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

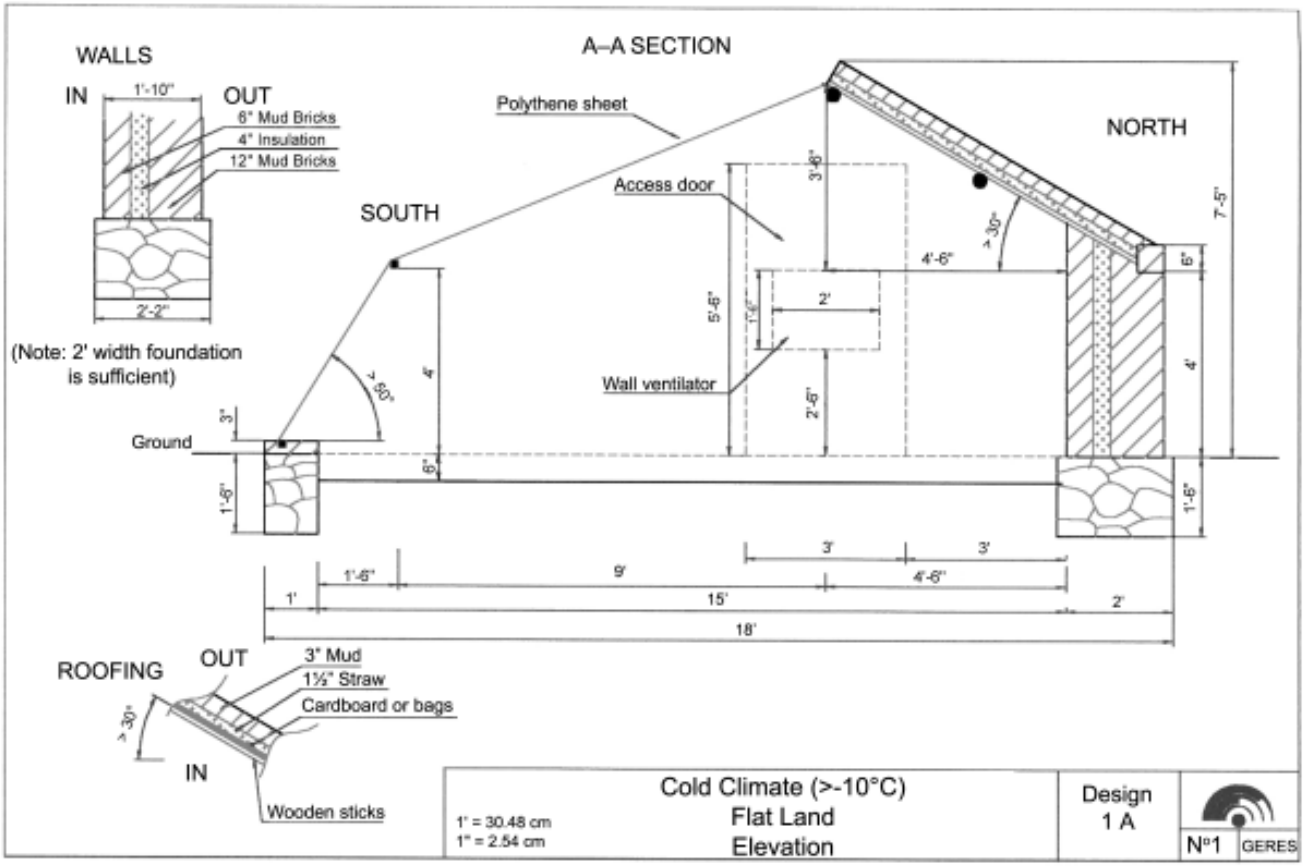
There are three basic designs to suit different climates, each with three different basic shapes to suit the different types of site, and one basic design for areas of high snowfall (see Section A). The detailed construction plans for each of these are provided in the following.

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	30°
	Depth of soil surface below outside level	6"
INSULATION	Wall insulation	4"
	Roof insulation	1½"
	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).



