenters and masons to build greenhouses in remote areas.

The following NGOs contributed greatly to adapting the initial design to suit specific local contexts.

Ladakh (Jammu and Kashmir, India)
- LEHO (Ladakh Health and Environment Organisation)
- LEDeG (Ladakh Ecological and Development Group)
- LNP (Leh Nutrition Project)
- CRO (Chief Representative Organisation)

Lahaul and Spiti (Himachal Pradesh, India)
- Himachal Pradesh Government through the Watershed Project
- Pragya
- Dawa Development

Qinghai (China)
- ATA (Appropriate Technology for Asia)

Badakshan, Hazara Jat, Lowgar, and Parwan (Afghanistan)
- Ministry of Animal Husbandry and Agriculture
- AKDN (Agha Khan Development Network)
- AFRANE Developpement (Amitié franco-afghane)
- SOLIDARITES

Mustang (Nepal)
- ATA (Appropriate Technology for Asia)

The experimentation, implementation, and publication of the manual, would not have been possible without the financial support of the European Commission, French Ministry of Foreign Affairs, SOLIDARITES, Frères de nos Frères, and ATA. In particular we would like to acknowledge the European Commission which has been supporting field projects in Ladakh, Lahaul & Spiti, Mustang, and Qinghai since 1988. We thank ICIMOD for their support and encouragement to publish the manual for wider distribution, in particular Greta Rana – Division Head, IMCO for recognising the potential value of the manual; Kamal Rijal – former Energy Specialist for his support and valuable comments; A. Beatrice Murray – for her editorial support; Dharma R. Maharjan for layout and design; and all the other members of the publications unit.

Finally, it is important to mention that the greenhouse design and the manual itself were developed in partnership with contributions from many individuals, in particular, from GERES, Christophe Viltard and Laetitia Rivagorda, who did the agricultural experimentation; Philippe Rynikiewicz, Benoit Giraud, and Claude Tounellec, who thought of many practical improvements; Rodolphe Castelani, who did the drawings; Thomas Mansouri, who set up the manual; and Alain Guinebault, who initiated the project; from LEHO Tashi Tokhmat, Dorge Raftan, and Gulam Razul, who carried out the first trials, and suggested major improvements; Sjoerd Nienhuys of SNV who made some useful suggestions in a review of different types of greenhouses in Mustang; and all the farmers and construction workers at the different project sites whose enthusiasm, interest, and hard work helped to improve the design and ensured the project was successful.

UNITS AND GEOMETRY

1’	1 ft = 1 foot= 0.3048 m
1”	1 inch = 2.54 cm
1 cm	1 centimetre
1 m	1 metre = 100 cm
°C	Degree Celsius
ø	diameter

Contents

INTRODUCTION

BACKGROUND

The northern parts of the Hindu Kush and Himalayan ranges are mostly cold desert lying between 2500 and 5000 metres above sea level. This area, often called the trans-Himalayas, stretches from Tajikistan in the west to Bhutan in the east, with the Tibetan Plateau in the centre. The environment is very harsh: the winter temperatures frequently fall below -30°C and precipitation – both rain and snowfall – is low (less than 300 mm per year). The natural resources are very limited and the lack of trees and forests results in a very low population density. Even so, some of the highest villages in the world can be found here.

During the short summer season, communities devote their energy to stocking up for the winter. Women spend two months a year on average collecting cow dung from the pastures for cooking and winter heating. The whole way of life is geared towards surviving the long harsh winter. Subsistence farming is limited in most of the area to one crop per year and is focused on barley and wheat with some peas, potatoes, and occasionally other vegetables. The average agricultural landholding is small, less than 0.5 ha per household. The inhabitants of the high altitude plateau depend almost entirely on cattle rearing. Poor transportation infrastructure limits the supply of fresh food in all parts of the region. In winter, snowfall blocks the high passes and the roads are mostly closed; foodstuffs are flown in to the major cities at high cost; in rural areas they are simply not available. At the same time it is very sunny, especially in winter. The solar radiation offers great potential for improving people's lives. It can be used not only to warm the interiors of houses, schools, dispensaries, and handicraft centres, it can also be used as a basis for developing off-season agricultural activities such as composting, production in greenhouses and trench greenhouses, and poultry farming.

In the following, we focus on the design and construction of greenhouses for the Trans-Himalayan region.

What is a Greenhouse?

A greenhouse is designed to provide an environment suitable for growing fruit, vegetables, flowers, or others, at a time when the

Figure 1: Winter view of a high valley in Zangskar, Ladakh

outside conditions are not favourable for the specific purpose. In the trans-Himalayas, the emphasis is on vegetables. Vegetable growing depends on two main factors: solar radiation and climate. Vegetables need solar radiation for photosynthesis, and the interior environment (temperature and humidity) must match the vegetable requirements.

Solar Greenhouses for the Trans-Himalayas

A passive solar greenhouse, or solar greenhouse for short, is a greenhouse heated entirely by sunlight, with no additional fuel-based heating. In the trans-Himalayas, the temperature inside these greenhouses can be kept high enough to grow vegetables throughout the year, even in winter, if the greenhouse is built efficiently. Thus greenhouses can be of great use, particularly in those areas where there are continuing concerns about food security and economic development. The main benefits of solar greenhouses are

- vegetable production in winter;
- fulfilment of basic subsistence needs in remote areas; and
- income generation in peri-urban areas.

The model proposed in this manual is an efficient greenhouse constructed almost entirely with local materials (apart from the polythene and some minor parts like nails and hinges). The initial model was tested, developed, and improved by farmers in Ladakh, India, working together with the non-government organisation (NGO) LEHO (Ladakh Health and Environment Organisation) to reduce the investment cost, facilitate construction, and increase the life span. The improved version was further developed and adapted to the specific local conditions by farmers and NGOs in Lahaul & Spiti and Ladakh in India; Qinghai province in China; Mustang in Nepal, and Badakshn, Hazara Jat, Lowgar, and Parwan in Afghanistan. The designs presented in this manual reflect the experience gained and lessons learned in all these areas. Greenhouses of this type are suitable for use in other areas of the Hindu Kush, Himalaya, and Pamir ranges with a similar climate and socioeconomic situation, such as the high valleys of Sikkim and Arunachal Pradesh in India; Humla, Simikot, and Dolpo in Nepal; the Tibetan Plateau in China; Bhutan; other parts of Afghanistan, Tadjikistan, and Kirghizstan in Central Asia; and Chitral and Baltistan in Pakistan.

Vegetables can be grown in mid-winter even in extremely cold climates where outside temperatures fall below -15°C. In very cold climates like that of Leh at 3500m (minimum temperatures in January of around -15°C) vegetables like spinach,carrots, and onions can be grown in winter. The greenhouse is even more efficient in less cold areas like Kabul in Afghanistan at 1800m (minimum temperature -5 to -10°C) where tomatoes (actually a fruit) can be harvested until January. The average growing efficiency of fresh vegetables is 0.8 kg/m² in very cold climates and 1.4 kg/m² in cold climates. Table 1 shows the typical crops that can be grown in these greenhouses during the year in different climates.

To be useful in development, a solar greenhouse must be adapted to the local context. In other words, it must be financially and physically viable for local people to construct and run without outside support. The following criteria were used to assess whether this need was being met, and to guide development where it was not:

- the materials are locally available (mud, wood, straw, stone), except for the transparent cover sheet;

Table 1: Greenhouse crops in different seasons

Season	Cold (min. >-10°C in winter)	Very cold (min. -10°C to -15°C)	Extremely cold (min. <-15°C)
Winter	Tomatoes if planted in Autumn Root vegetables	Root vegetables if planted in Autumn Leafy vegetables	Leafy vegetables
Spring	Seedlings Root vegetables/ tomatoes	Seedlings Root vegetables/ tomatoes	Seedlings Root vegetables
Summer	Exotic vegetables	Exotic vegetables	Exotic vegetables/ tomatoes
Autumn	Tomatoes	Tomatoes	Root vegetables

Typical examples of vegetables are spinach (leafy), carrots (root), and tomatoes (actually a fruit).

• it can be constructed by local builders;
• the cost can be recouped in less than three years if the production is well-managed and the products sold.

Solar greenhouses can contribute to human development in a number of ways including empowering women, since they are often in charge of the production and the selling; helping overcome nutritional deficiencies by enabling more diversified food production all year round; and providing a means of income generation.

However, a greenhouse is only efficient if it is constructed in the right place and used properly.

Past experience has shown the importance of planning the dissemination method to ensure that the maximum benefit is gained. Points to consider include the following

- Stakeholder selection – focus on
  - communities with poor families
  - innovative and dynamic farmers

- Site selection – consider
  - availability of water (river, wells, canals, snow)
  - availability of direct and abundant sunshine
  - need to adjust dimensions and materials according to the site
  - minimising waste of land at the back of the greenhouse

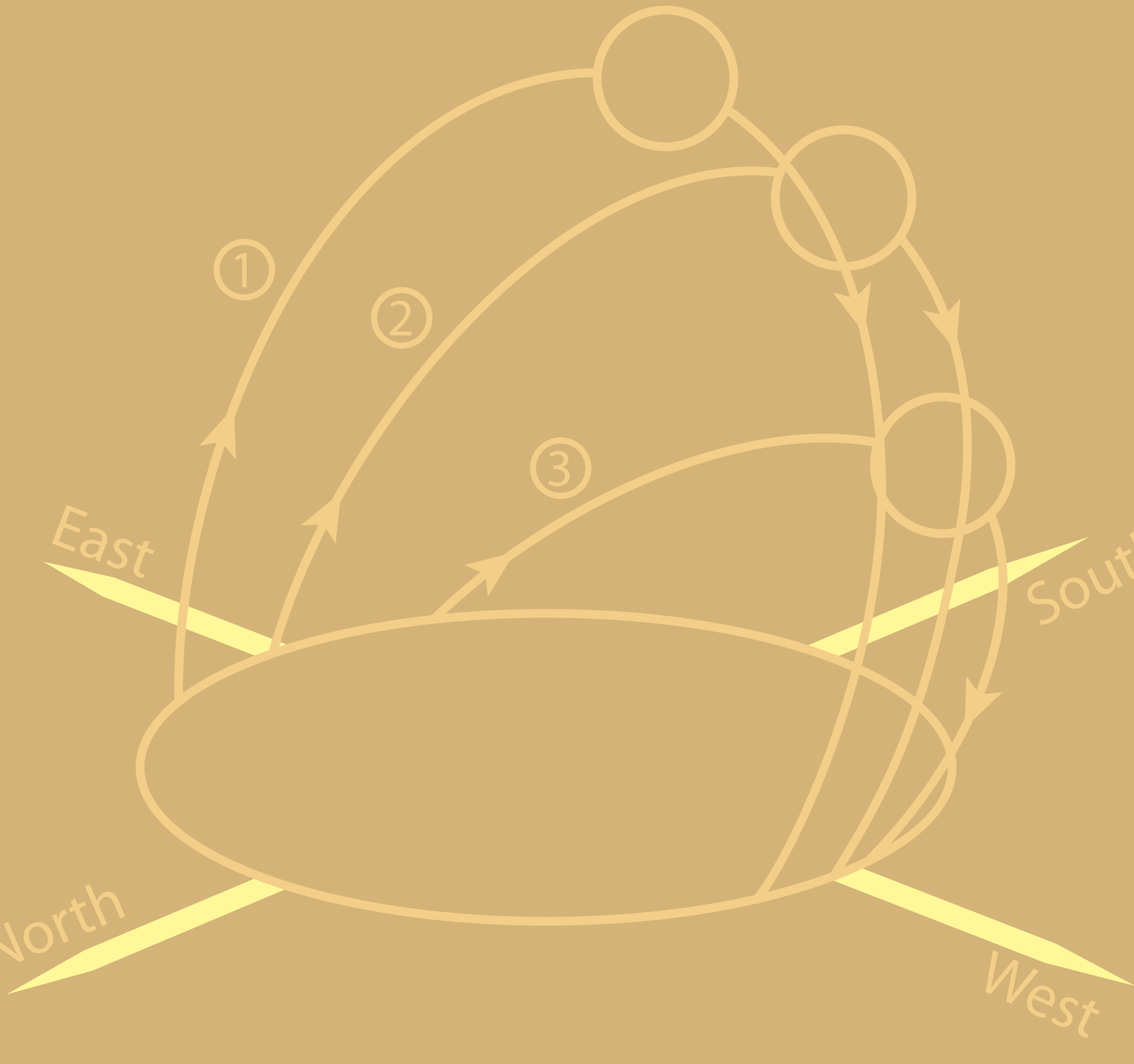
- Setting up of facilities – plan for
  - training builders
  - training farmers in greenhouse cultivation methods
  - developing networks for the supply of seeds, tools, and polythene, and for vegetable marketing

This manual focuses on the guidelines for design and construction of an efficient greenhouse. The economic feasibility, dissemination methodology, and agricultural use will be covered in other booklets (in preparation).

The manual is divided into two parts: a description of the theoretical principles, which provides the basis for understand the concept of using passive solar greenhouses in cold areas and knowing how to select a suitable site and design; and a description of the practical elements of construction with detailed instructions on each step and the points to consider to ensure that the greenhouse is efficient.

Figure 2: Constructing a greenhouse in Afghanistan

Figure 3: Solar greenhouse built in Leh, Ladakh, India


①
②
③
East
South
North
West

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)

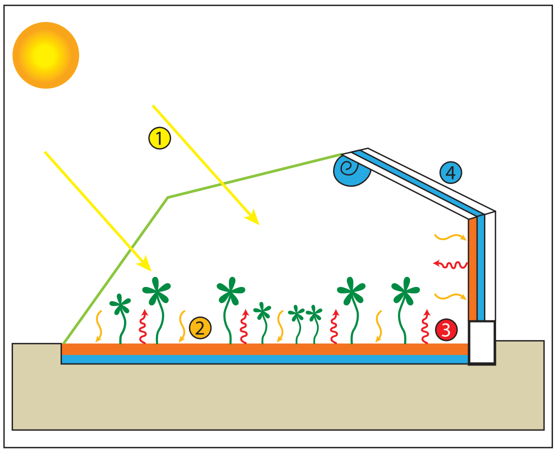


Figure 4: Passive solar concept in a greenhouse

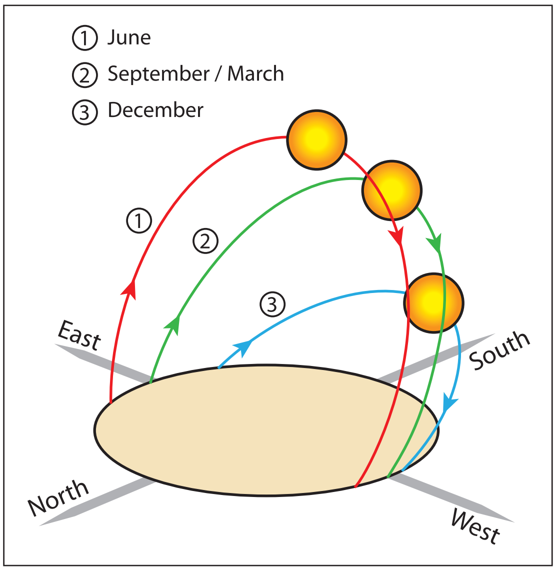


Figure 5: Seasonal variation of solar radiation

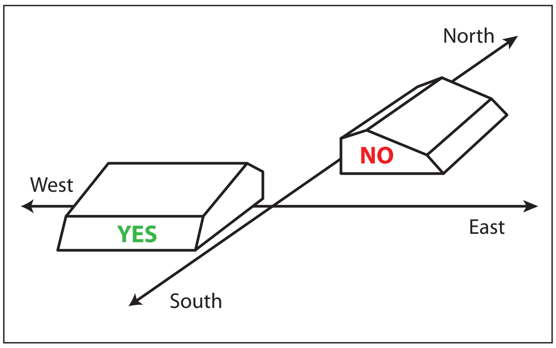


Figure 6: Configuration and orientation of a greenhouse

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), 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: 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 loadbearing wall and the thermal mass wall.

Transparent materials

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

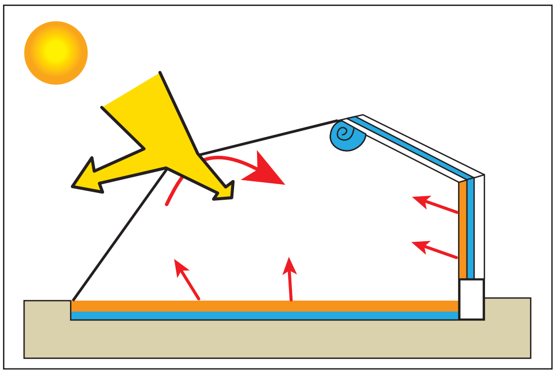


Figure 7: The greenhouse effect

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	• higher transmission • less heat loss	• cheap • easy to carry • easy to repair
Disadvantages	• expensive • replacement if breakage • difficult to carry	• less efficient • short life (in windy area) • not biodegradeable

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.

Colour	Absorptance
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

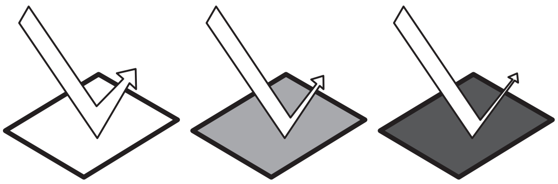


Figure 8: Absorptance related to the colour

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.

Figure 9: Inside views of a greenhouse in Ladakh

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.

A passive solar greenhouse
- ❖ picks up solar radiation
- ❖ stores the 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

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).

Figure 10: Greenhouse walls and structure

• 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).

Figure 11: Greenhouse covered with polythene

• 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).

Figure 12: View of the roof from inside the greenhouse

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.

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

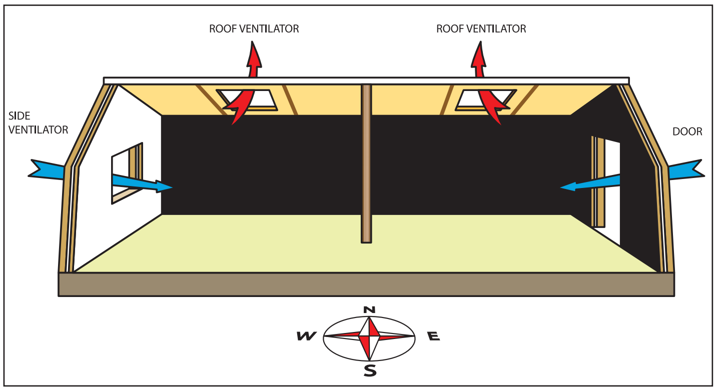


Figure 14: Air circulation in a greenhouse

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 (200 m) in winter and 300 feet (100 m) 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 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.
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 water	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			YES/NO

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 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 between 1.5 and 4 feet high)	5		
South-facing slope	3		
Flat	2		

Table 5: Site selection		
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
For sites with a cold climate: lowest temperature above -10°C.
Examples: Nubra (Ladakh, India), Lahaul (Himachal Pradesh, India), and Kabul (Afghanistan)

Design 2
For sites with a very cold climate: lowest temperature -10°C to -15°C.
Examples: Leh (Ladakh, India), Bamyan (Afghanistan), Qinghai (China)
- Roof insulation layer is increased to 2”

Design 3
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
For snowy areas.
- The slope of both roof and polythene increase 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

	Climate			
Site	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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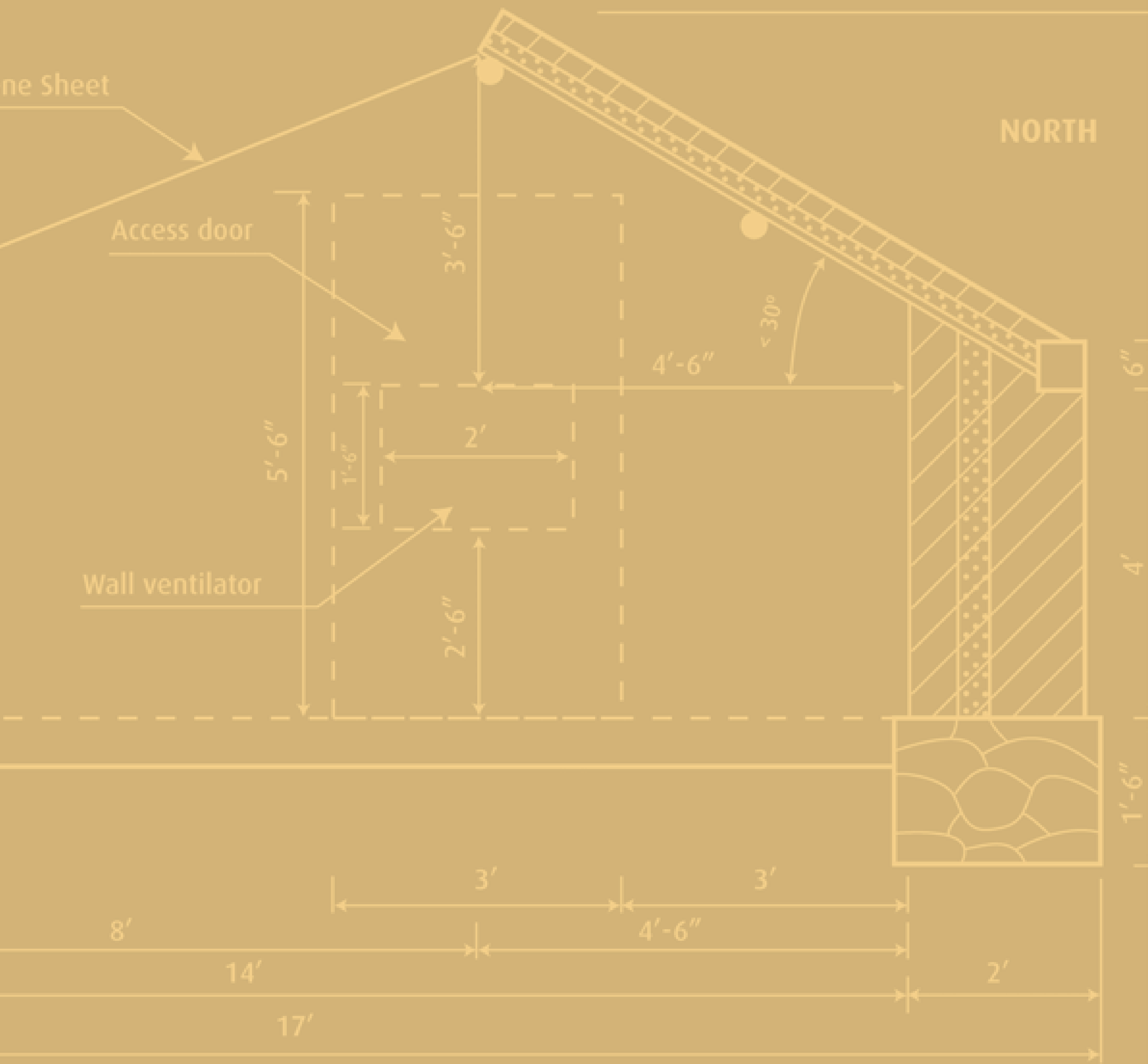


ne Sheet
NORTH
Access door
3′-6″
< 30°
4′-6″
6″
2′
1′-6″
5′-6″
Wall ventilator
2′-6″
4′
1′-6″
3′
3′
8′
4′-6″
14′
2′
17′

PART B

TECHNICAL GUIDELINES FOR BUILDING A GREENHOUSE

BUILDING A GREENHOUSE

Part B provides technical guidelines to help people build a greenhouse in the most efficient way. In the first part, detailed plans are given for the different designs. This is followed by a section on the construction process itself, and then by the methods to be used for the specific steps involved in the construction. The latter are provided in the form of individual datasheets that follow the chronological order of construction of the greenhouse.