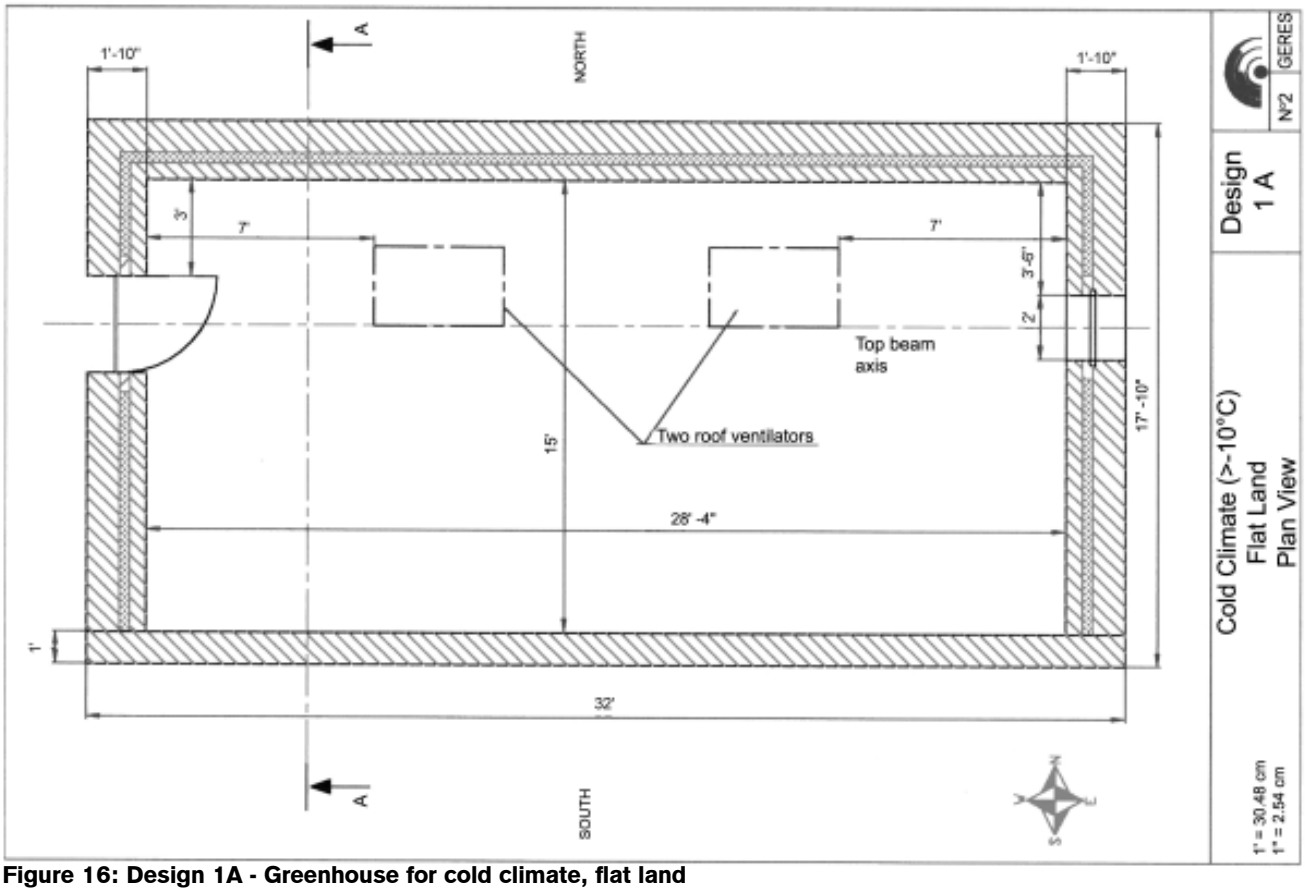
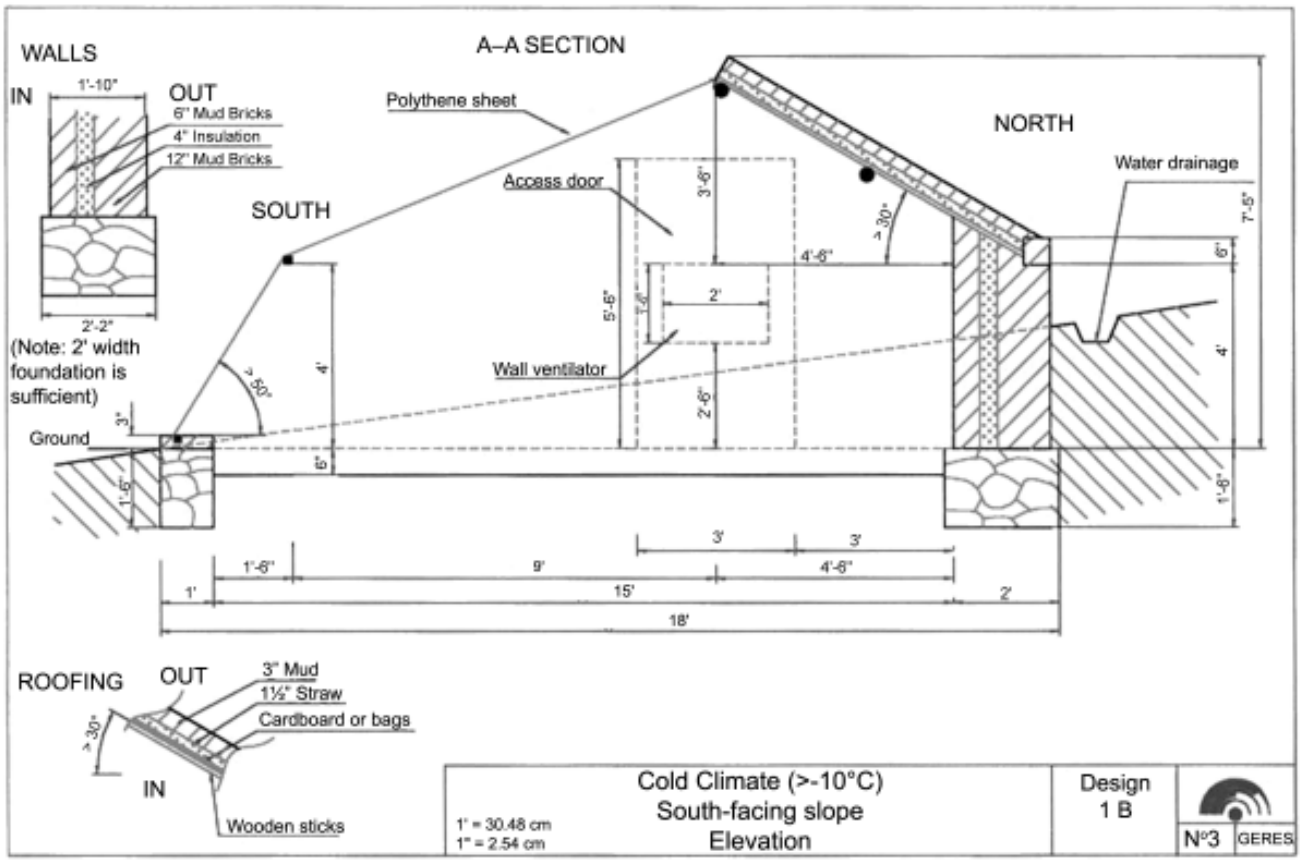


Figure 16: Design 1A - Greenhouse