The dimensions are given in feet and inches as these are the units most commonly used by builders in the trans-Himalayan countries. A set of basic designs for flat plots drawn up in centimetres is provided in the Annex.

BASIC DESIGNS

There are three basic designs to suit different climates, each with three different basic shapes to suit the different types of site, and one basic design for areas of high snowfall (see Section A). The detailed construction plans for each of these are provided in the following.

Design 1

Cold climate: lowest temperature above -10°C

BASIC CHARACTERISTICS OF DESIGN 1		
	Characteristic	Description
Structure	Orientation	South
	External dimensions	32' x 17' 10"
	Internal dimensions	28' 4" x 15'
	Door position	Opposite to prevailing wind
	Inner partition	No
	Roof slope	30º
	Depth of soil surface below outside level	6"
Insulation	Wall insulation	4"
	Roof insulation	11/2"
	Ground insulation	No
Ventilation	Wall ventilation	Yes
	Roof Ventilation	2 roof ventilators
Polythene	Single / Double	Single
	Manually operated night insulation	Yes

Choose Design1A for a flat site (Figure 16), 1B for a site on a south-facing slope (Figure 17), and 1C for a site adjacent to a south-facing terrace wall (Figure 18).

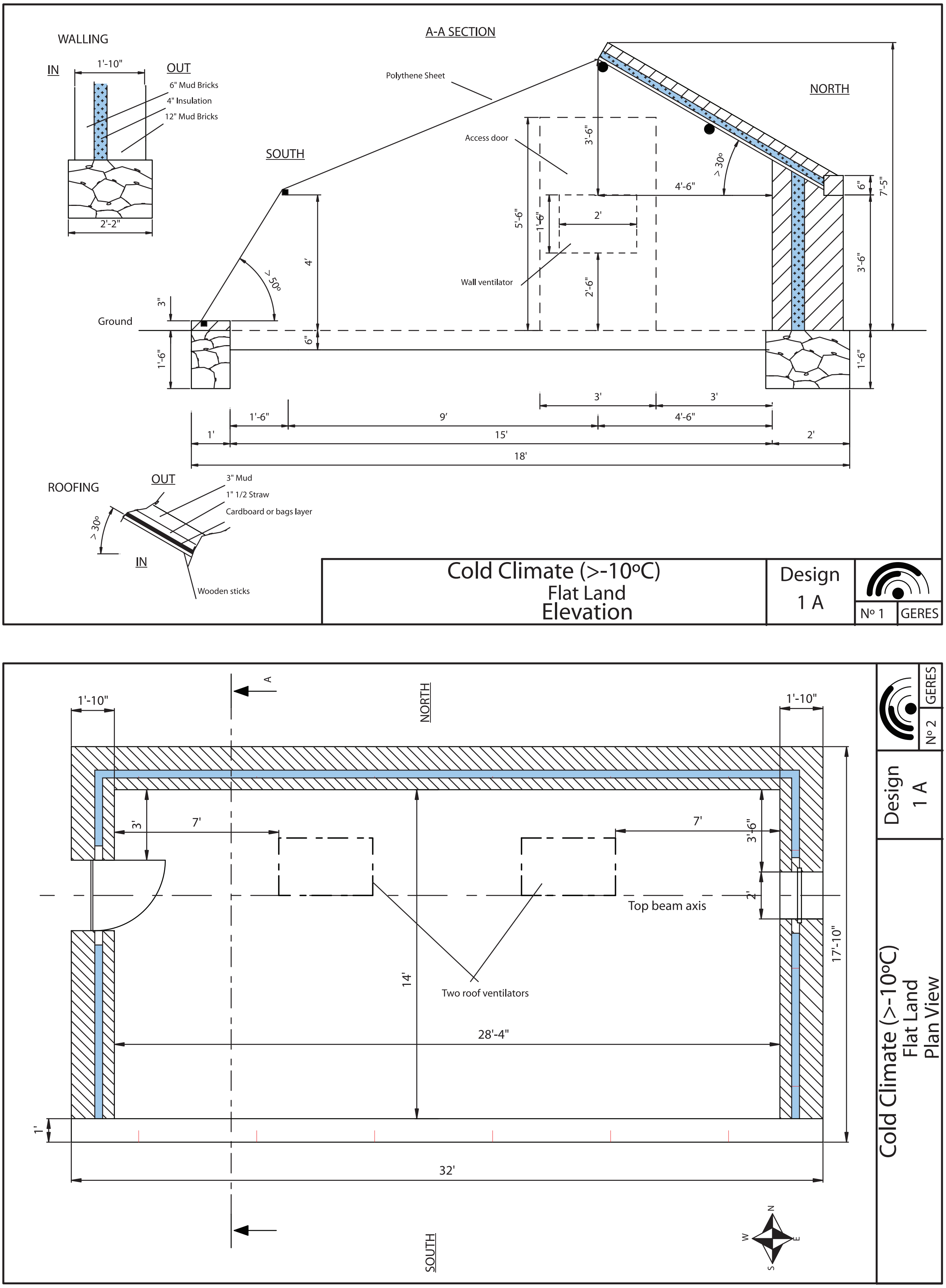
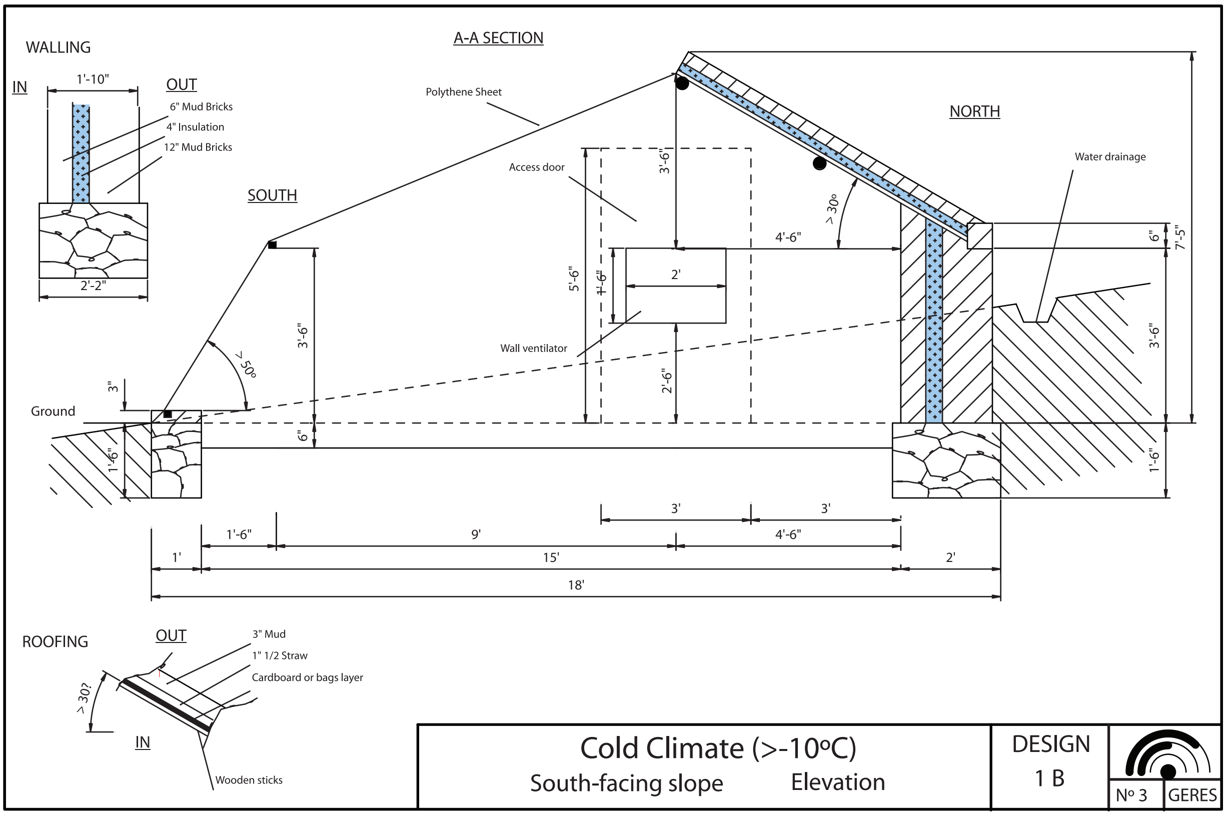


Figure 16: Design 1A - Greenhouse for cold climate, flat land



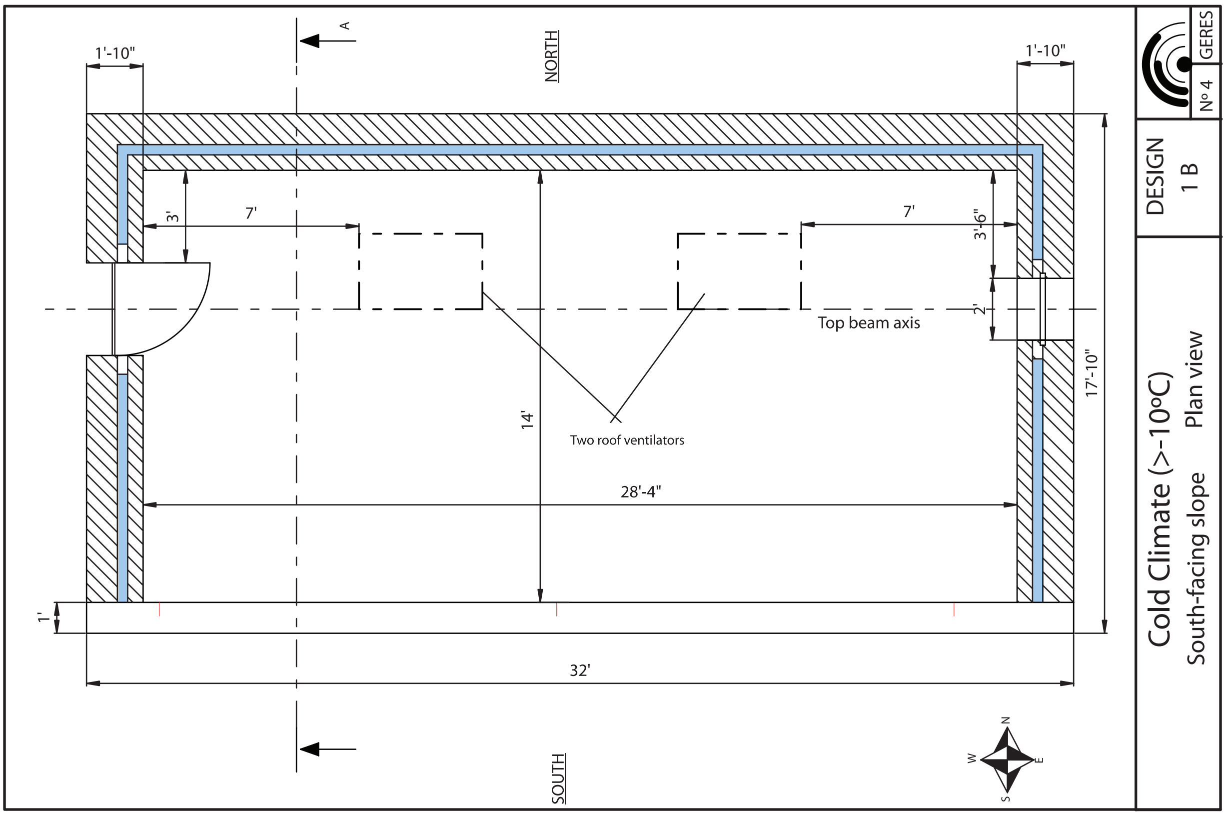
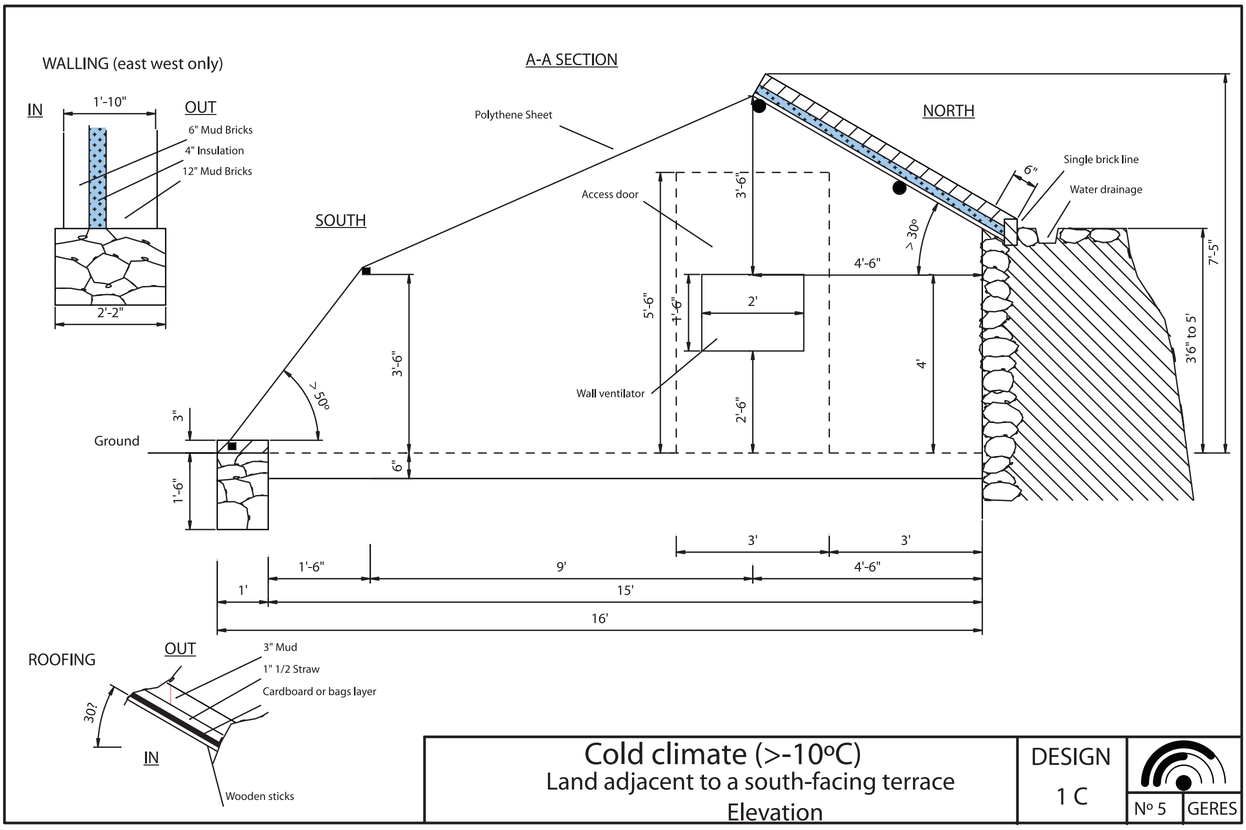


Figure 17: Design 1B - Greenhouse for cold climate, south-facing slope



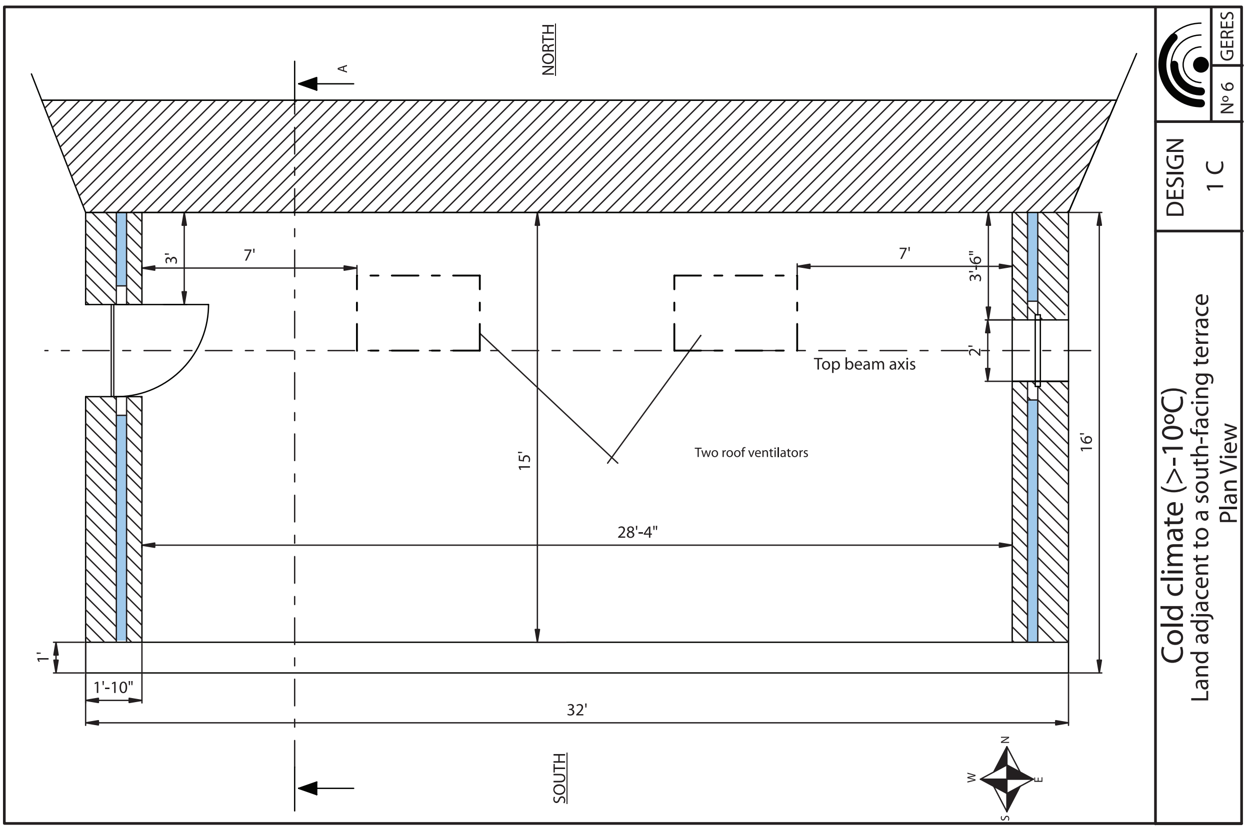
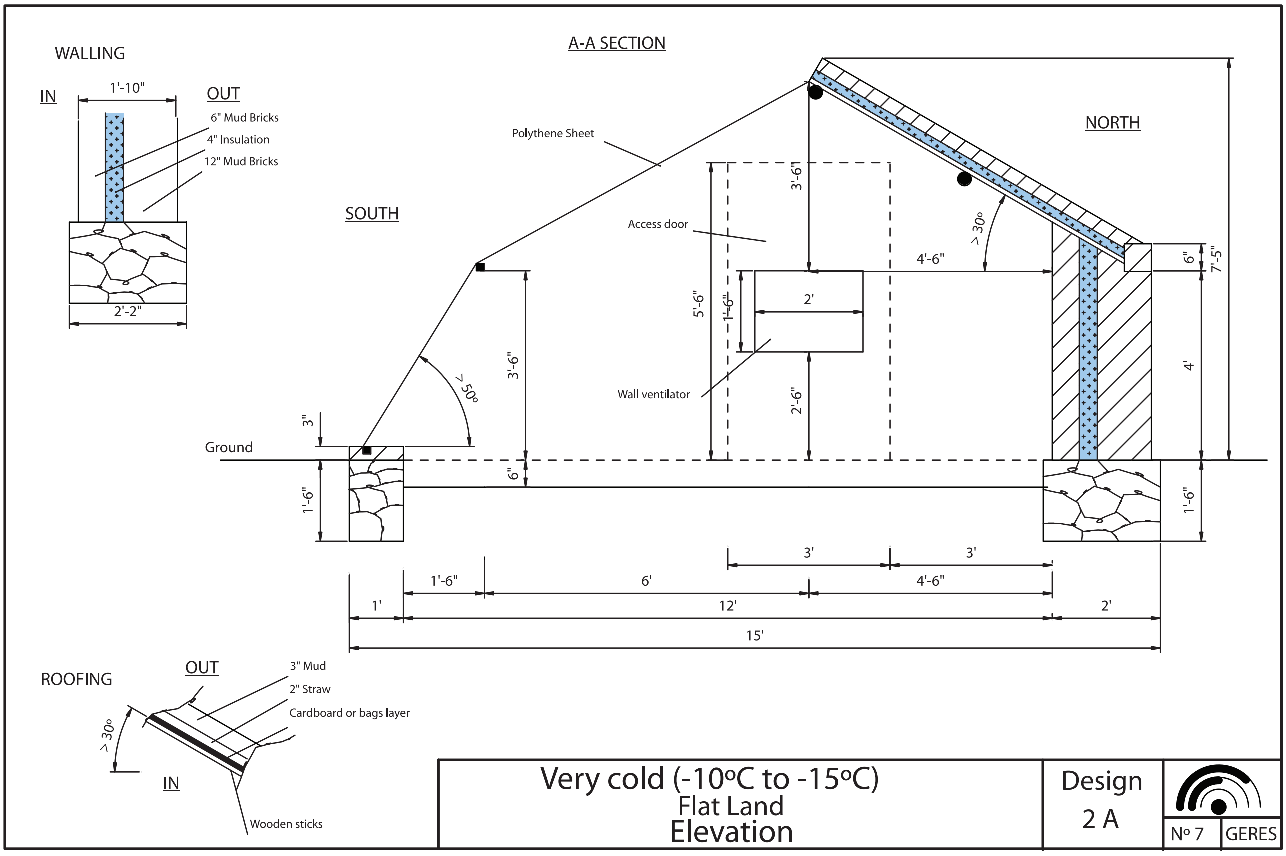


Figure 18: Design 1C - Greenhouse for cold climate, site adjacent to a south-facing terrace wall

Design 2
Very cold climate: lowest temperature between -10°C and -15°C

Basic characteristics of Design 2		
	Characteristic	Description
Structure	Orientation	South
	External dimensions	32' x 14' 10"
	Internal dimensions	28' 4" x 12'
	Door position	Opposite to prevailing wind
	Inner partition	No
	Roof slope	30º
	Depth of soil surface below outside level	6"
Insulation	Wall insulation	4"
	Roof insulation	2"
	Ground insulation	No
Ventilation	Wall ventilation	Yes
	Roof Ventilation	2 roof ventilators
Polythene	Single / Double	Single
	Manually operated night insulation	Yes

Choose Design 2A for a flat site (Figure 19), 2B for a site on a south-facing slope (Figure 20), and 2C for a site adjacent to a south-facing terrace wall (Figure 21).



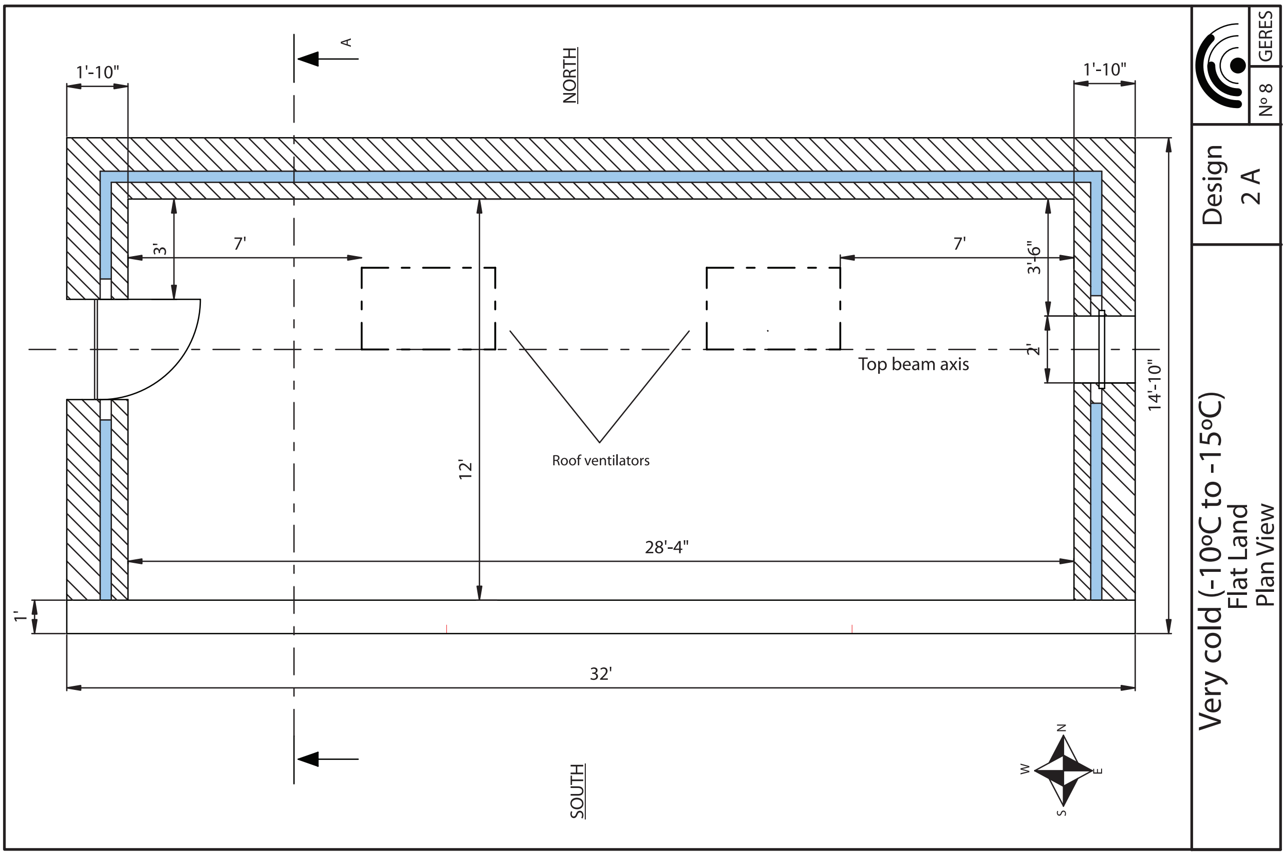
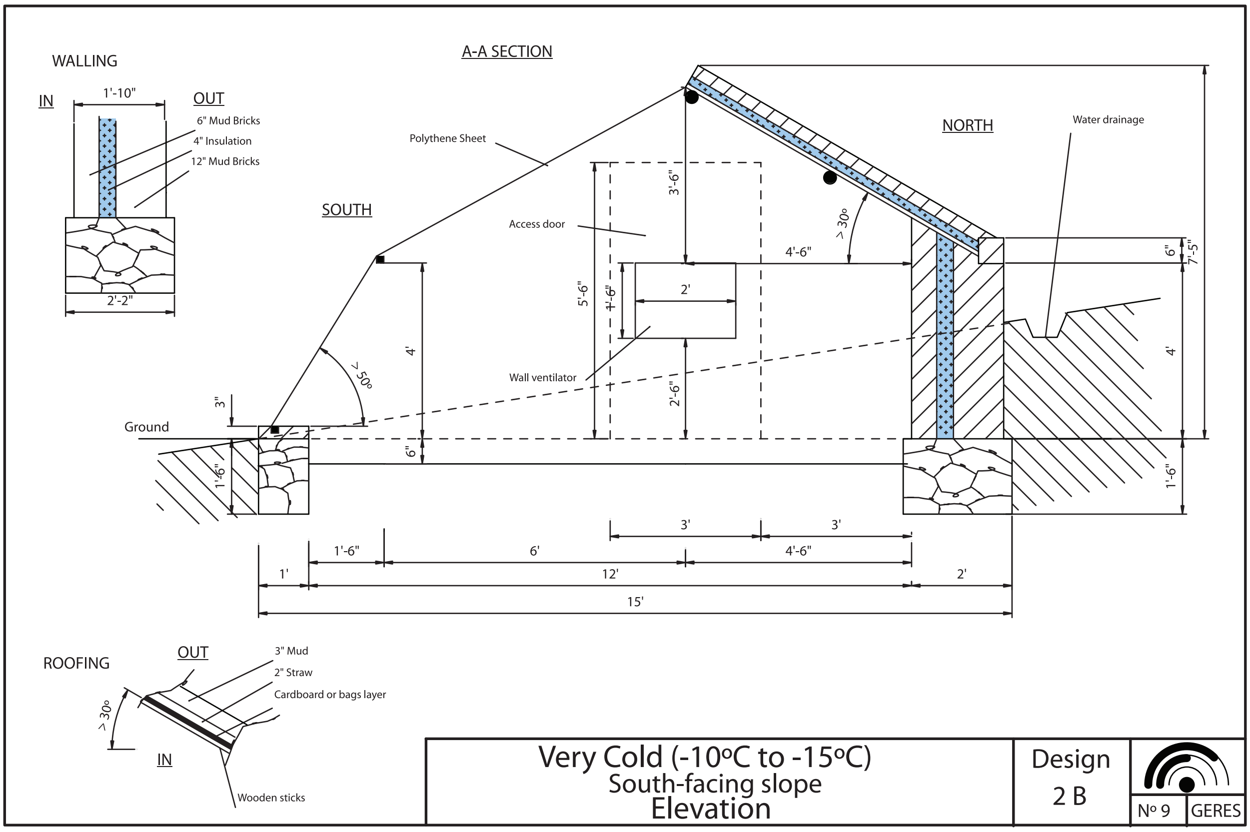


Figure 19: Design 2A - Greenhouse for very cold climate, flat land



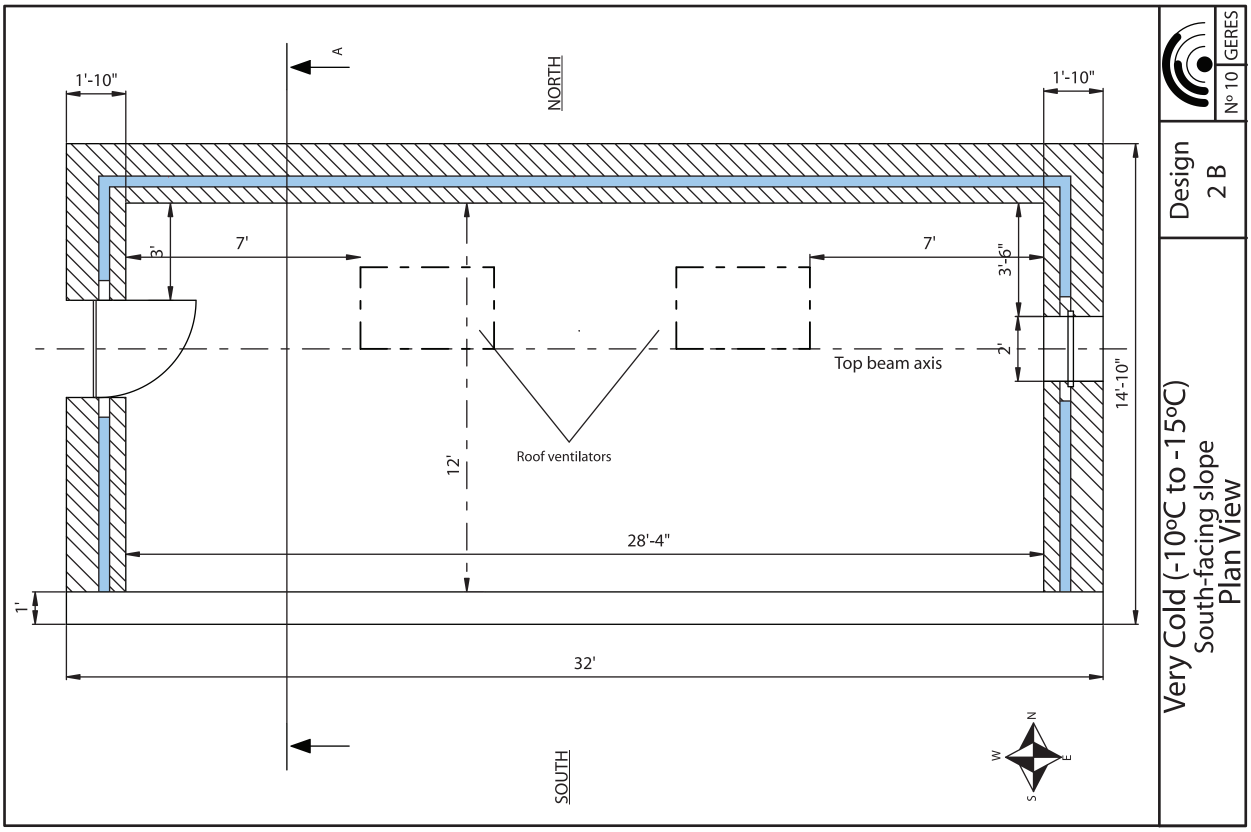


Figure 20: Design 2B - Greenhouse for very cold climate, south-facing slope

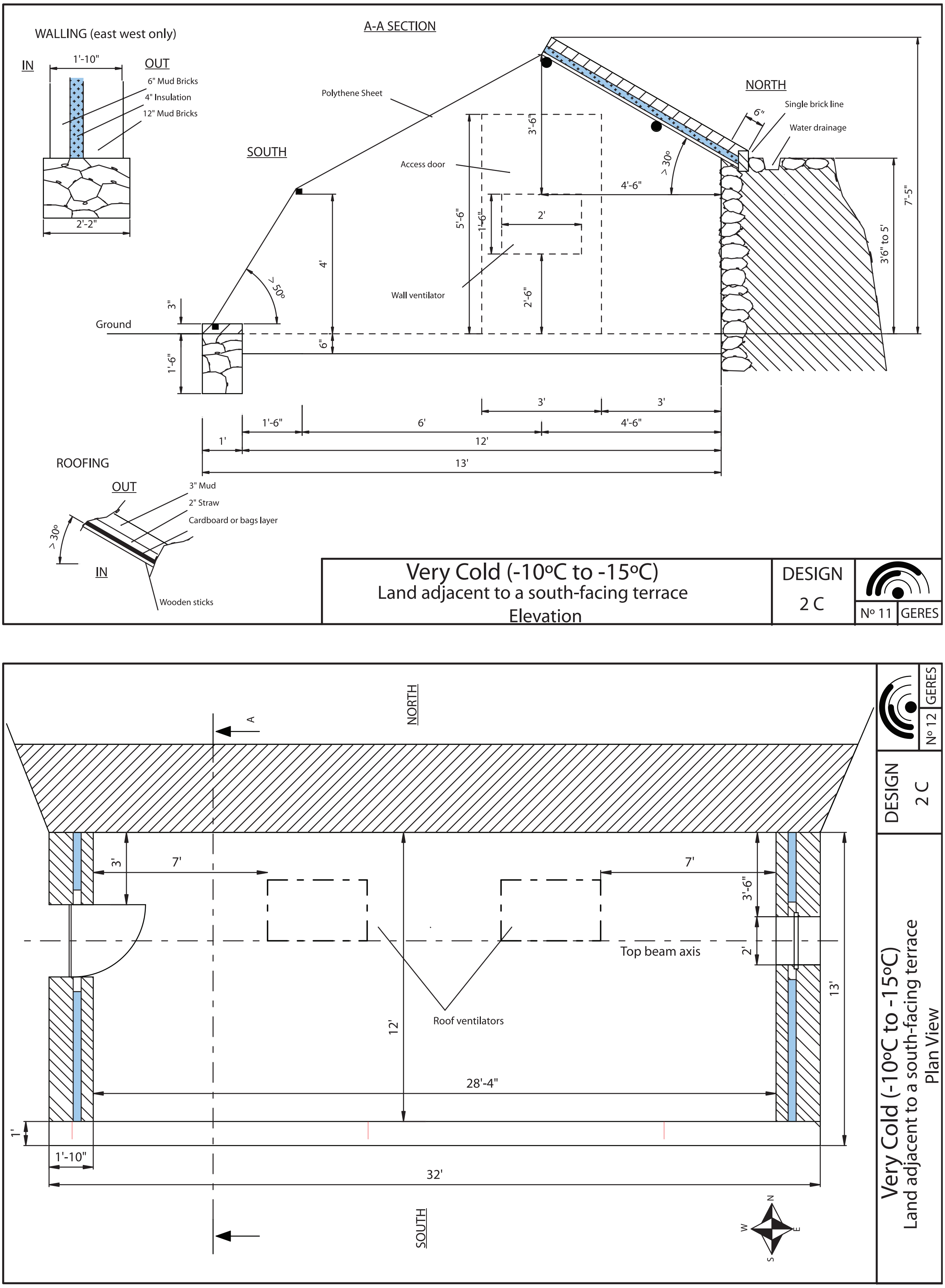
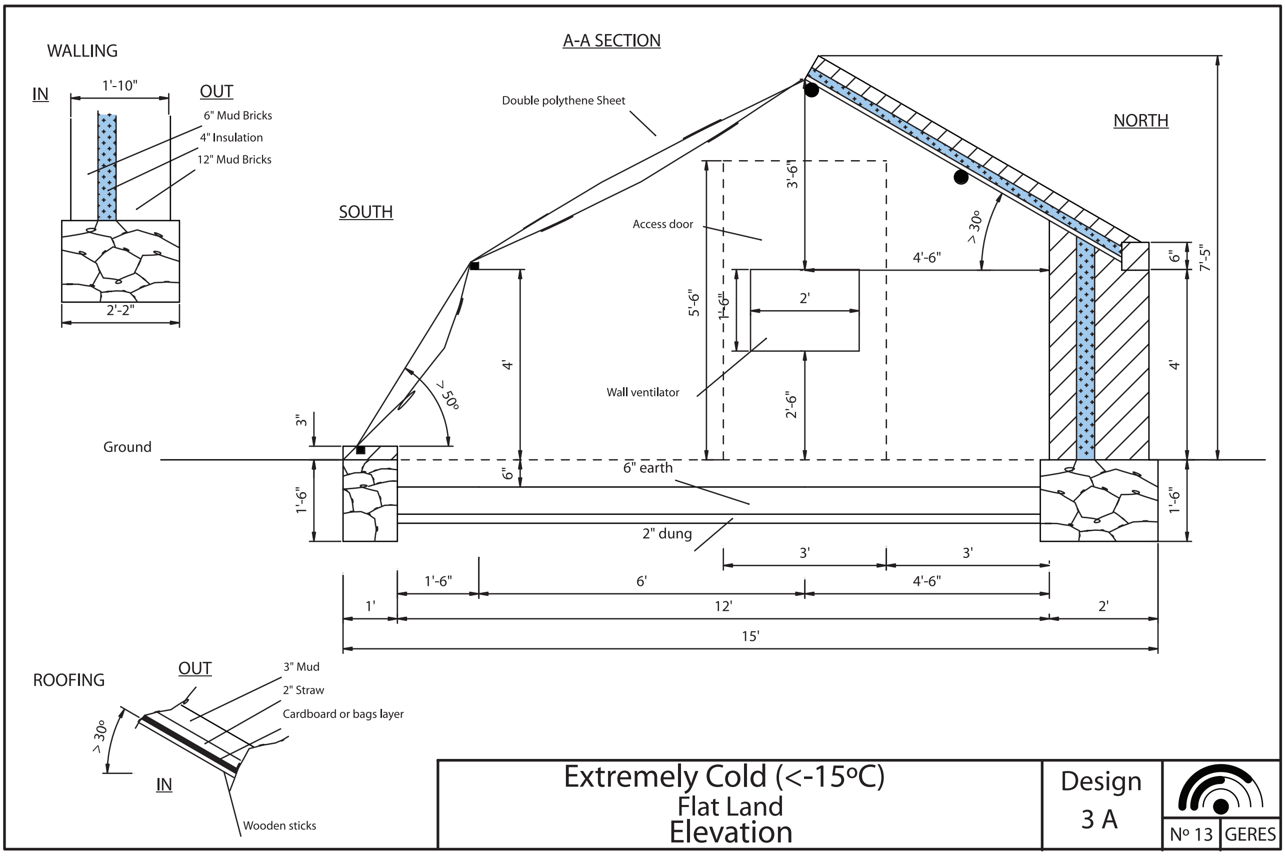


Figure 21: Design 2C - Greenhouse for very cold climate, site adjacent to a south-facing terrace

Design 3
Extremely cold climate: lowest temperature below -15°C

Basic characteristics of Design 3		
	Characteristic	Description
Structure	Orientation	South
	External dimensions	32' x 14' 10"
	Internal dimensions	28' 4" x 12'
	Door position	Opposite to prevailing wind
	Inner partition	Yes
	Roof slope	30º
	Depth of soil surface below outside level	6"
Insulation	Wall insulation	4"
	Roof insulation	2"
	Ground insulation	Yes
Ventilation	Wall ventilation	Yes
	Roof Ventilation	1 roof ventilator
Polythene	Single / Double	Double
	Manually operated night insulation	Yes

Choose Design 3A for a flat site (Figure 22), 3B for a site on a south-facing slope (Figure 23), and 3C for a site adjacent to a south-facing terrace wall (Figure 24).