for cold climate, flat land



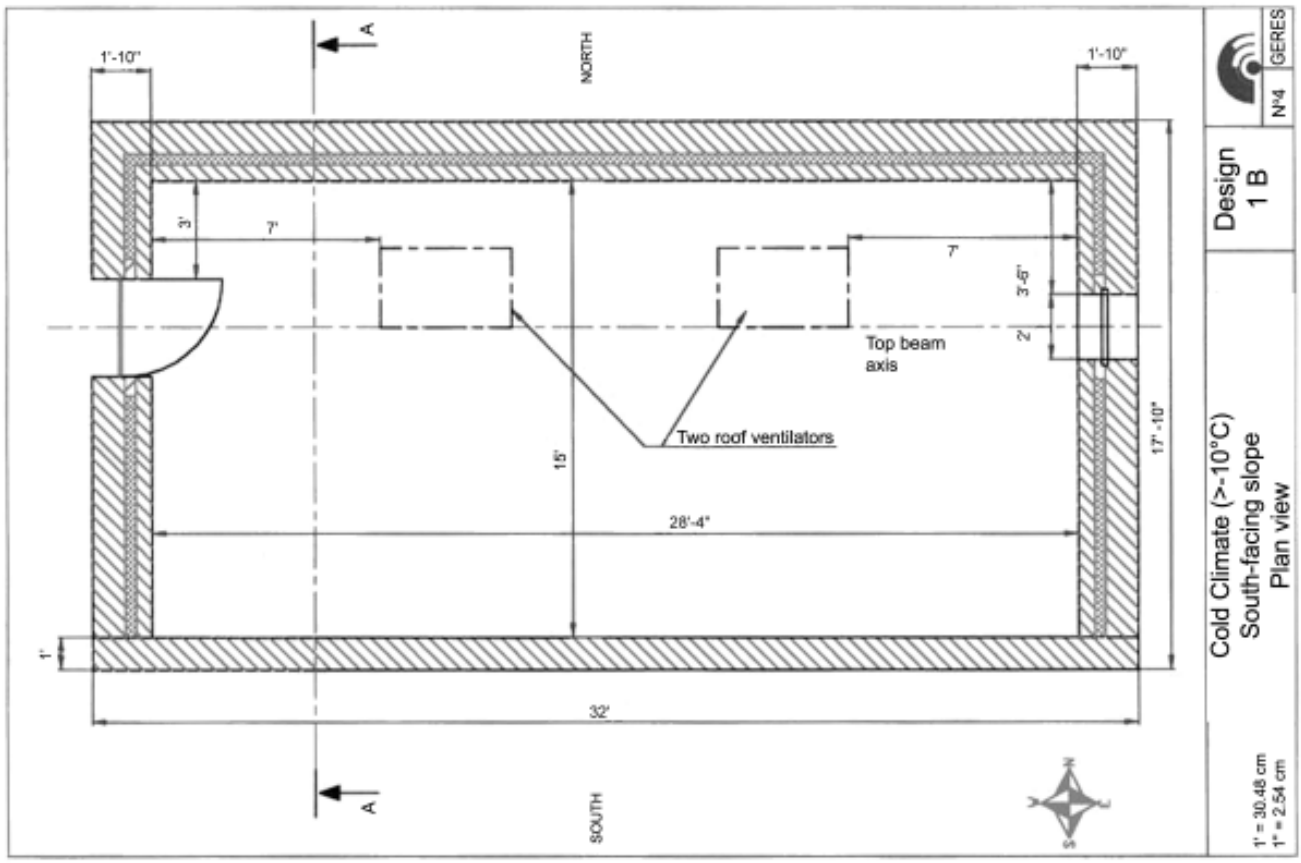
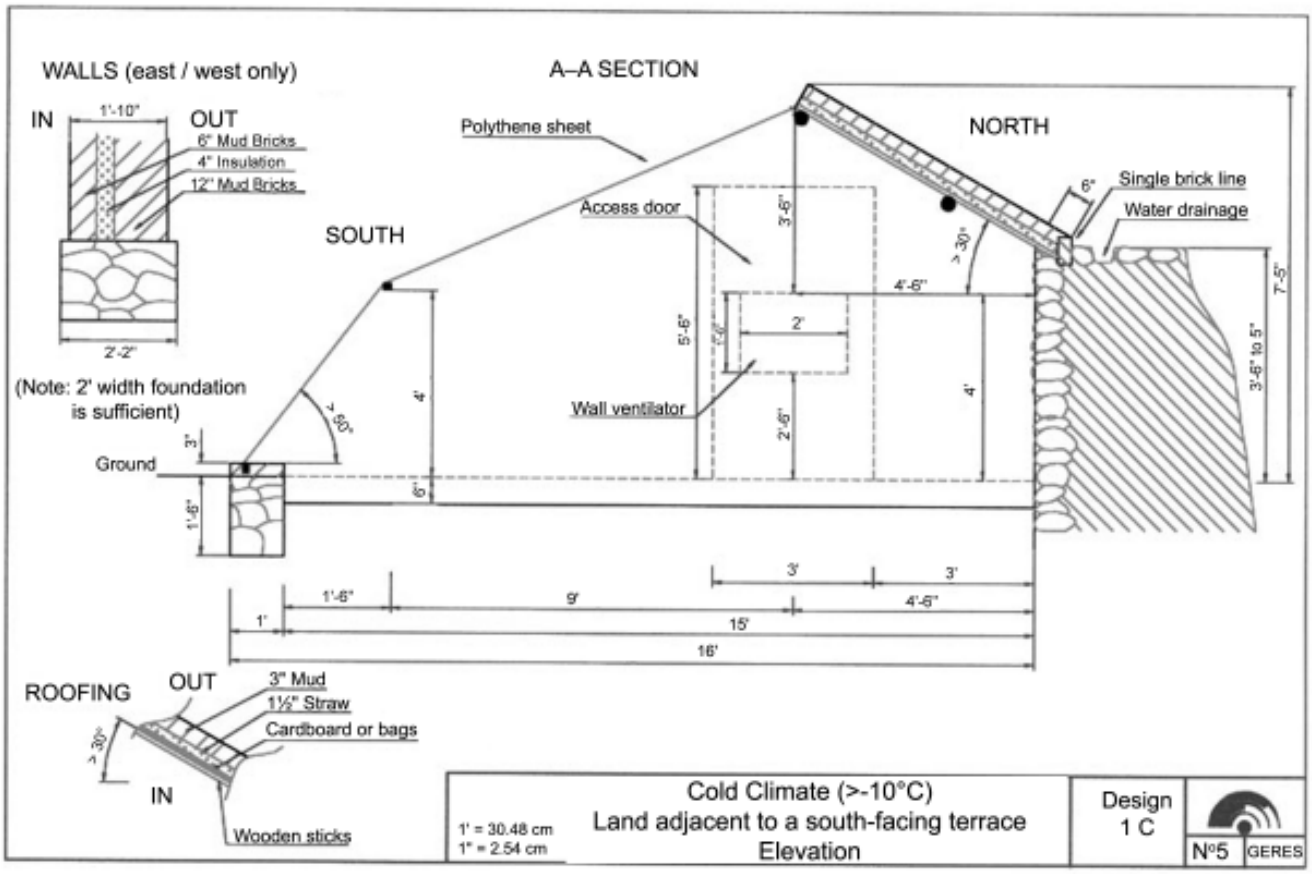