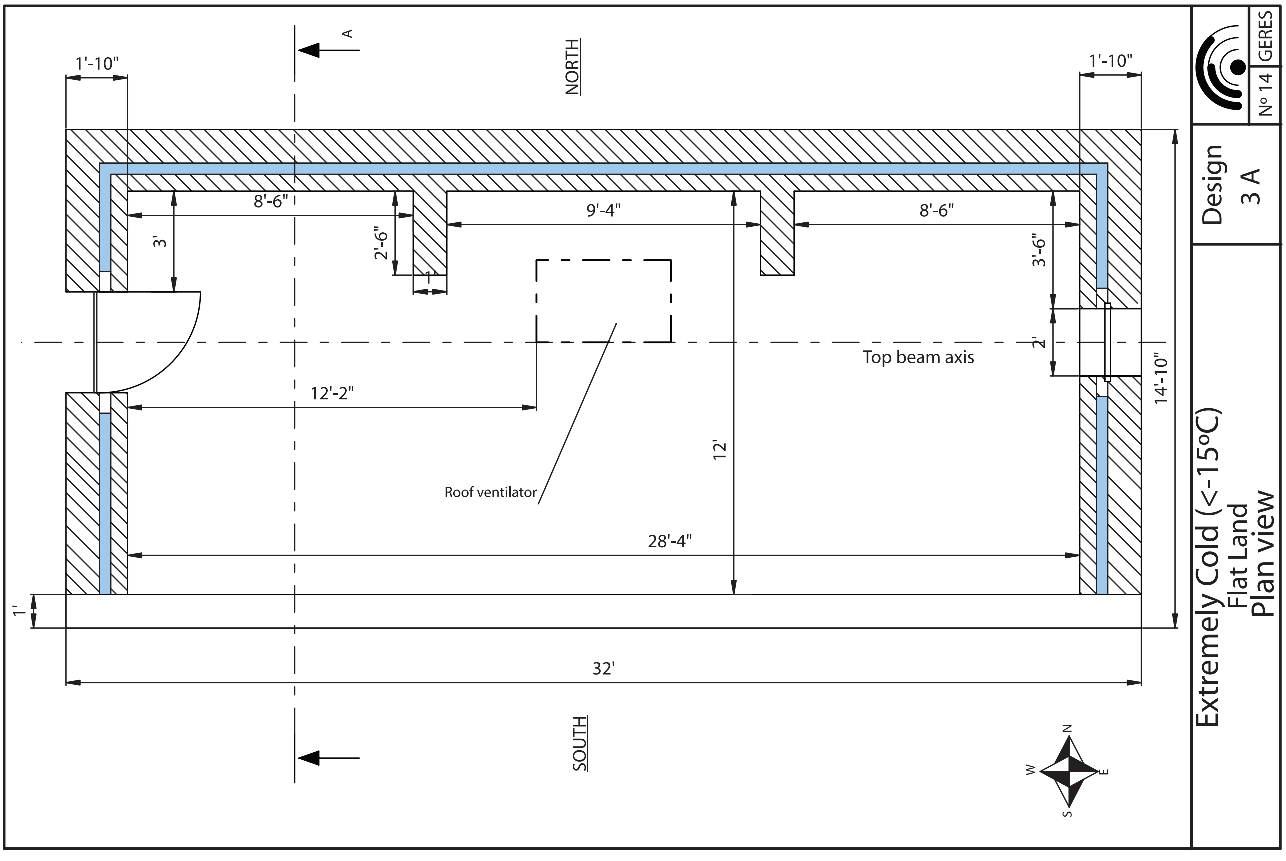
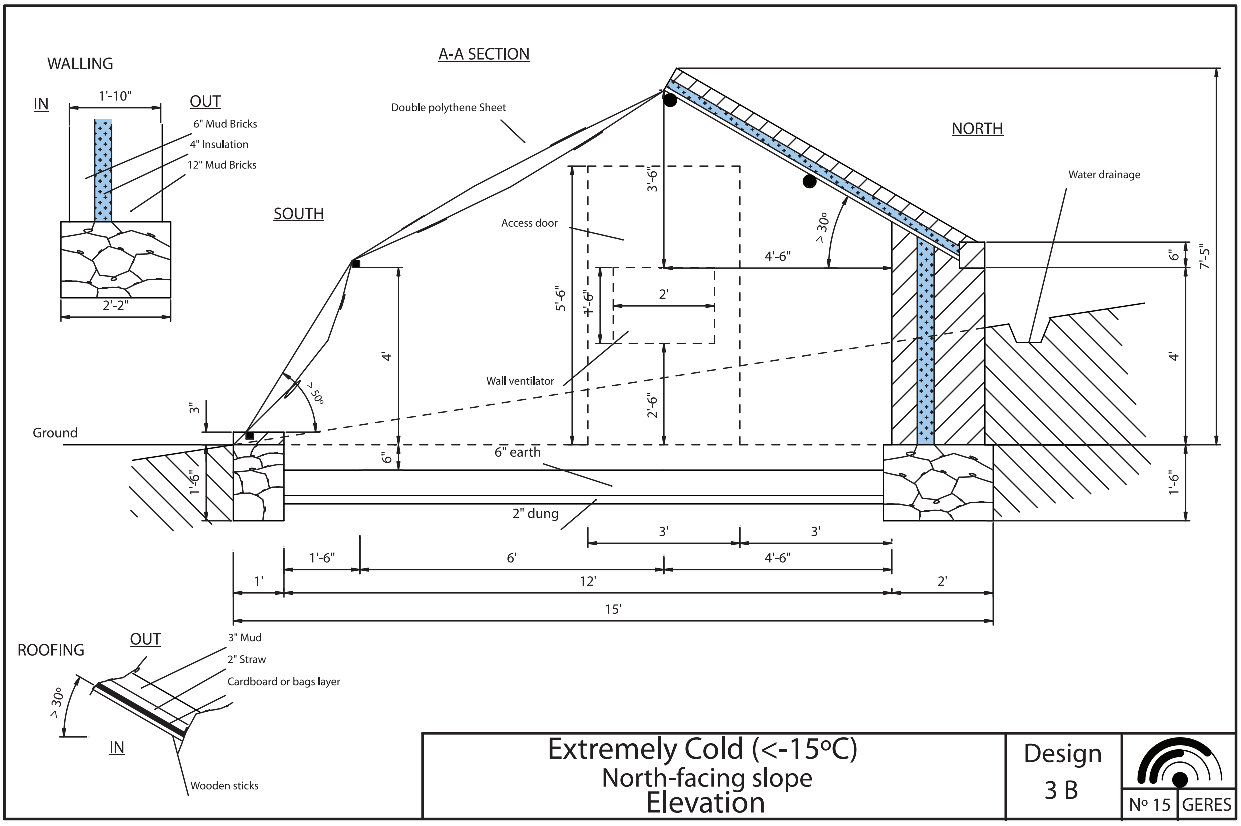


Figure 22: Design 3A - Greenhouse for extremely cold climate, flat land



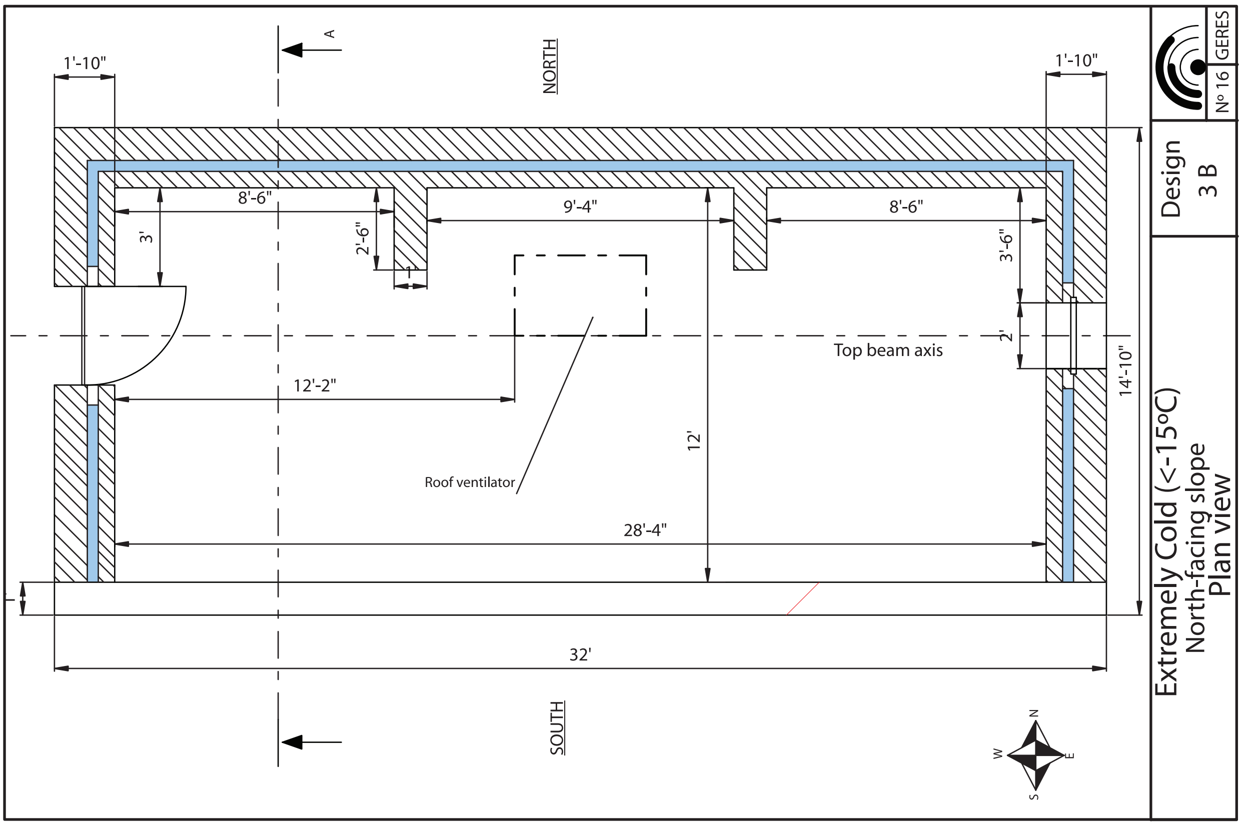
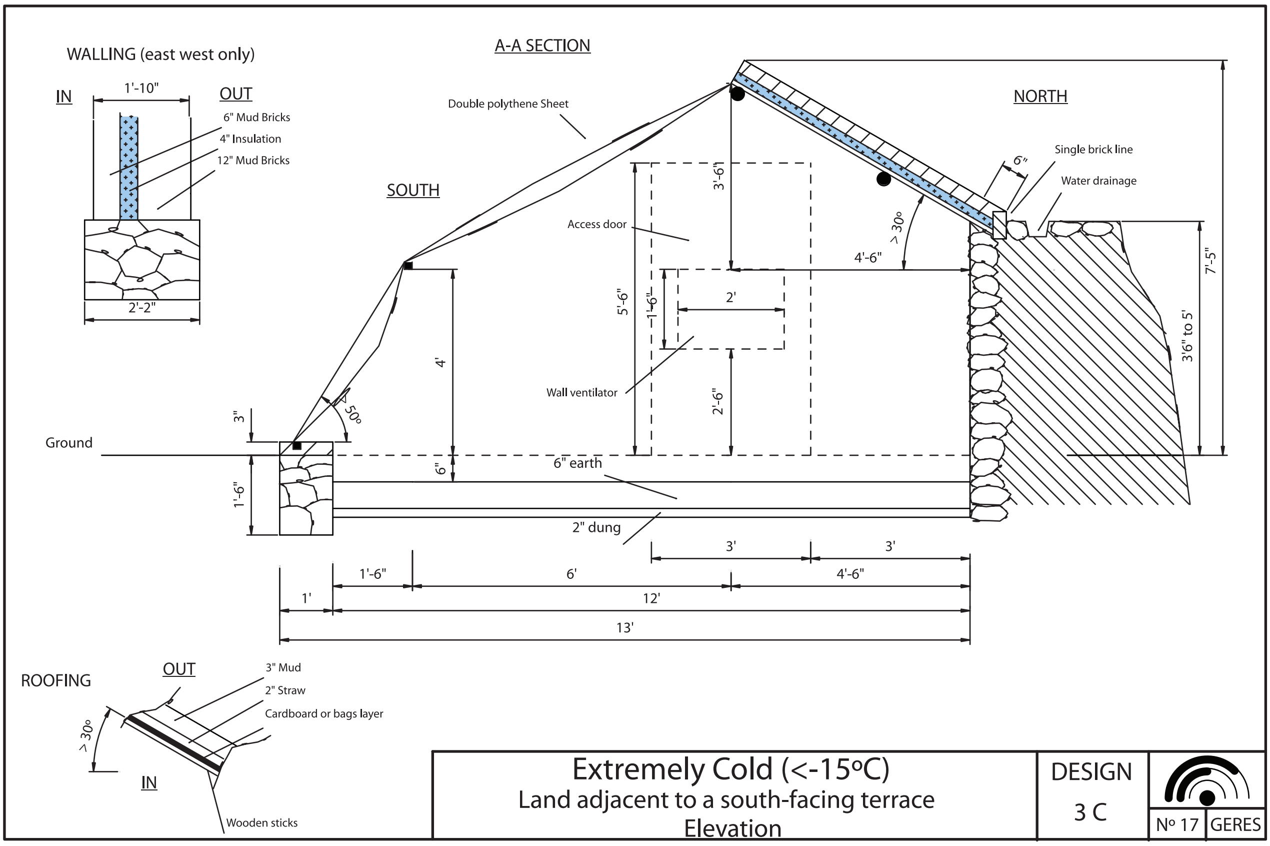


Figure 23: Design 3B - Greenhouse for extremely cold climate, south-facing slope



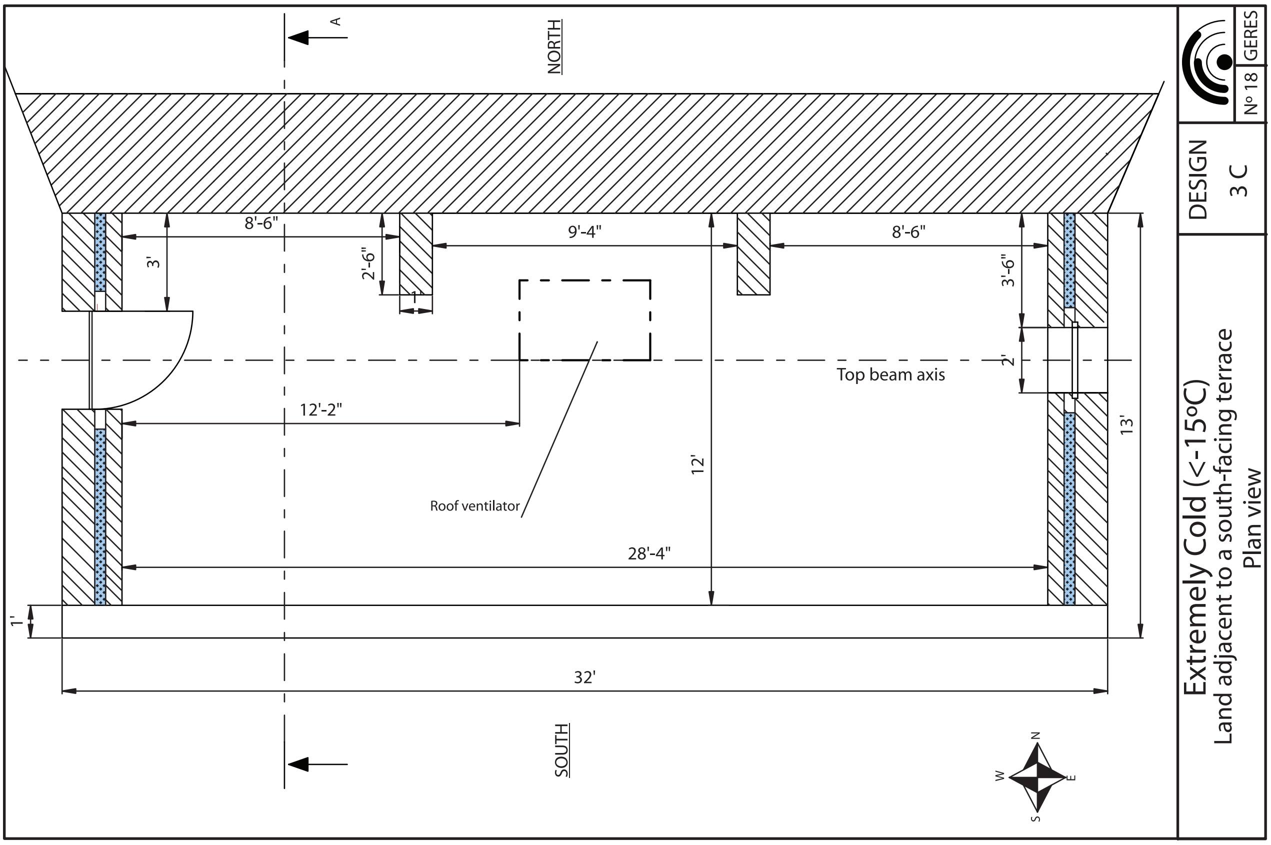
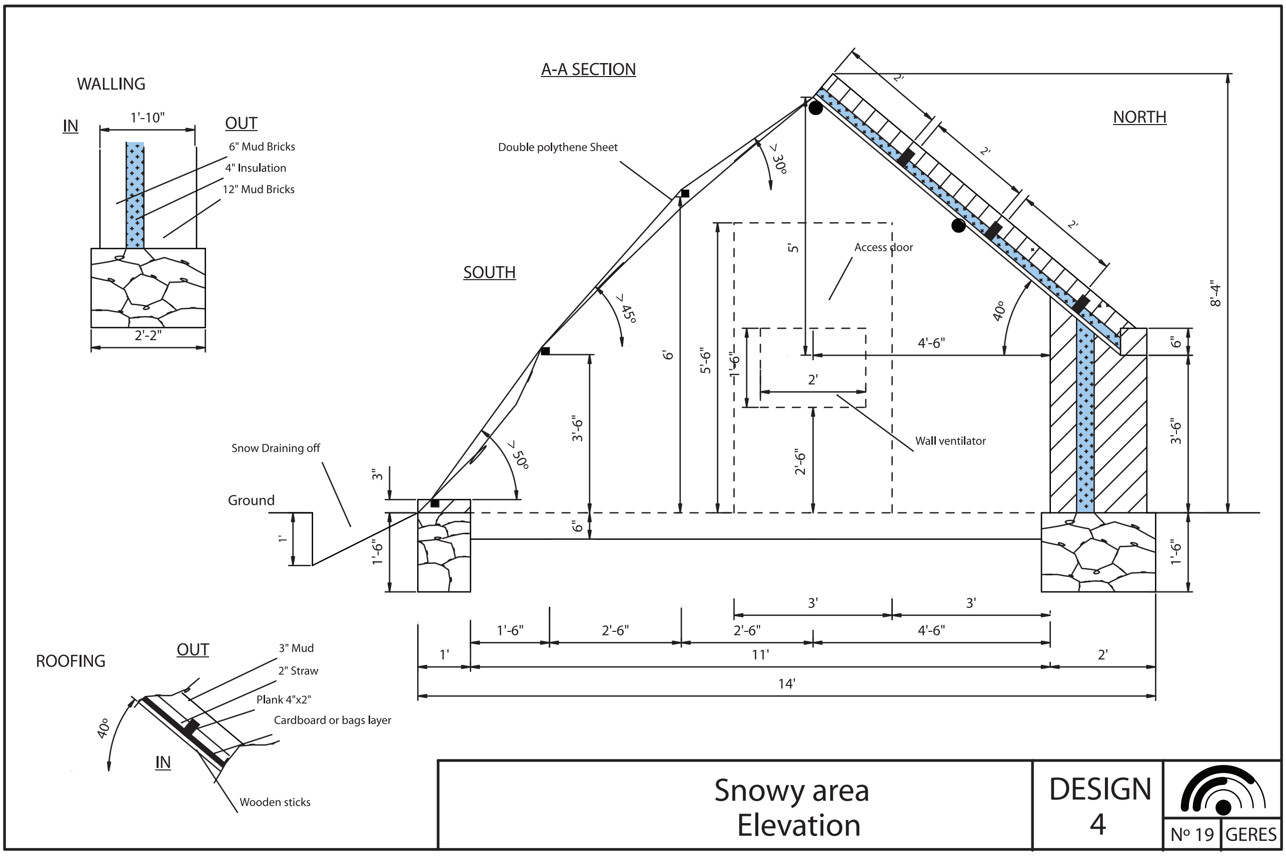


Figure 24: Design 3C - Greenhouse for extremely cold climate, site adjacent to a south-facing terrace

Design 4
Snowy areas

Basic characteristics of Design 4		
	Characteristic	Description
Structure	Orientation	South
	External dimensions	32’ x 13’ 10”
	Internal dimensions	28’ 4” x 11’
	Door position	Opposite to prevailing wind
	Inner partition	No
	Roof slope	40º
	Depth of soil surface below outside level	6”
Insulation	Wall insulation	4”
	Roof insulation	2”
	Ground insulation	No
Ventilation	Wall ventilation	Yes
	Roof Ventilation	1 roof ventilator
Polythene	Single / Double	Double
	Manually operated night insulation	Yes

The design for a flat plot is shown in Figure 25.



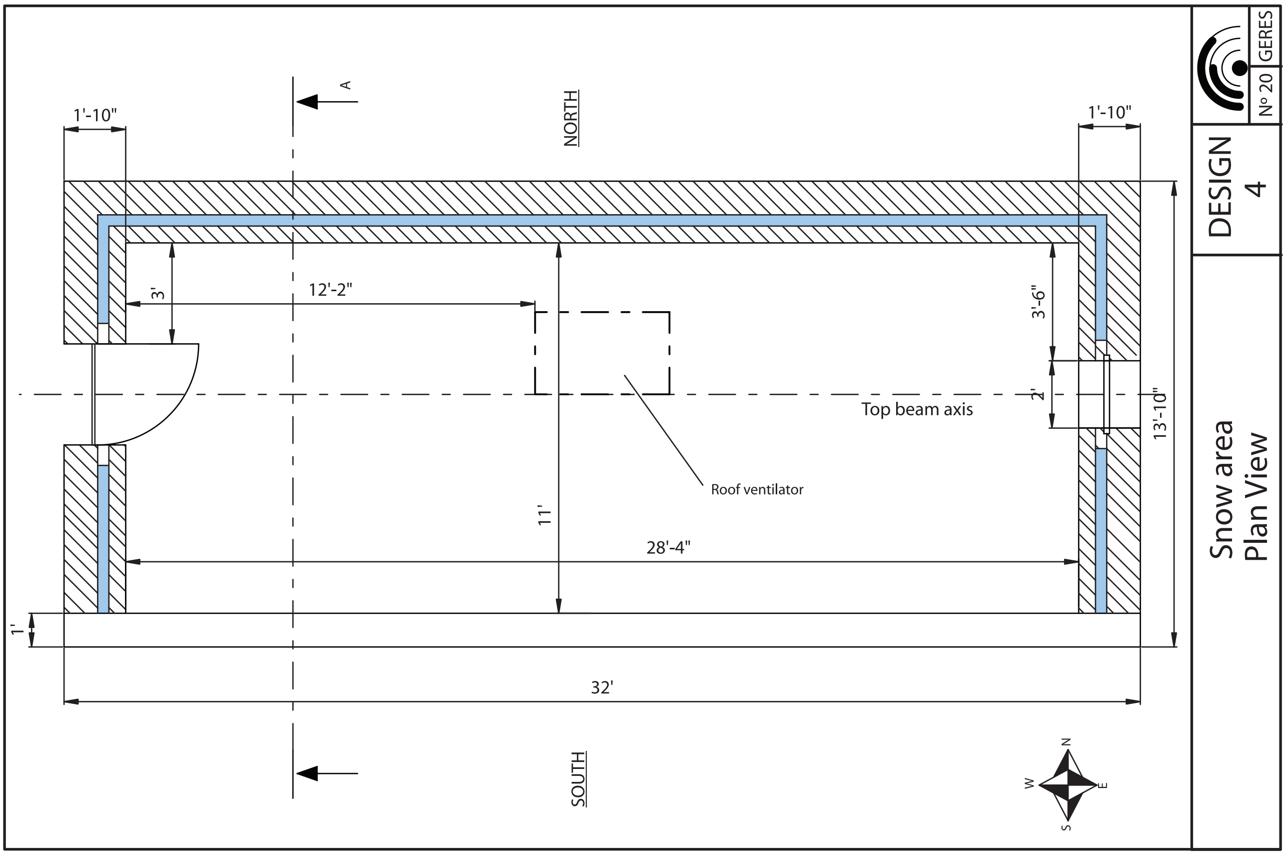


Figure 25: Design 4 - Greenhouse for snowy areas (flat land)

THE CONSTRUCTION SCHEDULE

Before Construction

Select the best site and the most suitable design as described in Part A.
Study the design and list the materials needed, use the table in Technical Datasheet 10 as a guide.
Collect all the materials together and store them on site.