Figure 17: Design 1B - Greenhouse for cold climate, south-facing slope



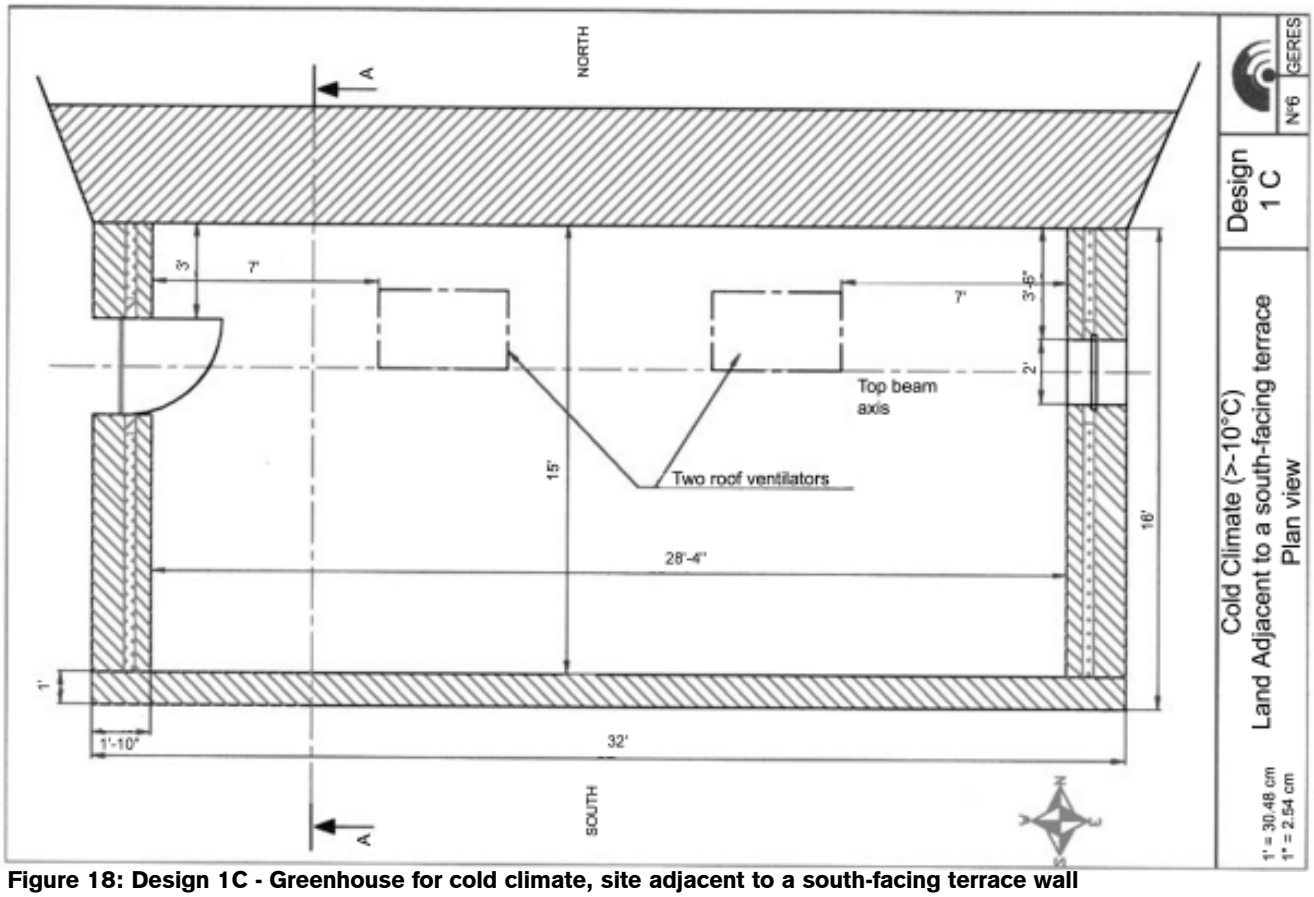