The Construction

The construction itself can be divided into ten basic steps, each is described in detail in the Technical Datasheets provided in the following. The steps are as follow:

- Constructing the foundation
  Technical Datasheet 1
- Building the walls
  Technical Datasheet 2
- Building the partition walls
  Technical Datasheet 3
- Making and installing the door
  Technical Datasheet 4
- Making and installing the wall ventilator
  Technical Datasheet 5
- Constructing the roof
  Technical Datasheet 6
- Making and installing the roof ventilator(s)
  Technical Datasheet 7
- Finishing the walls
  Technical Datasheet 2
- Installing the polythene sheet
  Technical Datasheet 8
- Installing night insulation
  Technical Datasheet 9
- A list of materials is provided in
  Technical Datasheet 10

Figure 26: A team constructing a greenhouse in Qinghaï

TECHNICAL DATASHEET 1: CONSTRUCTING THE FOUNDATION

Principle

Foundations are the basis of every structure. The orientation and outline of the wall positions must be exactly as given in the design to ensure maximum efficiency of the greenhouse. The outline of the walls is first drawn on the ground and the foundations are then dug and filled.

Methods for Orientation

Orientation: finding south

The greenhouse must face south for maximum efficiency. The orientation may vary by up to 10° from due south towards east or west if this is an advantage in terms of the site configuration, and to save agricultural land.

The first step is to draw a line on the ground showing the orientation of the south-facing main wall (an east-west axis). There are two ways to do this.

- **Use a compass**

In the Hindu Kush-Himalayas, magnetic north is very close to geographic north (+ 5°) and you can use the direction shown on a compass to find 'south'. Lay a rope on the ground parallel to the east-west axis given by the compass. Draw a line parallel to the rope to mark the orientation of the south facing wall.

- **Use the 'plumb-line' method**

First you must know the exact time of true midday, when the sun is at its highest point in the sky. In Ladakh, for example, this is at 20 minutes past 12 (12:20 pm).

Figure 27: Finding south with a plumb line 38

If you don't know the exact time of midday, place a stick firmly in the ground and mark the position of the tip of its shadow every 10 minutes from about 11.30 to 12.30 or later. Note the time of the position when the shadow is shortest. This is midday.

Then hang a stone from a rope and hold the rope in your hand. Draw a line on the ground along the line of the shadow of the rope at exact midday: this line is the north-south axis. Now draw the four cardinal points north, east, south, and west on the ground as shown in Figure 27. Make a line for the position of the south face of the greenhouse by drawing a line along the east-west axis using a rope.

Now draw a line to mark the position of the full length of the outer wall of the south face of the greenhouse.

Constructing a right angle

One of the most important parts of wall construction is making sure that the walls are perpendicular to each other, in other words forming a right angle between adjacent walls. There are two ways to do this: the '3,4,5 method' and the 'bisecting lines' method. These methods are used when marking the position of the foundation as well as later when building the walls.

- **The '3,4,5 method'**

Fix a thin rope to a thin post at one end of the line marking the position of the south face. Fix the other end of the rope to a second post exactly 3' along the south face line. Unwind exactly 9' of a measuring tape and fix or hold the two ends of the tape to the two marker posts. Hold the tape at a point exactly 4' from the post marking the end of the southern face of the greenhouse. This point is 5' from the second post. Pull the tape towards the north until it is taut. It will form a triangle with sides of 3' along the south side, 4' along the north-south sidewall, and 5' along the diagonal between them. The tape will form an exact right angle (Figure 28). Mark the position of the side-wall by drawing a line along the tape. Repeat for all four corners and mark the position of the outside of all the walls.

Figure 28: Drawing a right angle using the ‘3,4,5’ method

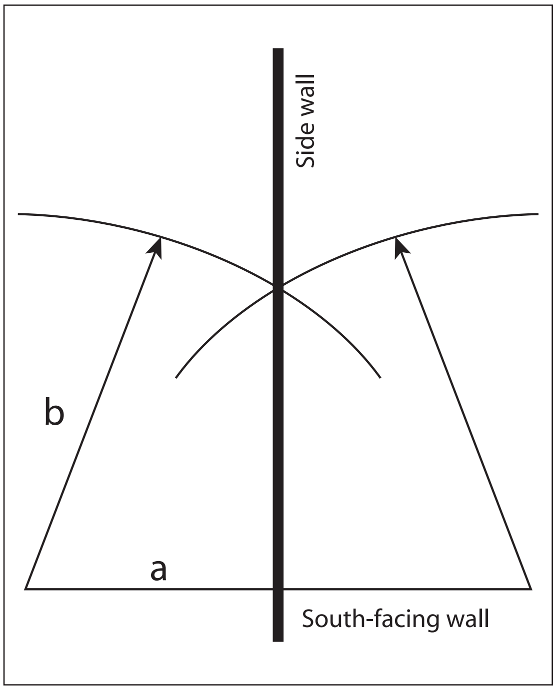


Figure 29: Bisecting lines method to draw a right angle

• **The bisecting lines method**
Starting at the point marking one end of the line showing the position of the south face, draw two lines of the same length a in opposite directions, one along the line and one along its extension (Figure 29). Draw an arc of a circle of radius b from the end of each of the lines such that they intersect. Draw a line between the point where the arcs intersect and the point marking the end of the wall along the south face: this line marks the position of the side-wall, and is perpendicular to the south face.

Note: Similar methods are used to determine the position of the inner partition in Design 3, see Datasheet 5.

Preparing and Marking the Ground

• **Excavating the slope**
If the plot is on a slope, the first step is to excavate the land to provide a flat area. The dug out area at the back protects the back wall (Figure 30).

Figure 30: Excavating a slope

• **Marking the wall position**
Mark the position of the foundations of the greenhouse with stakes and string, and a chalked line on the ground, as described above (Figure 31). The foundations of the back and side-walls are 2’ wide (or 2’2” as in the plans). The south wall foundation is 1’ wide, in a line stretching from the southern edges of the east and west walls, as shown in the plan. For Design 3, also mark the position of the internal partition walls. No foundation is necessary along the north wall in Design C.

Note that the scale plans show a foundation 2’ 2” wide, i.e., 4” wider than the walls and extending 2” beyond the wall on each side. This may be marginally stronger but experience shows that a 2' wide foundation, extending 1" beyond the walls on either side, is sufficient.

If the walls have to be built with rammed earth or stone (see Technical Datasheet 2), then the foundation trench must be made wider accordingly.

Figure 31: Marking the position of the walls

Constructing the Foundation

- **Digging the trench**

Dig a trench 1' 6" deep within the markings. Mark the position of the door frame 3' from the interior of the north wall on either the east or west side, whichever is opposite to the prevailing wind, as shown in the plan.

- **Filling the foundation**

Fill the trench with mediumsized loose stones and dry/mud mortar, according to the usual practice in the area. In rainy areas, the foundations can be strengthened by concrete mortar, but the price will be higher. A 2" thick layer of concrete can be laid on the top of the foundations to strengthen the structure of the greenhouse and reduce the risk of damp (Figure 32).

Preparing the Floor of the Greenhouse

In Designs 1, 2 and 4, when the foundation is complete, dig out the greenhouse floor to a depth of 6" so that the level of the floor is lower than that of the outside ground.
In Design 3, dig out the floor to a depth of 1'2" after wall construction is complete but before installing the plastic cover. Cover the surface with a 2" layer of dung, and replace half the soil in a 6" layer to give a final floor level inside the greenhouse that is 6" below the level of the outside ground.

Figure 32: Covering the top of the foundation with a layer of concrete

TECHNICAL DATASHEET 2: BUILDING THE WALLS

Principle

The walls are built on the foundations, leaving 1" of the (2' wide) foundation clear on either side of the wall. The walls must be shaped in the precise way shown in the designs so that the roof angle is correct. The back wall is a simple vertical wall whose top is parallel to the bottom.

If the greenhouse is built in a extremely cold climate area (Design 3), two partition walls must also be built, as described in Technical Datasheet 3.

If the site is adjacent to a south-facing terrace wall, then this wall can be used as the north wall of the greenhouse. The stones shown in designs 1C, 2C, 3C represent the terrace wall, although in general the wall will be solid earth. If necessary, the wall can be strengthened with additional stones, especially the top, which supports the roof.

Care must be taken to ensure that water is drained away from the back of the greenhouse in Designs B (on sloping land) and C (built against a terrace). Construct a drainage channel behind the greenhouse as shown in the plans.

Outlining the Shape / Setting the Angles of the Walls

Outline the shape of the top of the finished east and west walls in the air using the rope and stakes method as follows. Hammer three long stakes into the ground along the outer edge of the side wall, one at the position of the outer edge of the north wall, one 4'6" from the inside edge of the north wall (6'4" from the first stake), and one 2'6" from the outer edge of the south foundation. Tie a piece of string around the first stake at a point 4' above the foundations (the height of the north wall), then tie it around the second stake at a point 7'6" above the foundation (3'6" above the level of the north wall), and around the third stake at a point 4' above the foundation, and finally fix it to the ground at the outer edge of the south foundation. The line of the string marks the edge of the roof at a 30° angle to the top of the north wall, and the top of the side-wall (Figures 33, 34).

Repeat for the other side-wall. The wall is then constructed up to the level of the rope (Figure 34). A piece of string tied between the points marked on the middle stakes marks the position of the central beam and the top edge of the roof.

Use a plumb line (stone hanging from a piece of string) to ensure that the walls are vertical.

Figures 33, 34: Outlining the position of the top of the wall with thick string (in Qinghai and Ladakh)

Constructing the Wall

Planning the wall

Generally, the wall should be built of three vertical layers (Figure 35):

- an external load-bearing wall, 12" wide, built with mud bricks, rammed earth, or stone
- a layer of insulation, 4" thick
- an internal thermal storage wall, 6" wide, built with mud bricks

The mud bricks are cut fresh (not sun-dried) and should measure about 12" x 6" x 6". The wall thicknesses given are a minimum (12" for the load-bearing wall and 6" for the internal thermal storage wall). It is advisable not to reduce these sizes when using the mud brick technique, although they can be increased.

The form is shown in Figures 35 & 36. Mark the position of the door frame and wall ventilator and install these while constructing the wall as described in Technical Datasheets 4 and 5.

Erect 2 mud walls 6” and 12” thick, leaving a 4” gap between them.

Fill the gap with:
- 1’-6” seabuckthorn + insulator mixed
- straw or other insulator
- cover with (plank and) a layer of mud

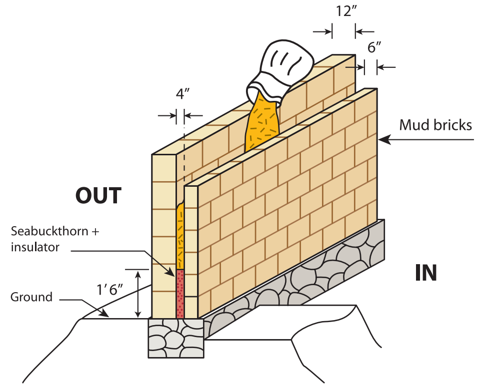


Figure 35: Plan of double wall construction

Figure 36: Building a double wall with mud bricks in Afghanistan

Figure 37: View of double wall separated by insulation layer (sticks are added to reinforce the gap)

Building the wall

When the walls are constructed with mud brick, then the outer and inner walls are constructed simultaneously (Figure 36). The structure can be reinforced with sticks every 8’ along the wall and every 2’ of wall height (Figure 37). When stone or rammed earth is used, the walls are constructed one after the other. Be careful to leave spaces for the door and ventilator and to line the door frame with mud bricks as described in Technical Data Sheets 3 and 4.

Filling the Insulating Layer

The gap between the inner and outer walls is filled with insulating material.

Suitable insulating materials include straw (long stems), machine straw (short stems cut by machine), wild bushes, dried horse or donkey dung, dry grass, sawdust, and wood shavings. Dry leaves are not suitable as they generally turn to dust within four years or so, so that the insulation effect is lost.

First chop seabuckthorn or any other thorn bush into 4” to 6” long pieces and mix them with the chosen insulating material. Fill the lower 1’ 6” of the gap with this mix. The aim is to protect the greenhouse from rats and mice. A mix of chopped ‘water resistant grass’, such as ‘nai’ in Afghanistan or ‘yagzee’ in Ladakh, and chopped seabuckthorn can limit moisture problems arising from groundwater.

Fill the remaining gap with insulating material. When the gap is full, push the material down a little with a stick, and then completely fill again to the top with loose material. Don’t push down again.

Finishing the Walls

Finish the wall by covering the insulating layer with mud. A more durable, but more expensive, solution is to lay strips of waste planks (3" wide) on top of the insulating layer before adding the mud layer. A bank of earth can be added around the lower part of the outside of the walls to reduce heat loss through the foundations.
Plaster the walls completely, outside and inside. Traditional mud plaster is suitable for the outside; cement wash plaster is preferable inside. If mud plaster is used for the inside, do not add straw to it as this will rot in the hot damp atmosphere. The walls have to be very smooth so that they can be whitewashed or painted.

Painting the walls
Paint black or whitewash the inside walls as follows (Figure 38).

- The inner side of the west wall is whitewashed to reflect the morning radiation to the vegetables.
- The inner side of the east wall is painted black to absorb and store the afternoon solar radiation.
- The bottom two feet of the inner side of the north wall are whitewashed and the upper part painted black for similar reasons.

The black paint can be made with a mixture of oil and ashes or with powder paint.

Figure 38: View of whitewashed west wall and black painted north wall.

Alternatives

Various alternatives are possible according to the availability of local materials. If mud bricks are not available, the walls can be built with rammed earth or stone, but the foundation width (and wall width) will need to be increased and the greenhouse will be more expensive and the useable area smaller. In special situations other modifications are needed. In Qinghai, for example, the quality of the soil (for mud bricks) is poor and a 4" thick outer wall is built with baked bricks to protect the wall from the rain and a 12" thick inner wall is constructed with rammed earth stabilised by 5% cement to increase the thermal

Figure 39: Construction of an outer wall with baked bricks and an inner wall with stabilised rammed earth in Qinghai

mass (see Figure 39). In Spiti (India), where the clay content of the soil is high, skilled masons are able to construct the double wall using a single frame with two layers of rammed earth inside (2 x 8" thick) separated by a 4" sandwich layer of straw. Another possibility is to construct a double wall out of stone with a 2-3"cavity between the walls packed with insulating material. Such a wall may need inside reinforcement in the form of a strip of knotted galvanised wire joining the two layers.

Technical datasheet 3: building the partition walls

Principle

Two small (1' thick) internal partition walls are built at the back of the greenhouses built for extremely cold climates (Design 3) to increase the thermal mass. These walls can usually also be used to replace the wooden pillars that are otherwise needed to support the roof.

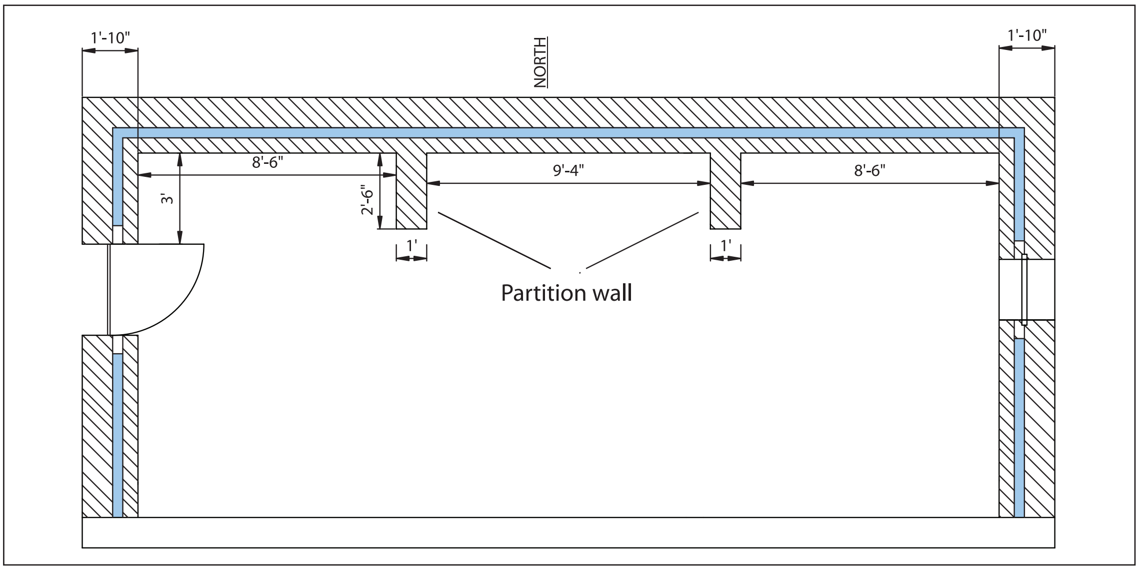


Figure 40: Plan view of greenhouse partition walls

Procedure

• The partition walls should be built on a foundation for strength. Mark the position of the partition walls when marking out the foundation, and dig and prepare a foundation for them at the same time as for the other walls (Technical Datasheet 1).

• Erect the partition walls at the same time as the back (north) wall (Figure 40).

• The walls need to be sloped at the angle of the roof. Stop building when the walls have reached a height of 4' above the outside ground and mark the shape of the wall slope in the same way as described for the east and west walls in Technical Datasheet 2. Build up the wall to this shape.

Figure 41: Finishing off the partition walls

Figure 42: Completed inner partition walls, greenhouse in Zeback district, Afghanistan

TECHNICAL DATASHEET 4: MAKING AND INSTALLING THE ACCESS DOOR

Principle

A door is built into the wall to provide access and act as a ventilator for cooling. It is constructed in the wall opposite to the prevailing wind to reduce unwanted drafts.

Carpentry

The door frame

• Prepare four wooden beams cross-section 4" x 3" and impregnate them with oil (to make them moisture resistant), two 5' long and two 3' long.
• Cut the inner edges as shown in Figure 43.
• Fix them together to obtain a rectangular frame with outside dimensions of 5' 6" x 3' (4" thick)
• For the lintel, prepare two small beams 4' long (section 4" x 3" or diameter 4"), and a 1" thick plank, 1' 10" wide (or the wall thickness) and at least 3' 6" long.

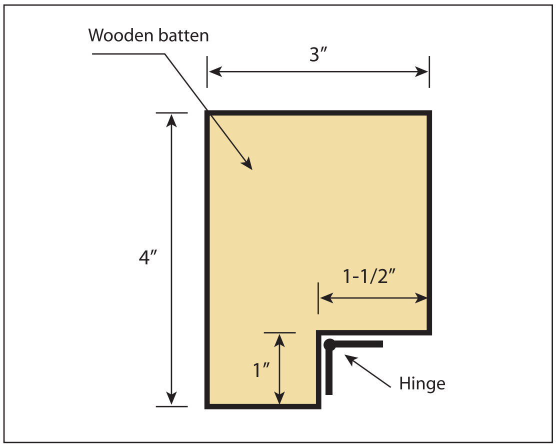


Figure 43: Framework for door

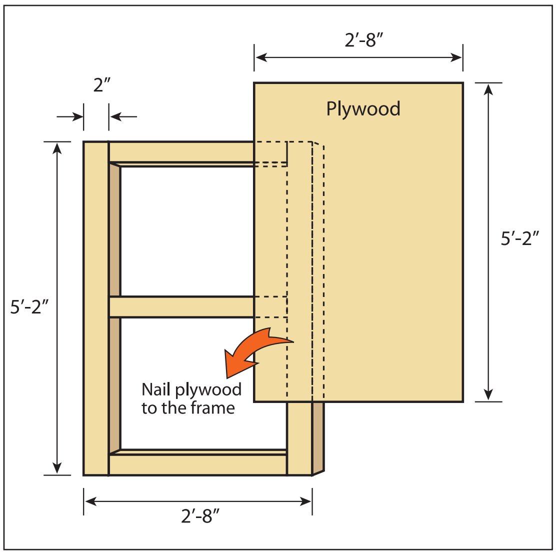


Figure 44: Plan for the door

Figure 45: Assembling the door

The door

• Select good quality wood, section at least 2" x 1½".
• Build a rectangular framework using wooden battens with external dimensions 5' 2" x 2' 8" (height by width) as shown in Figure 44.
• Nail another wooden batten across the width of the frame in the centre to reinforce it.
• Cut two pieces of plywood 5' 2" x 2' 8", one at least 6 mm thick (for the outside); and one 4 mm or more thick (for the inside). Paint them white or impregnate with oil.
• Nail one piece of plywood to one side of the assembled frame. Turn the door over and fill the spaces with insulating material as shown in Figure 45. Nail the second piece of plywood over the material (Figure 44).
• Attach two hinges to the side of the door.

Masonry – Installing the Door

• Mark the position of the door when marking out the foundation. The door is placed on the opposite side to the prevailing wind. The opening for the door frame starts 3' from the inside of the north wall (Figure 46).
• The door frame is fitted at the centre of the outside load-bearing wall (the outer 1' wide wall) after the foundation construction and before the wall erection, and in such a way that the door can swing open to the inside, with the hinges towards the inside of the greenhouse. (In Afghanistan, in contrast to most other areas of the trans-Himalayas, the door frame is usually installed after the walls have been constructed.)

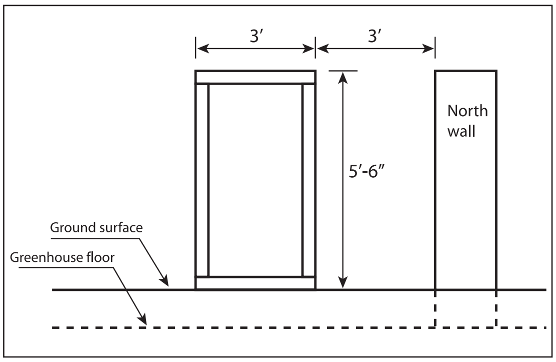


Figure 46: Position of door

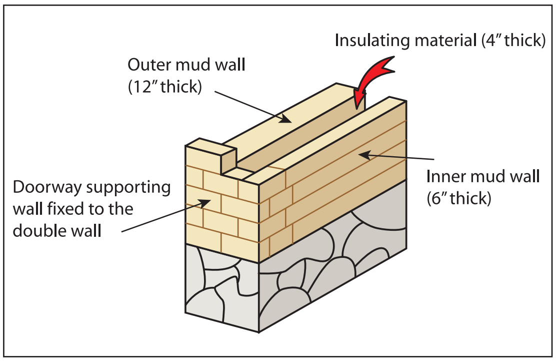


Figure 47: The masonry procedure for building the wall supporting the doorway

• Build the east or west wall (as appropriate) starting from the north and south walls as described in Technical Data Sheet 2. Line the opening for the door frame with mud bricks as shown in Figure 47.
• Continue erecting the wall until it reaches the top of the door frame.
• When the wall reaches the top of the frame, install the lintel. The best way is to balance two small beams (4' long, section 4"x3" or diameter 4") across the ends of the walls (one on the inside and one on the outside) so that they support one (or two narrow) horizontal 1" thick, 3'6" long, and 1'10" wide plank (Figure 48). A cheaper alternative is to fill the space between the two beams with wooden sticks and to place a jute bag over the sticks and beams.
• Continue constructing the double wall above the door frame according to the plan (Figure 48).
• When the wall is complete, fix the door itself to the hinges on the door frame.
• An additional half shutter covered with chicken mesh or metal bands can be added to the outside of the door. This can be closed to keep animals out when the greenhouse is ventilated by opening the main door (Figure 49).

Figure 48: The masonry procedure for building the wall supporting the doorway

Figure 49: A second shutter covered by metal bands

TECHNICAL DATASHEET 5: MAKING AND INSTALLING THE WALL VENTILATOR

Principle

In order to cool the greenhouse by natural ventilation, a side shutter is installed across from the main door in the opposite wall.

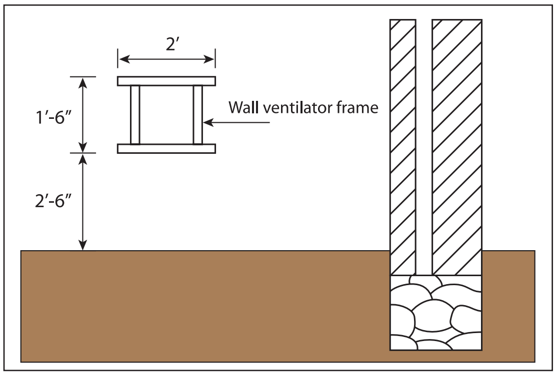


Figure 50: Diagram of shutter frame installation

Carpentry

The ventilator is composed of a fixed frame and an articulated shutter.

The shutter frame

• Use pieces of timber of cross-section 4” x 3” to make a fixed frame of outer dimensions 2′ x 1’6” as shown in Figures 50 and 51.
• Cut the inner edges similar to the way shown in Figure 43 (Technical Datasheet 4).
• Paint the frame white or use wood impregnated with oil to prevent weathering.

The shutter

• Make a frame with outer dimensions 1’2”x 1’4” using wooden battens of cross-section 2”x1½”.
• Cut two pieces of plywood 1’2”x 1’4”, one at least 6 mm thick (for the outside); and one 4 mm or more thick (for the inside). Paint them white or impregnate with oil.
• Nail one piece of plywood to one side of the assembled frame. Turn the shutter over and fill the spaces with insulating material (straw, wild grass, sawdust, as for the door). Nail the second piece of plywood over the material. Figure 51: The ventilator frame Figure 50: Diagram of shutter frame installation 50 Solar Greenhouses for the Trans-Himalayas

Fig 51: The ventilator frame

Masonry

Figure 52: Positioning the shutter frame on the wall

• Mark the position for the shutter. It should be directly opposite the door, in other words the edge of the frame is 3’6” from the inside of the north wall (Figure 50).
• Start constructing the double wall on the opposite side of the door (the east or west wall) as explained in Technical Datasheet 2.
• Construct the wall to a height of 2’6” feet above the ground. At the position of the ventilator, install a layer of bricks horizontally (across both walls and the cavity) as the last layer as shown in Figure 52.
• Install the shutter frame (outside dimensions 2’x1’6”) at the centre point of the wall width (above the inside edge of the load-bearing wall) as shown in Figure 52. Orient the frame so that the shutter will open to the inside.
• Continue erecting the wall around the frame, leaving an opening throughout the width of the wall.
• When the wall reaches the top of the frame, place one (or two) horizontal planks (1” thick, 2’6” long and 1’10” wide) or a layer of sticks over the top of the frame to support the wall above, as shown in Figures 53 and 54.
• Continue building the double wall (with insulation) on both sides of the ventilator and above the lintel to the full height shown in the diagram.
• When the wall is complete, attach the shutter to the hinges on the shutter frame.
• Cover the external side of the shutter with chicken mesh so that animals cannot enter the greenhouse when the shutter is open (Figure 53).

Figures 53 & 54: Inside and outside views of installed side shutter with chicken mesh outside

Technical datasheet 6: constructing the roof

Masonry and Roof Supports

The north and side-walls of the greenhouse are constructed in a shape that supports the roof.

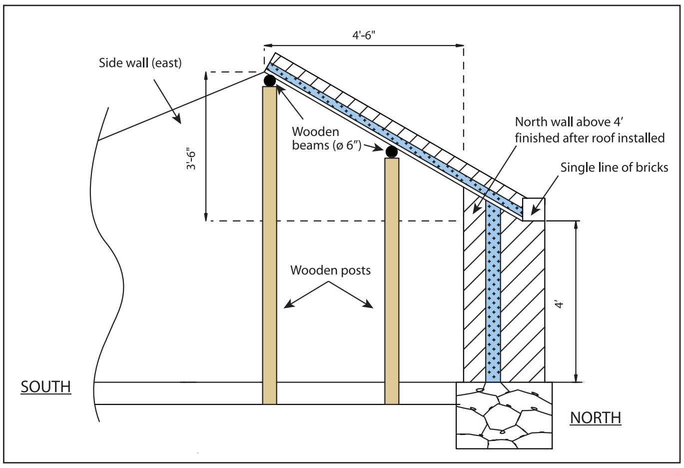


Figure 55: Position of roof and supports

Figures 56: Fixing the beam to a post, Ladakh (top) and Qinghai (bottom)

• Start erecting the north wall and side-walls following the guidelines given in Technical Datasheet 2. Complete to a height of 4'.

• When the north wall reaches a height of 4' above the foundations, build a single line of bricks of width 6" along the outside of the wall to sustain the roof material, as shown in Figure 55. Stop building the north wall.

• Build the east and west walls to the shape marked out (Technical Datasheet 2).

• Prepare two wooden beams 6" in diameter, each the same length as the greenhouse including the end walls (32'), or four beams each 16' long, or six beams each 11' long. Impregnate with oil to make them moisture resistant. Full 32' long beams are the most suitable.

• If necessary, join two (or three) beams together to achieve the length. For three beams, two posts are required as support.

• Install one (or two) vertical wooden posts (ø 6") impregnated with oil at equal intervals along the line marking the top edge of the roof to support the main roof beam. A second set of posts can be added inside the first to support the second roof beam depending on the materials used and design (as in Figure 55). This second set is never required in Design 3.

• Lay the main beam across the end walls at the point marking the edge of the roof and fix to the supporting posts using one of the two techniques illustrated in Figures 56.

• The second (inner) beam can be installed in the same way using posts, or supported by the cross-beam to the north used to stabilise the main beam (see next step), or supported by the partition walls (Figure 42). The inner beam supports the bottom of the shutter frame(s) (Figure 57).

• The roof structure is stabilised by a cross-beam towards the north or south. Either

a) cross beam to the south. Fix a 6" diameter crossbeam to the centre of the top beam (where it is supported by the post), with one end pressing against or under the beam and the other on the foundation of the south wall. This is stronger, but it reduces the freedom of movement inside the front part of the greenhouse (Figures 10 and 13). Or

b) cross beam to the north from the top of the roof to the top of the north wall. Fix an 8" diameter beam to the centre of the top beam (where it is supported by the post), with one end under the beam and the other resting on the top of the north wall (Figures 15 and 38). Or

c) cross beam to the north from the top of the roof to the bottom of the north wall. Fix a 6" diameter beam to the centre of the top beam (where it is supported by the post), with one end under the beam and the other resting on the bottom of the north wall (Figure 58).The most durable greenhouses are constructed with solutions a) and c).

• Install the top ventilator frame(s) as explained in Technical Datasheet 7.


Figure 57: Roof structure with two beams and shutter frames in position in Spiti


Figure 58: Cross beam to the south


Figure 59: General view of greenhouse structure

Note: If wooden beams are cheap, a stronger roof can be constructed using a single horizontal top beam (6'' diameter) with transversal joists (4'' diameter) every 2 feet resting at the bottom on the north wall and at the top on the horizontal beam (see Figure 59).

Constructing the Roof

The basic composition of the roof is shown in Figure 60.

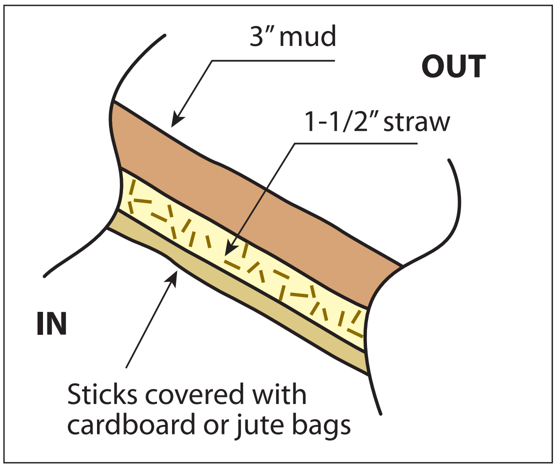


Figure 60: Roof composition

• Place thick sticks or bamboo canes (about 1" diameter) in a continuous layer lying across the beams with their lower ends resting against the line of mud bricks at the edge of the north wall (Figure 61). Trim the sticks to the correct length (7'). The sticks can be nailed to the top of the beam to prevent bending.


Figure 61: The layer of sticks forming the underside of the roof

• Completely cover the sticks with a layer of cardboard or jute bags.

• Cover the cardboard or jute bags with a 1½" (Design 1) or 2" (Designs 2, 3, 4) thick layer of straw.

• Apply a 3” thick layer of mud mixed with coarse chopped straw (‘pushka‘ in Ladakh) (Figure 62).

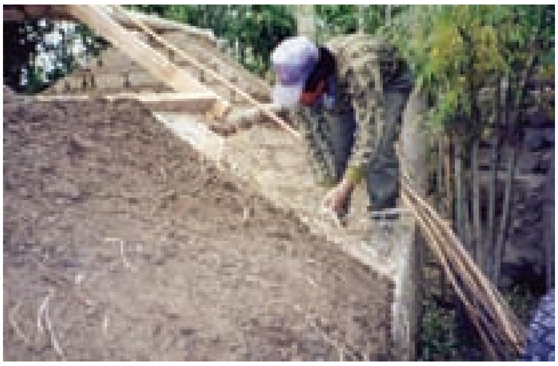


Figure 62: Applying the layers of cardboard, straw, and mud

• A white cloth may be added under the roof to increase the insulation and reflect more solar radiation onto the crops (Figure 63).

Figure 63: A white cloth added under the roof

• Do not use polythene film for any of the layers of the roof, as it will cause the sticks to rot. The roof must be able to breathe in order to avoid trapping moisture.

• After the roof has been constructed, build the inner part of the north wall up to the sticks or bamboo as shown in Figure 55.

Note: in rainy areas, a small overhang (about 6’’ wide) made with metal sheet or small wooden sticks can be added at the back of the greenhouse to protect the wall from rain (Figure 64).

Figure 64: Small overhang at the back of a greenhouse in Spiti

In some places, such as Qinghai, timber and bamboo are cheaper than beam and sticks (Figure 65).
The bamboo canes are nailed onto the wooden joists (Figure 66).

Figures 65 & 66: A roof structure made of timber and bamboo (Qinghai)

TECHNICAL DATASHEET 7: MAKING AND INSTALLING THE ROOF VENTILATOR (SHUTTER)

Principle

During spring and summer (April to September), the air in the greenhouse can become very hot reaching temperatures of 45°C or more. Temperatures above 30°C can damage the vegetables, so when the interior temperature rises above 28°C, the greenhouse has to be cooled.

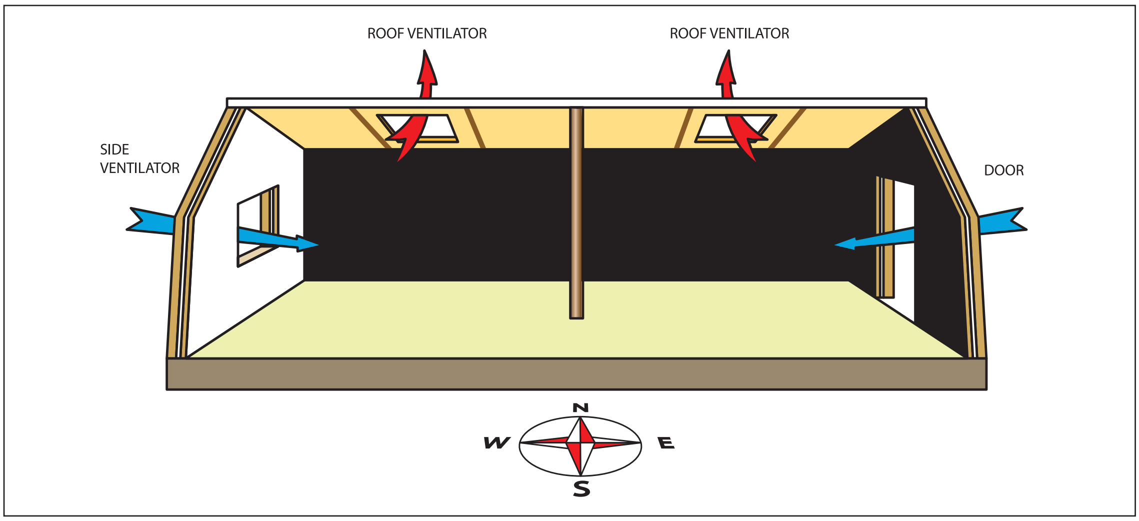


Figure 67: View of air circulation through roof ventilator

Properly designed natural ventilation offers an efficient way of cooling the greenhouse: the warm air rises and leaves the greenhouse through openings in the roof, drawing in cooler air from outside through openings located at the bottom of the greenhouse. In this design, one (Designs 3 and 4) or two (Designs 1 and 2) ventilators are installed in the roof of the greenhouse, and the door and wall shutter provide the lower openings (Technical Datasheets 4 and 5). The ventilation system is shown schematically in Figure 67. When the interior temperature rises above 28°C, all the ventilators are opened to cool the greenhouse (Figure 68). When the temperature falls below 28°C, they are closed.

Figure 68: Inside view of the roof shutter propped open

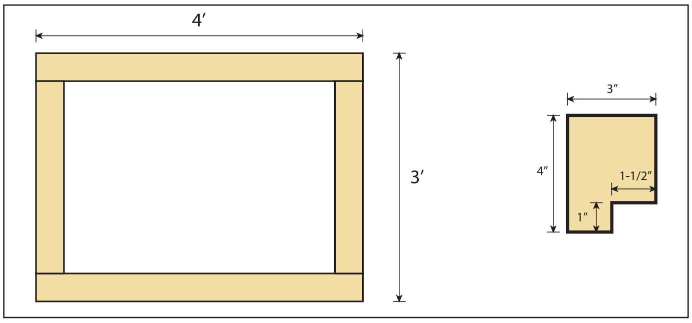


Figure 69: Construction of the frame

Carpentry

The ventilator is composed of a fixed wooden frame and an insulated articulated shutter which can be opened and shut manually. The construction method is similar to that for the door and wall ventilator, but the upper side of the shutter is covered with a metal sheet.

The shutter frame

• Use pieces of timber of cross-section 4" x 3" to make a fixed frame of outer dimensions 4' x 3' x 4" as shown in Figure 30. Cut the inner edges as shown in Figure 69 in order to fix the shutter and make the shutter/frame joint air tight.

• Paint the frame white or use oiled wood to prevent weathering.

The shutter

• Make a frame with outer dimensions 2'9"x 3'9" using wooden battens of cross-section 2" x 2".
• Cut a piece of 4 mm plywood the same size as the frame and nail it to the internal side of the assembled frame.
• Turn the shutter over and fill the spaces with insulating material. The best material is 'machine straw', but ordinary straw, wood shavings, and horse dung are also suitable. Sawdust and goat dung, which may leak, should be avoided.
• Nail a metal sheet to the external side of the frame to cover the insulating material.
• Paint the inner side of the shutter white to reflect the solar radiation to the crops. A coating of waterproof paint can be added to the outer side of the shutter to protect the metal sheet and help prevent water infiltration.
• Take a 4' long flat iron bar. Drill 5mm diameter holes every 4" along the lower half and attach to the inside of the shutter at centre bottom with a 2" hinge. The bar is used to push and pull the shutter open and shut, and to prop it fully or half open (Figures 38, 68).

Installation

The roof ventilator frames are installed at the same time as the roof structure is constructed (Figure 70). In Designs 1 and 2 two frames are inserted each located 7' from the inside sidewall, and fitted into the roof. In Designs 3 and 4, a single frame is installed in the roof midway between the two side-walls.

• Place the frame lengthways so that the top is resting on the main roof beam and the bottom on the second roof beam in such a way that the shutter will open to the outside (Figures 70 and 71). The canes or sticks that provide the base of the roof lie between the frame and the lower beam (Figure 38).

Figure 70: Fixing the frame of the roof shutter

Figure 71: Open roof shutter from outside

Figure 72: Open roof shutter from inside

• Nail the frame to the beams and continue to construct the roof around it so that it is embedded in the layers that make up the roof (Figure 70).
• Fix the shutters on the top of the frame to the outside with two hinges after the roof is completed.
• Hammer a nail into the centre of the lower part of the frame or the inner beam inside the shutter in such a way that it can slip into the holes in the iron rod or bar attached to the shutter and be used to prop the shutter open (Figures 38, 72). The amount of ventilation is regulated by using different holes in the bar to prop the shutter partially or fully open.
• Place a strip of rubber along the shutter/ frame joint to make it air tight when the ventilators are closed at night.

Note: A centre strut can be added to the frame to make it stronger (Figure 72).

TECHNICAL DATASHEET 8: INSTALLING THE POLYTHENE SHEET

Principle

It is very important point to ensure that the polythene sheet is stretched tight and attached firmly to prevent it flapping in the wind. If this is done properly, the sheet can last as long as seven years. If not, damage resulting from flapping and rubbing can destroy the sheet in one season. Polythene expands with heat, so it should be fixed during the warmest hour of a sunny day when it is well-expanded so that it becomes taught as it cools. If it is fixed when cold, it will later expand and become loose, and be more susceptible to wind damage.

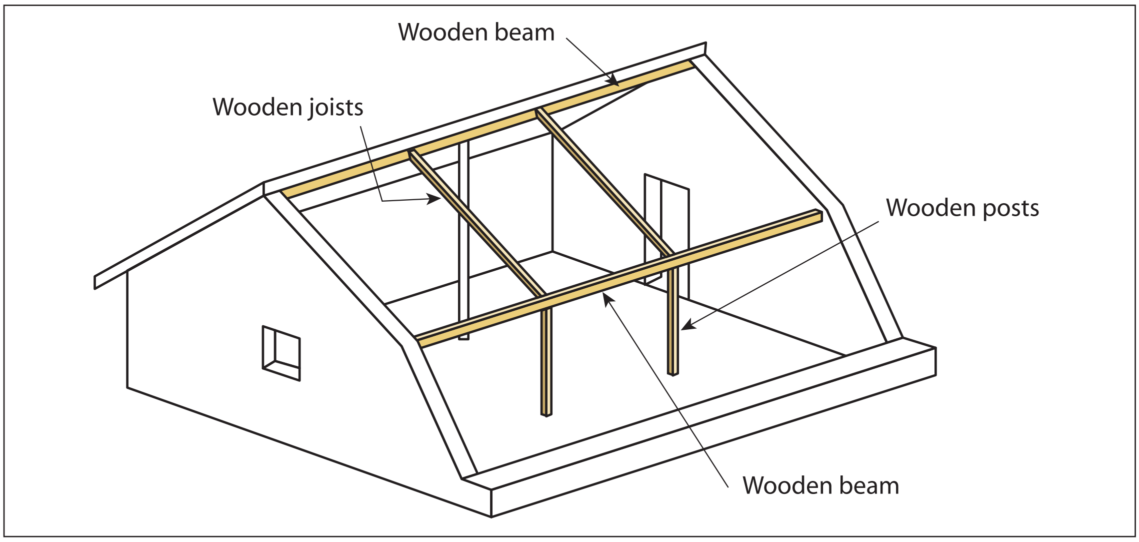


Figure 73: Wooden support structure for the polythene sheet

Constructing the Support Structure

The polythene for the front part of the roof can be supported by a wooden structure or a structure made out of reused steel pipe. Construction of the wooden structure is described below and shown in Figure 73 and 74. Steel pipe structures are constructed in a similar way to provide the same support shape.

• Prepare 2 wooden posts (4" diameter, 5'6" long) and 3 wooden beams (3" x 2" section, 11' long). Round beams are also suitable. (It is also possible to use 2 wooden beams 16' long, with 3 wooden posts as support.)

• Fix the 2 posts at a position 9' from each side-wall, and 1'6" from the inside edge of the south side of the greenhouse along the line that marks the change in wall angle. Embed the posts 1' into the ground (1'6" below the outside ground level) so that the tops reach a line joining the walls at the point where the wall angle changes.

• (If a double layer of polythene is used the thinner inner sheet is draped in position over the posts before the next step, see below.)

• Fix the 3" x 2" (or round) wooden beams on a line from the top of the walls (at the position of the angle change) across the top of the posts. The beams should be embedded in the sidewall, cut to size, and nailed to the top of the posts.