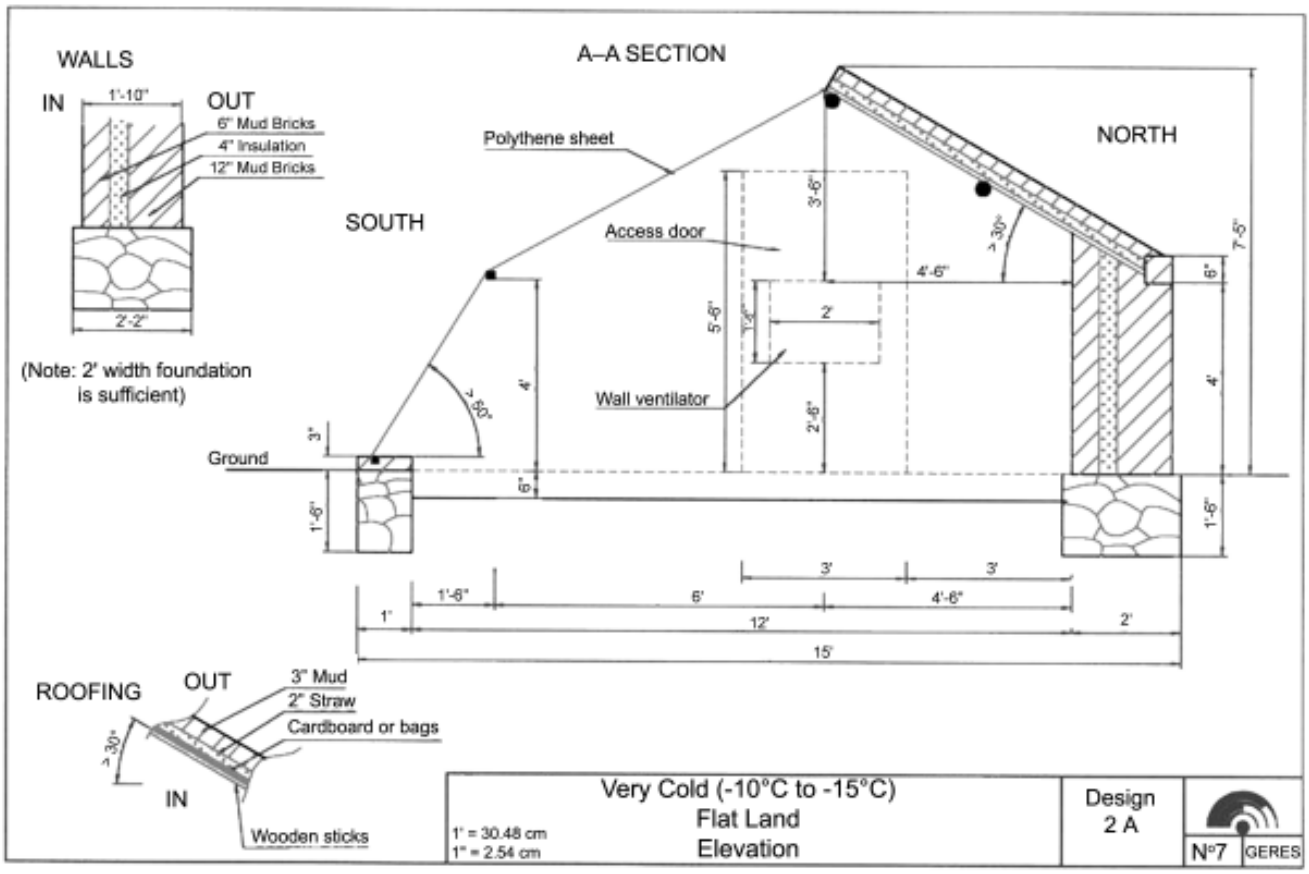
Figure 18: Design 1C - Greenhouse for cold climate, site adjacent to a south-facing terrace wall

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	30°
	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).