• Add wooden joists between the central supports and the top beam, one above each post and/or at intervals as described below. The joists can be 2" diameter wooden sticks, 3" x 2" wooden strips, or strips of 4" bamboo split into quarters. The number and spacing depend on the wind and snow load. More joists provide more support and reduce the danger of wind damage, but they also reduce the solar transmission and impair plant growth.

❖ For low wind or snow load space joists at about 5'. No transversal iron wires are required.
❖ For medium wind or snow load space joists at about 4' and add transversal iron wires (2 mm diameter) every 3'.
❖ For high wind or snow load space joists at about 3' 4" and add transversal iron wires (2 mm diameter) every 2'.
❖ Paint the iron wires white to prevent them burning the plastic sheet in summer).

Figure 74: Wooden support structure for the polythene sheet (Lowgar, Afghanistan)

• Other methods preferred by local builders are also possible, see for example Figure 42.

• Add additional joists between the central support and the foundations of the south wall as a continuation of the upper joists. The joists should not rest directly on earth; this is less durable because the earth layer crumbles (Figure 75). Iron wire is not needed.

Appropriate Technology for Asia

Figure 75: Joists balanced on a crumbling earth layer (outside ground level) in a greenhouse without southern foundations

• Smooth the surface of the wooden support structure as much as possible, especially at the angle, to prevent damage to the polythene sheet. Cloth or sacking can be added between the wooden beams and the polythene film to provide further protection.

Attaching the Polythene Sheet

Single layer of polythene (Designs 1 and 2)
• Purchase a UV resistant polythene film, 0.4 mm thick, at least 32’ long and 18’ wide

• During the warmest time of a sunny day, lay it over the greenhouse from top to bottom.

• Roll the top end of the polythene around a beam, bricks, or a pipe and lay this just behind the main beam on the fixed roof (Figure 71). Weight the rolled over edge of the polythene down with mud bricks. First place sacking or jute bags (not plastic) or a layer of earth on the polythene and lay the bricks on this to avoid damaging the polythene. The bricks should lie over the main beam at the top of the fixed roof (Figure 76).

• Weight the polythene onto the side-walls in a similar fashion using mud bricks, or cement bags filled with sand, laid on a layer of earth (Figure 76).

Figure 76: Close-up view of fixing the polythene sheet with mud bricks laid on a mud coating

• At the bottom, tie it as strongly as possible by hand or by using knotted galvanised iron mesh with 8”-10” openings (the sort used to construct gabions) or box straps or packing bands, stretched and anchored into the end walls. Weigh the end of the sheet down at the base onto the foundation of the south wall, again using mud bricks placed on sacking or jute bags or a layer of earth. Cover the whole area with earth (Figure 77).

Figure 77: General view of fixing of the polythene sheet

Do not cover the fixed roof with polythene. The roof must breathe or the wood and straw will rot. The polythene will be stretched to a maximum if it is tied tightly, and won't vibrate in the wind.

Double layer of polythene (Designs 3 and 4)
The steps are similar to those for a single layer of polythene, but a second layer of very thin (0.2 mm) polythene is added first below the wooden structure. This double layer of polythene acts as an insulator as long as there is a layer of air between the two sheets; thus the two sheets should not touch each other. The upper layer of polythene is 0.4 mm thick as above. The second layer must be thin (0.2 mm) to allow as much solar radiation as possible to pass through.

• Fix the posts in place as described above under 'Constructing the support structure'.

• Purchase a thin plastic sheet 32' long and cut to the width of the greenhouse with a 1' overlap each side.

• Drape the sheet over the posts in the correct position but without fixing it. A thin piece of cloth or sacking can be placed on the posts first to protect the plastic.

• Install the central beam, joists, and iron wire above the lower plastic layer as described above under 'Constructing the support structure'.

• Fix the lower polythene layer to the frame by nailing through sticks lying under the frame and polythene.

• Weight the polythene onto the side-walls using a 2" layer of mud so that an air gap will remain between the layers of polythene.

• Fix the upper polythene layer above the wooden frame as described for a single polythene layer.

Recommendations for windy weather
Where there is danger of strong wind, the polythene sheet must be supported to prevent damage. Place a rope net over the polythene sheet after installation to add load to the greenhouse and minimise wind effects on the plastic. Install a second rope net tightly below the polythene between the middle beam and the top beam (Figure 78).

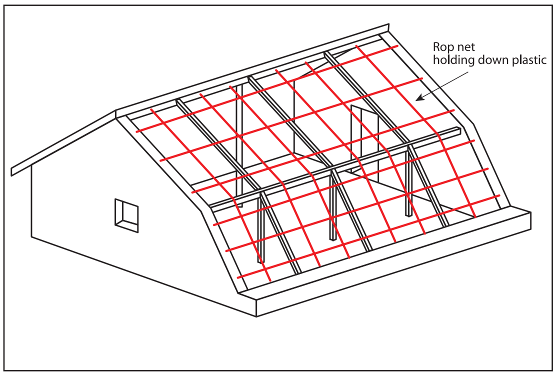


Figure 78: Rope net securing the polyethylene sheet against wind

Figure 79: South face of polythene lifted to improve cooling

Recommendations for areas with a hot climate in summer
In areas with a continental climate, the summer can be very hot (e.g. Kabul in Afghanistan). In these areas, we recommend increasing the ventilation by enlarging the surface that can be opened, especially in the lower part of the greenhouse. This can be done, for example, by lifting the polythene along its south face (Figure 79) or adding an operable frame covered by polythene. These openings must be tightly shut again if there is a chance of strong wind.
Recommendations for windy weather Where there is danger of strong wind, the polythene sheet must be supported to prevent damage. Place a rope net over the polythene sheet after installation to add load to the greenhouse and minimise wind effects on the plastic. Install a second rope net tightly below the polythene between the middle beam and the top beam (Figure 78).

TECHNICAL DATASHEET 9: INSTALLING NIGHT INSULATION

Principle

The heat loss through the polythene is very high, and if it is left uncovered at night the greenhouse can become very cold affecting vegetable growth. To prevent this, a manually operated insulator (night curtain) is drawn under the polythene after sunset and removed at sunrise. A cloth added underneath the polythene can halve the heat loss and increase the interior temperature by 5°C. But the insulation is only effective if a space is left between the polythene and the cloth and the air inside this space is trapped; the cloth must be air-tight and the join between the cloth and the polythene sealed at the top, bottom, and sides. The cloth may be wet in the morning and should dry during the day.

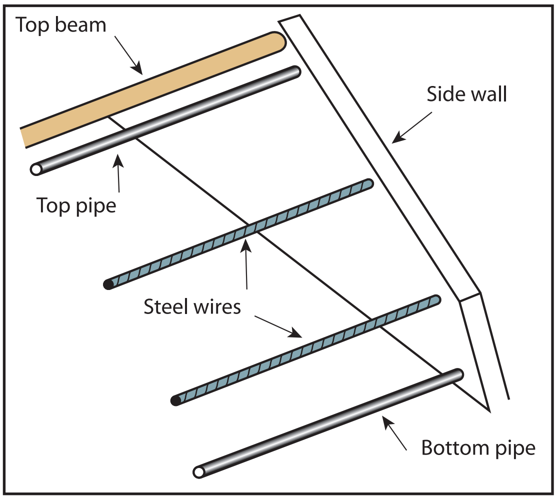


Figure 80: Diagram of framework for supporting the insulating material

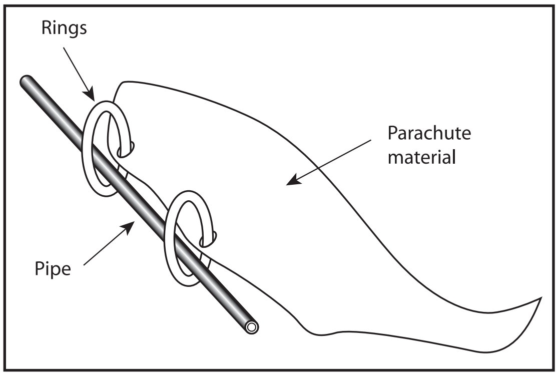


Figure 81: Attaching the cloth to the pipe (sliding device

Construction

The cloth (e.g. parachute material) is attached at the top and bottom by rings sliding on a pipe or iron wire (similar to a curtain) and supported in the middle by two steel wires (Figure 80). The cloth is made in separate pieces to fit between the posts supporting the polythene frame. The insulation is pulled to the side during the day. The cloth must be held close to the polythene so as not to damage the vegetables.

- Cut two pipes and two wires (or four steel wires) to fit between each pair of posts.
- Cut the cloth to fit the space between the posts with a 10 cm overlap.
- Make a hole every 12” at the top and bottom of the cloth, and fix the rings (Figure 81). A cheaper but less durable solution is to sew the cloth to the pipe (or wire).
- Between each pair of posts, fit two pipes or lengths of steel wire at the top (just below the main beam) and the bottom (just above the south wall foundation) of the greenhouse.
- Fix two steel wires at intervals between these as supports, the lower one at the change of angle of the wall.
- Hang the cloth(s) inside the greenhouse above the middle wires.
- Slide the rings onto the top and bottom pipes or wires.
- The gaps between the separate strips at the supporting posts can be sealed by linking the strips with buttons.

Figure 82: Night insulation in use

Technical datasheet 10: list of materials

The tables lists as a guide all the materials needed to build Design 1A. Optional components are shown in italics. The list can be modified to show the amounts needed to construct the other designs using the information given in the design plan and the technical datasheets. The numbers of days of labour shown are estimates based on experience in a number of countries; the exact times will depend on the local situation and the level of skill and training of those doing the work.

	Material required	Quantity*	Carpenter person days	Mason person days	Unskilled labour person days
1	**Foundation**				
	Excavation	234 cu.ft			3
	stone	234 cu.ft		3.5	7
	2" PCC concrete layer (M 60 kg/cm2, 1:2:4) (optional)	*21cu.ft*		0.25	0.5
	- cement	*1.5 bags*			
	- sand	*8.3 cu.ft*			
	- gravel	*16.6 cu.ft*			
2	**Walls**				
	Construction			7.5	23
	mud bricks (12" x 6" x 6") (350 cu.ft)	1800 pcs.			
	mud	154 cu.ft			
	sticks ø 2", 1' long	34 pieces			
	insulating material (straw, sawdust, etc)	11 bags			
	seabuckthorn (if available)	1 bag			
	waste planks 1'6" long, 3" wide (optional)	*100 pcs.*			
	Finishing	600 sq.ft		5	10
	mud for plaster	70 cu.ft			
	whitewash (lime)	2.75 kg			
	black powder	0.3 kg			
	straw glue	2.75 kg			
3	**Door**		2		2
	wooden timber 4" x 3" for frame	17'			
	wooden timber 2" x 11/2" for door	18'			
	6mm plywood for outside	5'2" x 2'8"			
	4mm plywood for inside	5'2" x 2'8"			
	insulating material (straw, sawdust, etc)	0.5 bags			
	hinge 4"	2 pieces			
	Door Lintel				
	timber 4" x 3" or beam ø 4"	8'			
	plank 1" thick	3'6"x1'10"			
	or sticks ø 2", 4' long	*10 pieces*			
	and jute bag	*2 pieces*			
4	**Wall ventilator**		0.5		0.5
	wooden timber 4" x 3" for frame	6'6"			
	wooden timber 2" x 11/2" for shutter	5'			
	6mm plywood for outside	1'2" x 1'4"			
	4mm plywood for inside	1'2" x 1'4"			
	insulating material (straw, sawdust, etc.)	small qty.			

	Material required	Quantity*	Carpenter person days	Mason person days	Unskilled labour person days
4	**Wall ventilator**			0.5	
	hinge 2"	2 pieces			
	chicken mesh	1'8" x 1'6"			
5	**Roof** Support Structure			2	8
	beam ø 6", 32' (*16' or 11'*) long	2 (*4/6*) pcs.			
	post ø 6", 10' long	2 pieces			
	post ø 6", 9' long	2 pieces			
	cross support ø 6", 12'6" long	1 piece			
	Roof Covering				
	sticks ø 1", 6'-9" long	200 pieces			
	cardboard	200 sq.ft			
	straw or bushes	4 bags			
	mud	65 cu.ft			
	White cloth (optional) 6' wide	*28'4"*			
6	**Roof ventilator** (for 2, 1/2 amount for 1)		2		2
	wooden timber 4" x 3"	28'			
	wooden timber 2" x 2"	26'			
	galvanised metal sheet for outside (25 gauge) 4' x 3'	2 pieces			
	or plywood for outside 6mm, 4' x 3'	*2 pieces*			
	plywood for inside 4mm, 4' x 3'	2 pieces			
	galvanised metal sheet (25 gauge) 4'x3'	*2 pieces*			
	straw	0.4 bags			
	hinges 3"	4 pieces			
	hinge 2" (for iron bar)	2 pieces			
	iron bar 4' long, 1" wide, 1/4" (5mm) thick	2 pieces			
7	**Transparent plastic covering**			1	1
	Support Structure				
	pillar post ø 4", 5'6" long	2 (*3*) pieces			
	beam ø 4" or 3" x 2", 11' (*16'*) long	3 (*2*) pieces			
	wooden joists ø 2" or 3" x 2" or ø 4" bamboo, 10' long	5 to 7 pieces			
	iron or plastic wire (ø 3mm)	55 yds			
	Cover				
	polythene sheet 18' wide, UV resistant (0.4 mm thick)	32' long			
	empty bags	20 pieces			
8	**Night insulation**		1		4
	cloth (parachute material) 16' x 10'8" long	3 pieces			
	metal wire (ø 3mm)	146 yds			
	rings (curtain rings)	64 pieces			
9	**Miscellaneous**				
	oil or varnish (2 coatings)	35 kg			
	white oil paint for opening	15 kg			
	nails	3 kg			

N.B. 1" = 1 inch = 2.54 cm; 1' = 1 foot = 0.305m; 1 yd = 3 feet = 0.915m
* 'Bags' indicates a full bag/sack of the type used to package cement, fertiliser, and other chemicals.

ANNEX: DESIGN WITH MEASUREMENTS IN CENTIMETRES

In the following pages, the four designs shown in Part B are presented with the dimensions in centimetres.

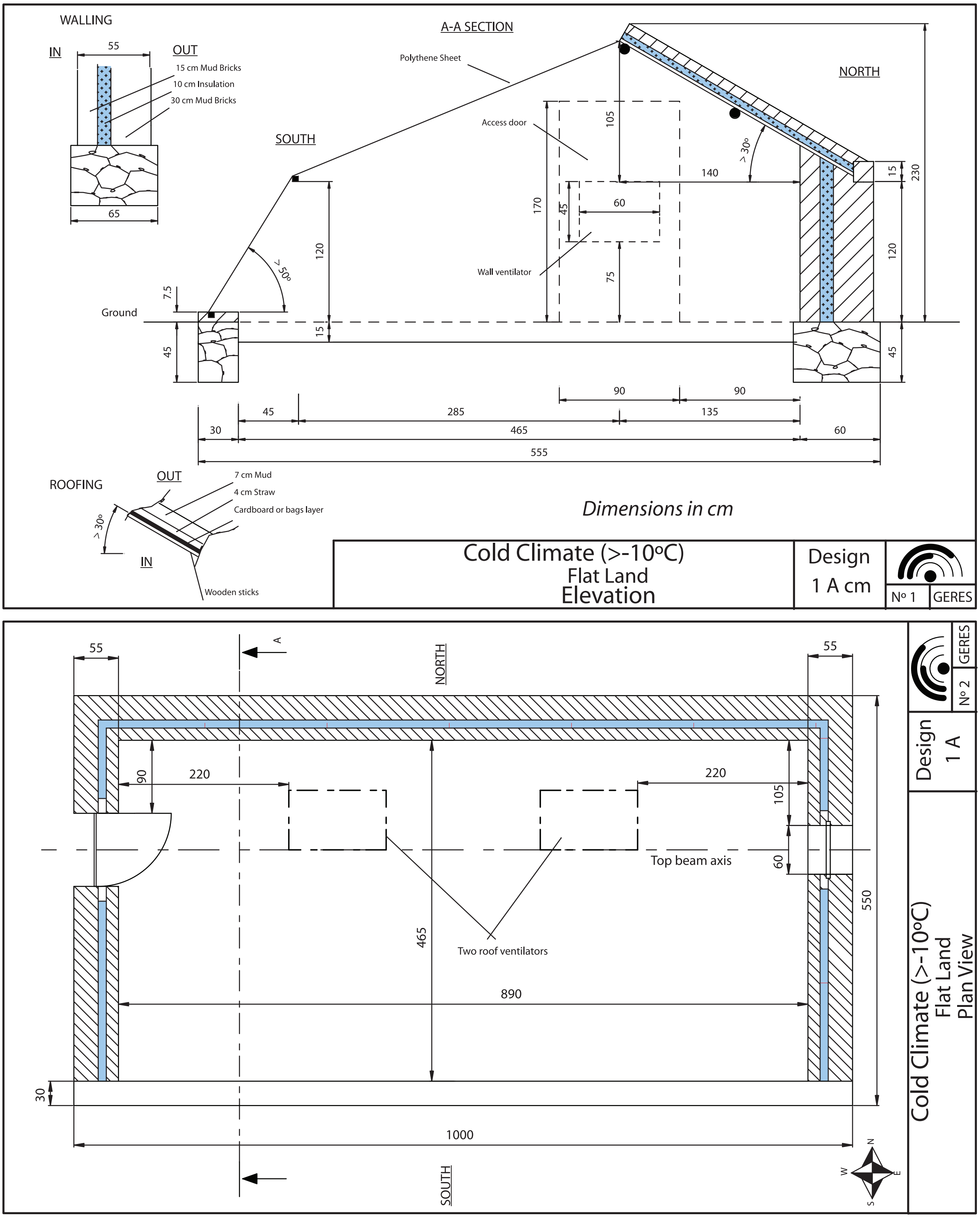
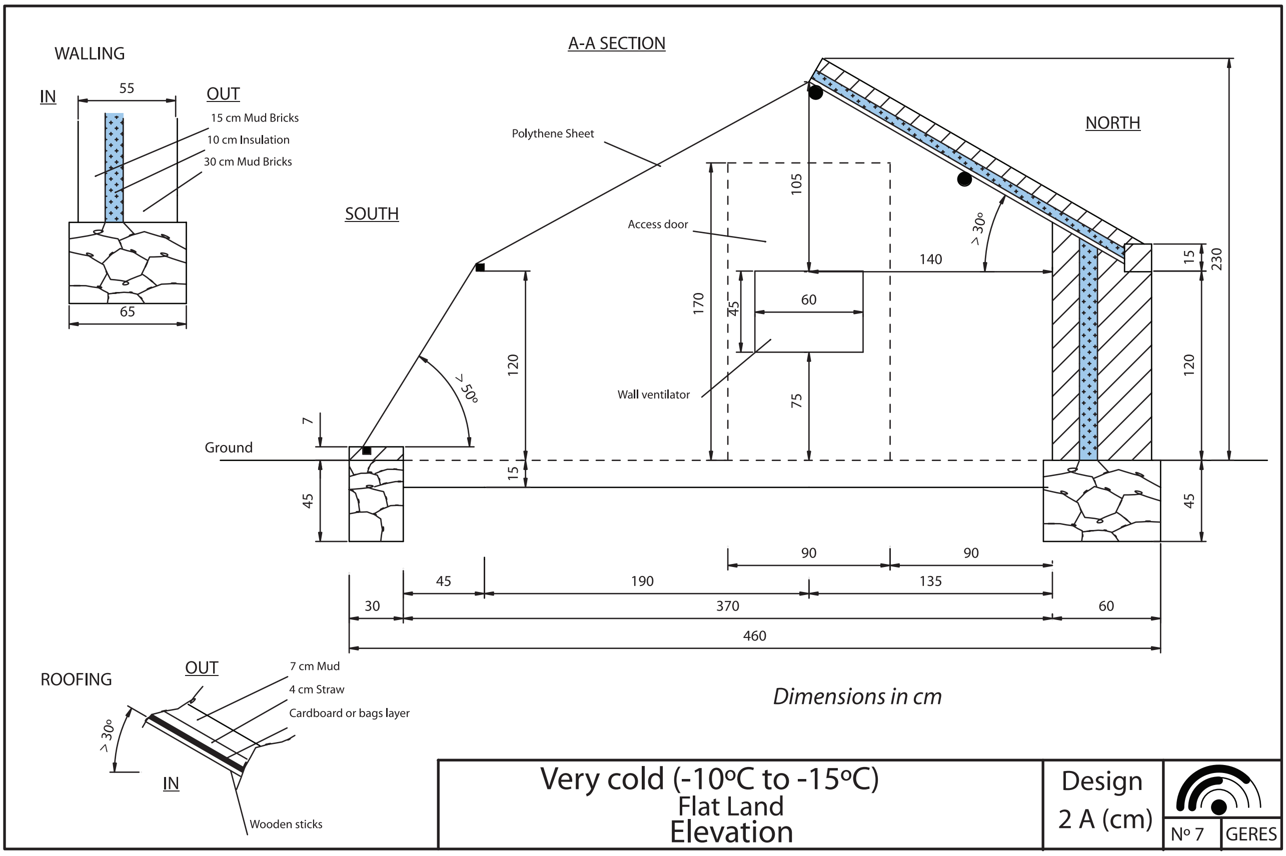


Figure 83: Design 1A (cm) - Greenhouse for cold climate, flat land



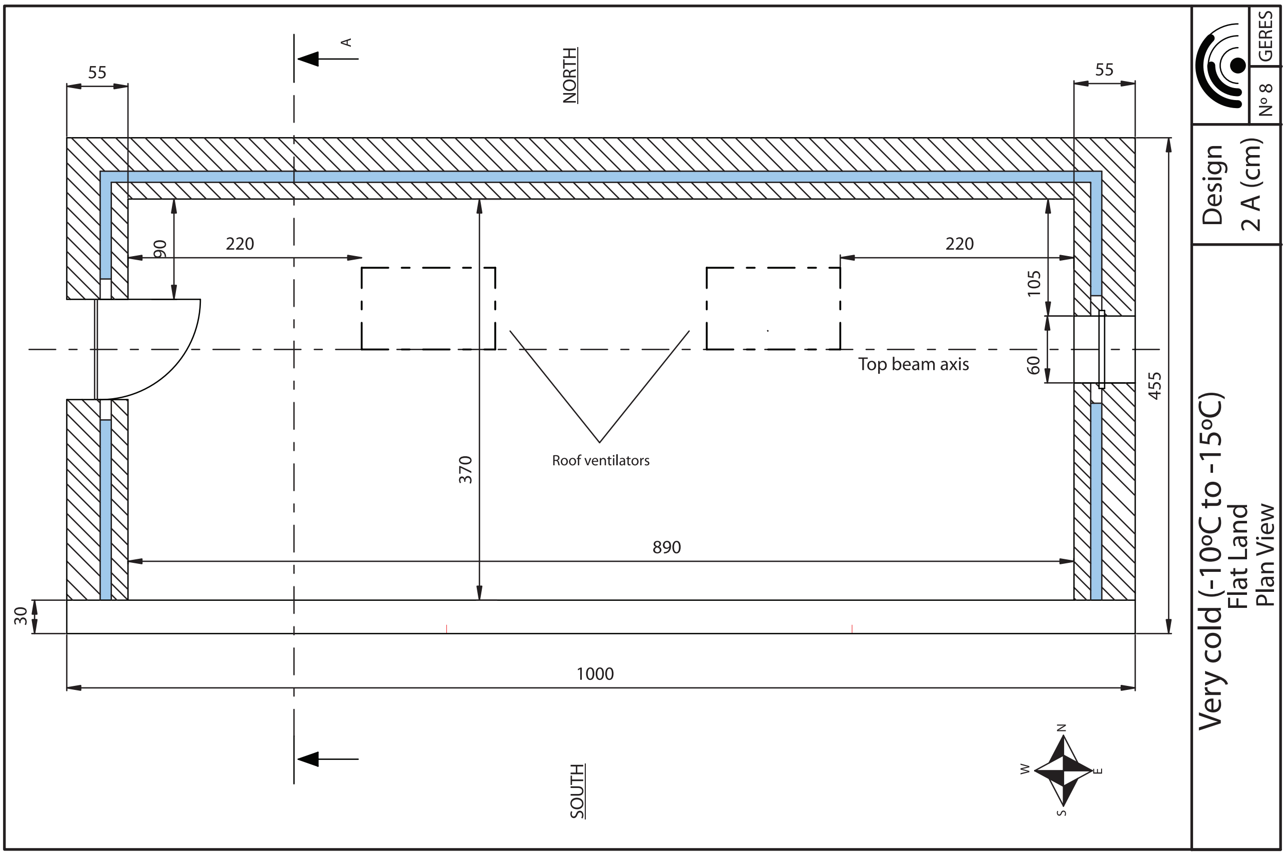
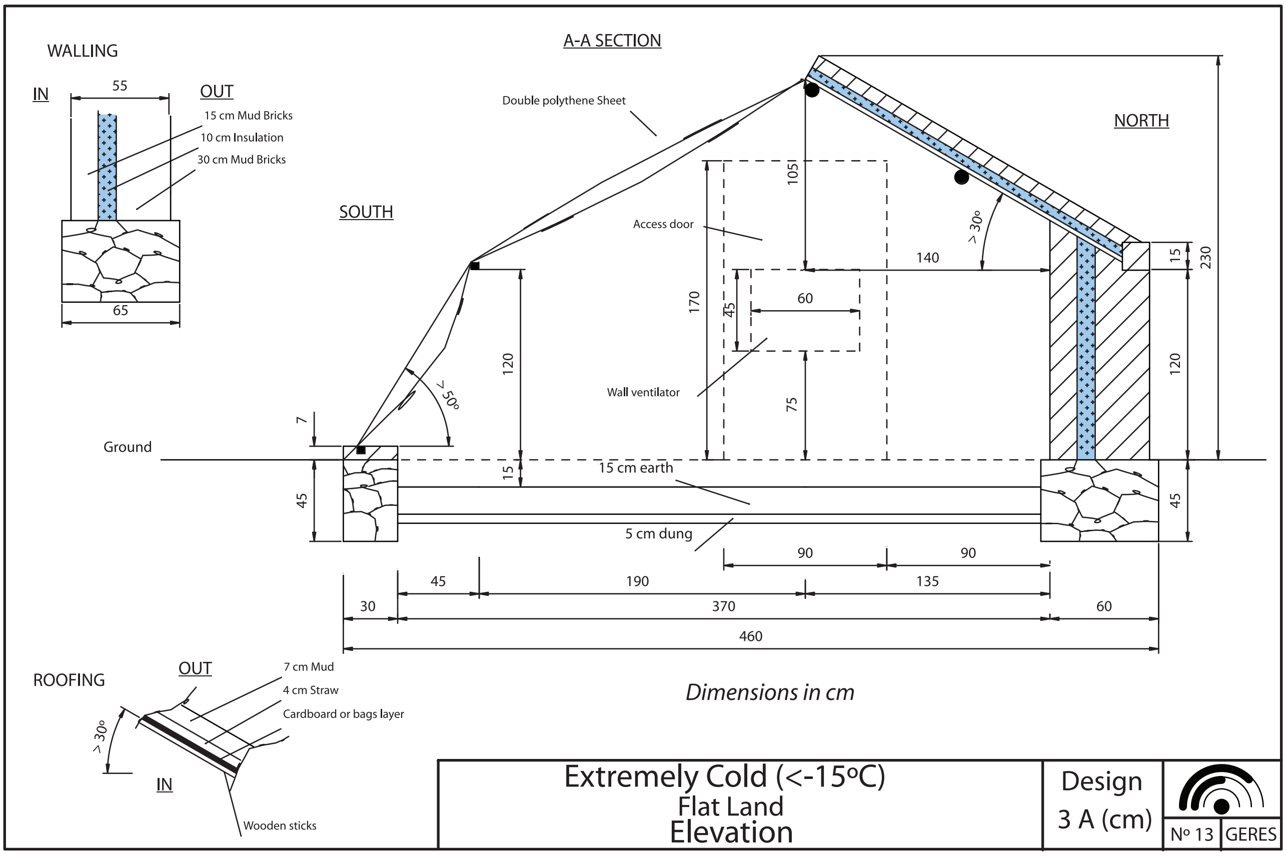


Figure 84: Design 2A (cm) - Greenhouse for very cold climate, flat land



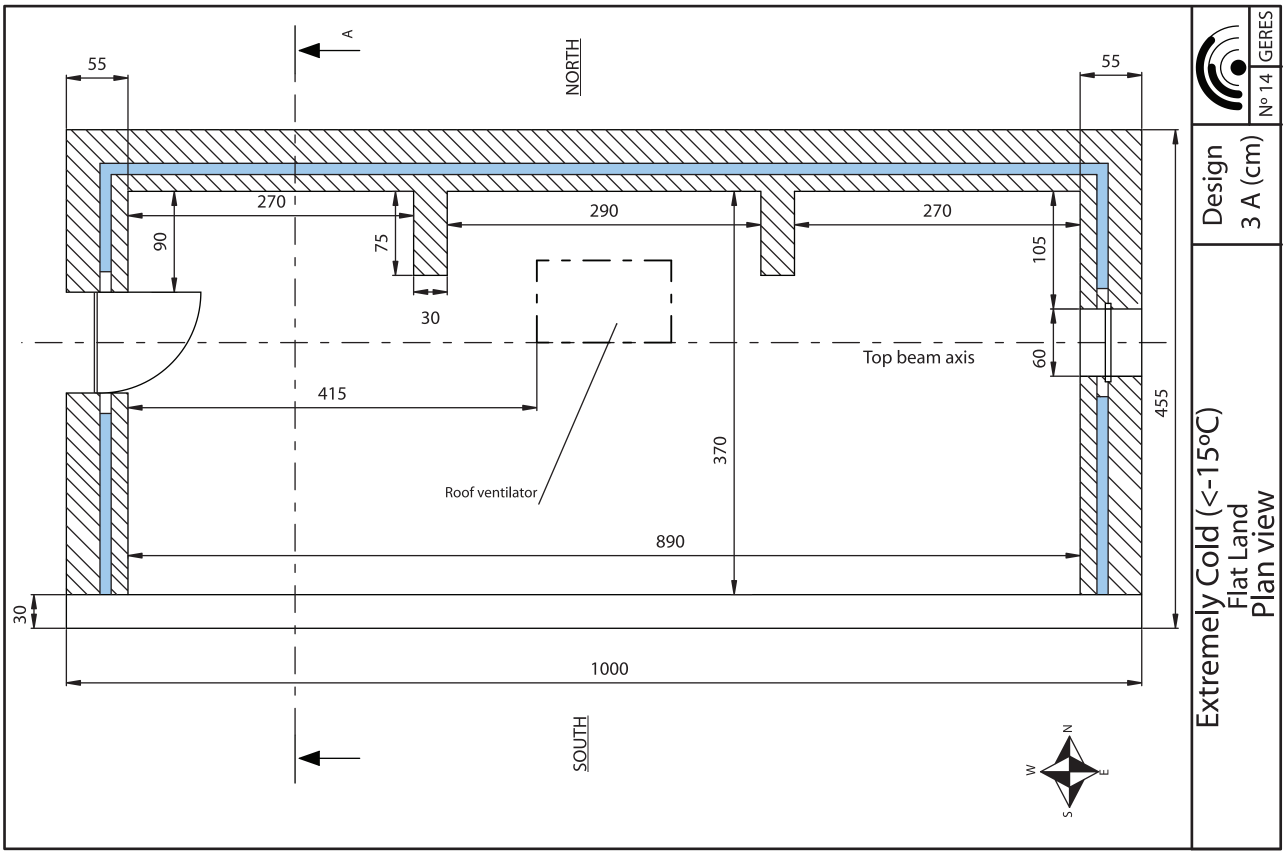
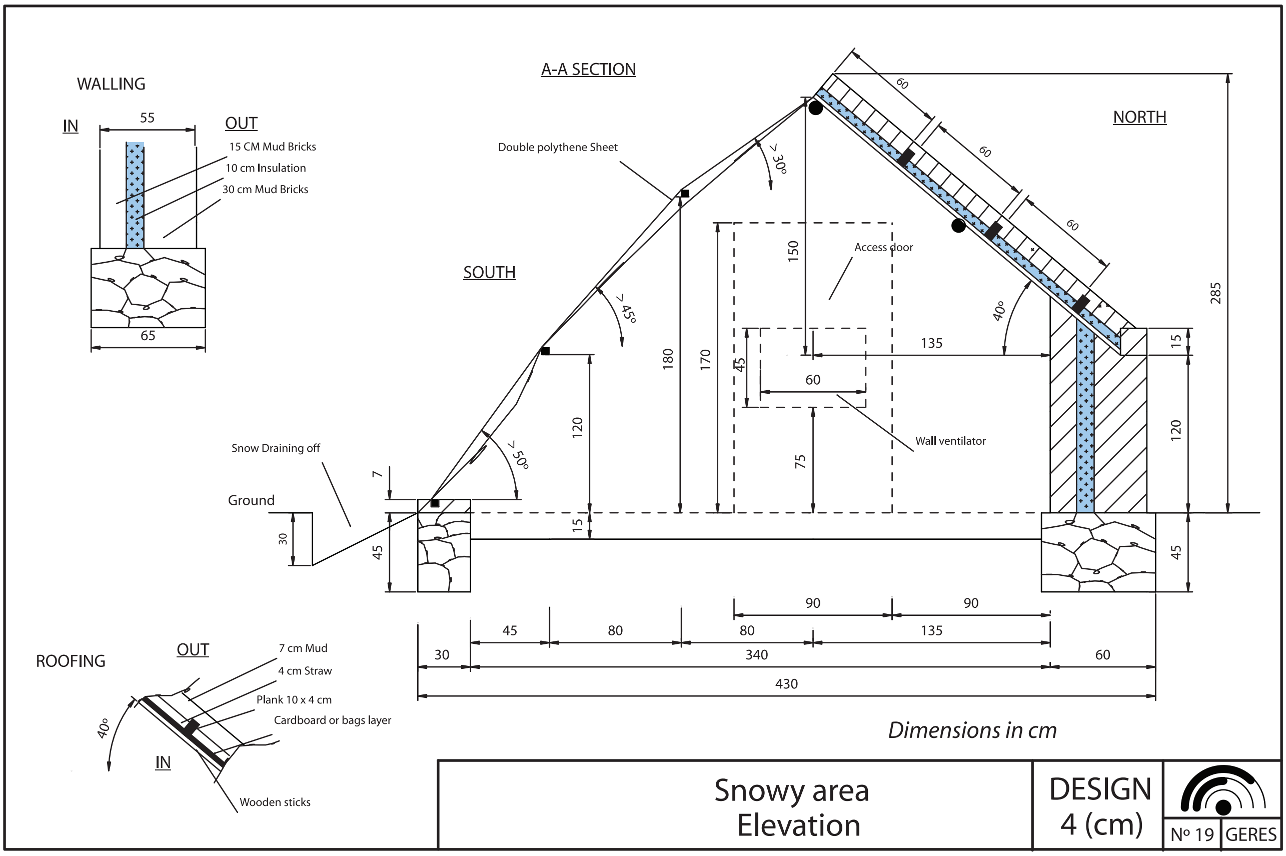


Figure 85: Design 3A (cm) - Greenhouse for extremely cold climate, flat land



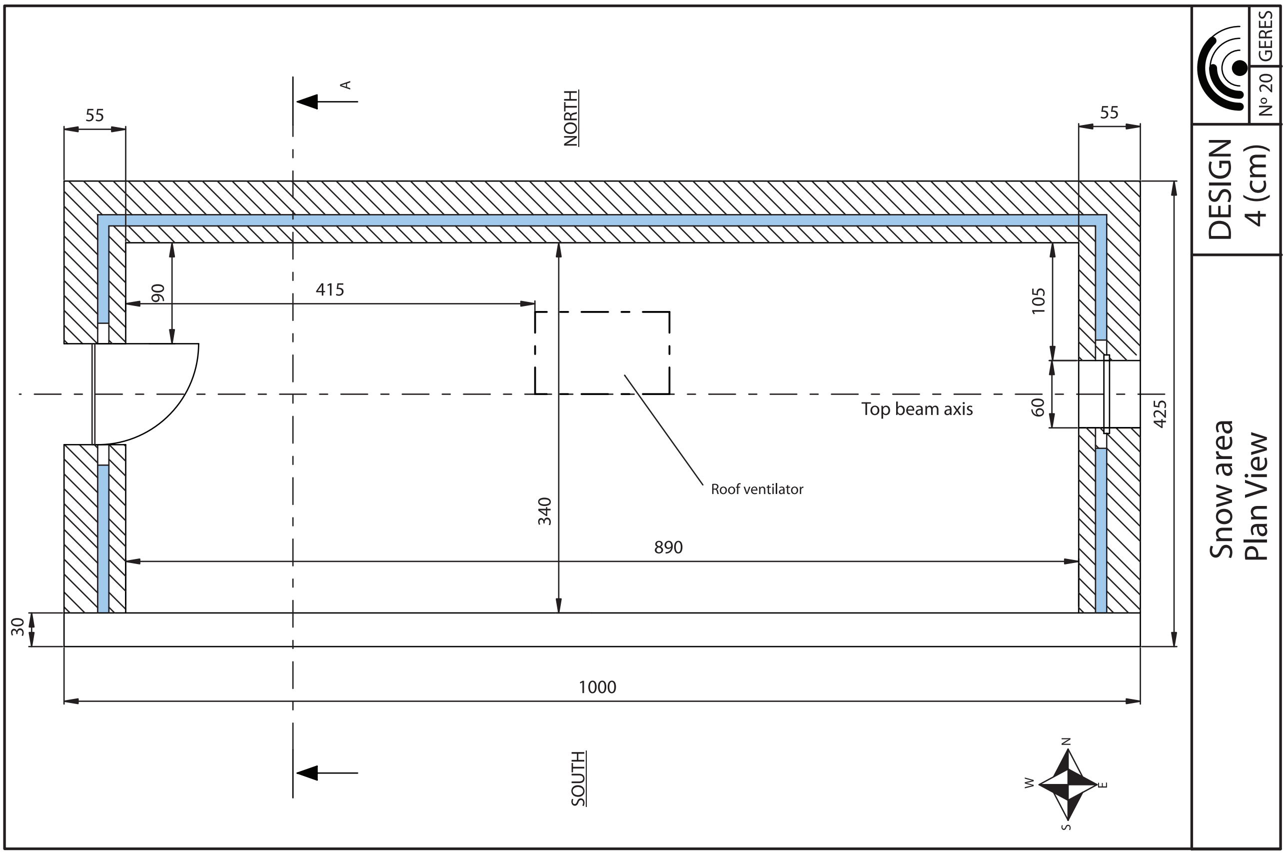


Figure 85: Design 4 (cm) - Greenhouse for snowy area, flat land

List of materials (metric)

The table lists as a guide all the materials needed to build Design 1A. Optional components are shown in italics. The list can be modified to show the amounts needed to construct the other designs using the information given in the design plan and the technical datasheets. The numbers of days of labour shown are estimates based on experience in a number of countries; the exact times will depend on the local situation and the level of skill and training of those doing the work.

	Material required	Quantity*	Carpenter person days	Mason person days	Unskilled labour person days
1	**Foundation**				
	Excavation	7 m^3			3
	stone	7 m^3		3.5	7
	2" PCC concrete layer (M 60 kg/cm2, 1:2:4) (optional)	*0.63 m^3*		0.25	0.5
	- cement	*1.5 bags*			
	- sand	*0.25 m^3*			
	- gravel	*0.5 m^3*			
2	**Walls**				
	Construction			7.5	23
	mud bricks (30 x 15 x 15 cm) (10 m^3)	1800 pcs.			
	mud	4.4 m^3			
	sticks ø 5 cm, 30 cm long	34 pieces			
	insulating material (straw, sawdust, etc)	11 bags			
	seabuckthorn (if available)	1 bag			
	waste planks 50 cm long, 7.5 cm wide (opt)	*100 pcs.*			
	Finishing	55 m^2		5	10
	mud for plaster	2 m^3			
	whitewash (lime)	2.75 kg			
	black powder	0.3 kg			
	straw glue	2.75 kg			
3	**Door**		2		2
	wooden timber 10 x 7 cm for frame	5.2 m			
	wooden timber 5 x 4 cm for door	5.5 m			
	6mm plywood for outside	160x80 cm			
	4mm plywood for inside	160x80 cm			
	insulating material (straw, sawdust, etc)	0.5 bags			
	hinge 10 cm	2 pieces			
	Door Lintel				
	timber 10 x 7 cm or beam ø 10 cm	2 m			
	plank 2.5 cm thick	100x55 cm			
	or sticks ø 5 cm, 1.2 m long	*10 pieces*			
	and jute bag	*2 pieces*			
4	**Wall ventilator**		0.5		0.5
	wooden timber 10 x 7 cm for frame	1.9 m			
	wooden timber 5 x 4 cm for shutter	1.65 m			
	6mm plywood for outside	35 x 40 cm			
	4mm plywood for inside	35 x 40 cm			
	insulating material (straw, sawdust, etc.)	small qty.			

	Material required	Quantity*	Carpenter person days	Mason person days	Unskilled labour person days
4	**Wall ventilator**				
	hinge 5 cm	2 pieces			
	chicken mesh	50 x 45 cm			
5	**Roof** Support Structure			2	8
	beam ø 15 cm, 10 m (*5 or 3.3 m*) long	2 (*4/6*) pcs.			
	post ø 15 cm, 3 m long	2 pieces			
	post ø 15 cm, 2.7 m long	2 pieces			
	cross support ø 15 cm, 3.8 m long	1 piece			
	Roof Covering				
	sticks ø 5 cm, 2.05 m long	200 pieces			
	cardboard	19 m^2			
	straw or bushes	4 bags			
	mud	1.9 m^3			
	White cloth (optional) 1.8 m wide	*8.8 m*			
6	**Roof ventilator** (for 2, 1/2 amount for 1)		2		2
	wooden timber 10 x 7 cm	8.8 m			
	wooden timber 5 x 5 cm	8.8 m			
	galvanised metal sheet for outside (25 gauge) 120 x 90 cm	2 pieces			
	or plywood for outside 6mm, 120x90 cm	*2 pieces*			
	plywood for inside 4mm, 120 x 90 cm	2 pieces			
	galvanised metal sheet (25 gauge) 120x90 cm	*2 pieces*			
	straw	0.4 bags			
	hinges 7.5 cm	4 pieces			
	hinge 5 cm (for iron bar)	2 pieces			
	iron bar 10cm long, 2.5cm wide, 5mm thick	2 pieces			
7	**Transparent plastic covering**			1	1
	Support Structure				
	pillar post ø 10 cm, 1.7 m long	2 (*3*) pieces			
	beam ø 10cm or 7x5cm, 3.3 m (*5m*) long	3 (*2*) pieces			
	wooden joists ø 5 cm or 5 x 4 cm or ø 10 cm bamboo, 3 m long	5 to 7 pieces			
	iron or plastic wire (ø 3mm)	55 m			
	Cover				
	polythene sheet 6 m wide, UV resistant (0.4 mm thick)	10 m			
	empty bags	20 pieces			
8	**Night insulation**		1		4
	cloth (parachute material) 4.9 x 3.5 m	3 pieces			
	metal wire (ø 3mm)	146 m			
	rings (curtain rings)	64 pieces			
9	**Miscellaneous**				
	oil or varnish (2 coatings)	35 kg			
	white oil paint for opening	15 kg			
	nails	3 kg			

* 'Bags' indicates a full bag/sack of the type used to package cement, fertiliser, and other chemicals.

ABOUT THE AUTHORS

Vincent Stauffer, a French thermal engineer, is the main contributor to this manual: he has led the design process, the experimentation, and the dissemination of the greenhouse model which is presented. He has been working since 1992 in the field of solar energy and since 1998 in the Hindu Kush-Himalayan region. At GERES, he is contributing to the development of solar poultry farms, passive solar housing, improved stoves, and food and wool processing in the Hindu Kush-Himalayas.

Important contributions were also made by the following:

Tashi Tokhmat, **Dorge Raftan**, and **Gulam Razul** (LEHO) – carried out the first experiments and suggested the main improvements.

Christophe Viltard and **Laetitia Rivagorda** (GERES) – did the agricultural experimentation **Philippe Rynikiewicz**, **Benoit Giraud** and **Claude Tournellec** (GERES) – suggested practical improvements.

Rodolphe Castelani (GERES) – did the drawings
Thomas Mansouri (GERES) – set up the manual
Alain Guinebault (GERES) – initiated the projects

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