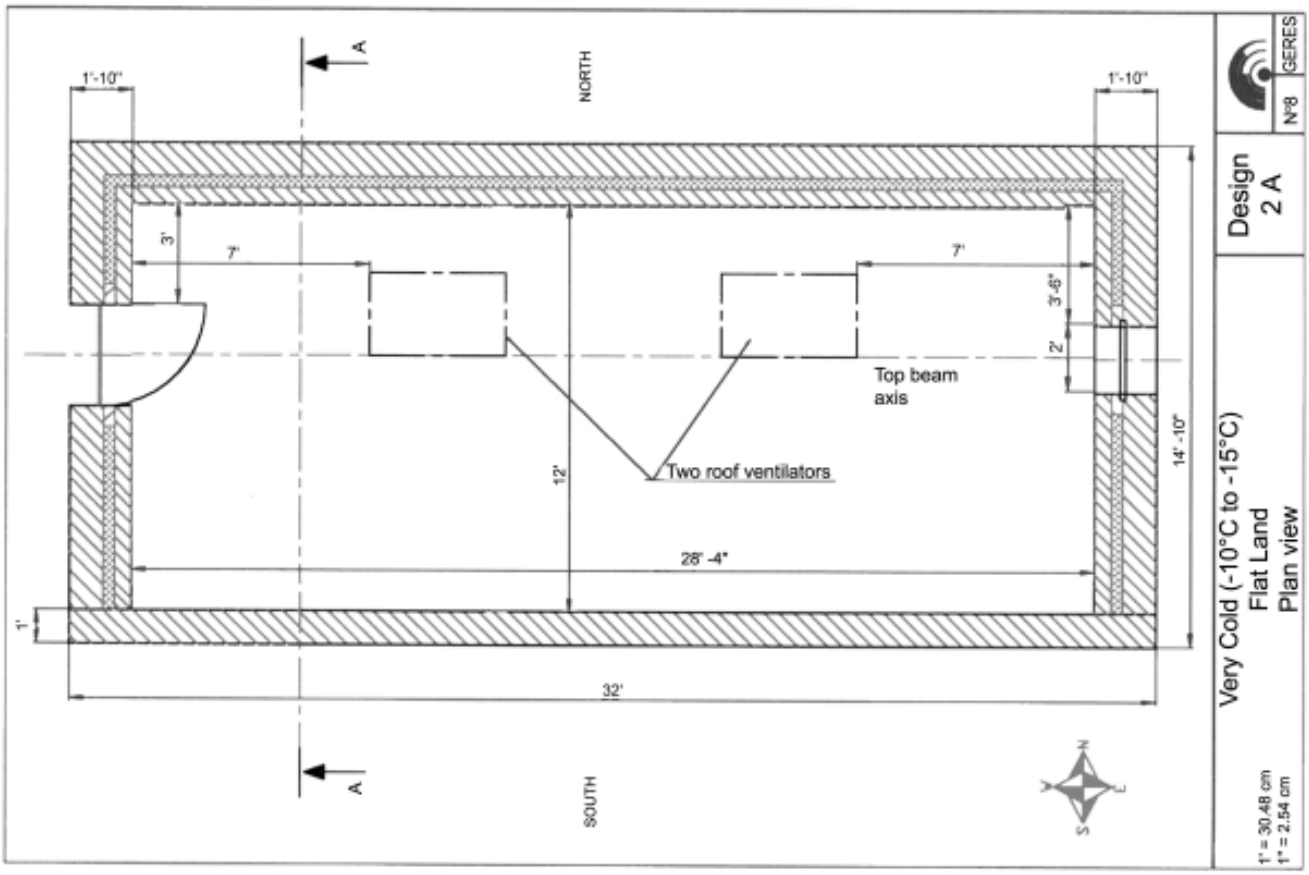
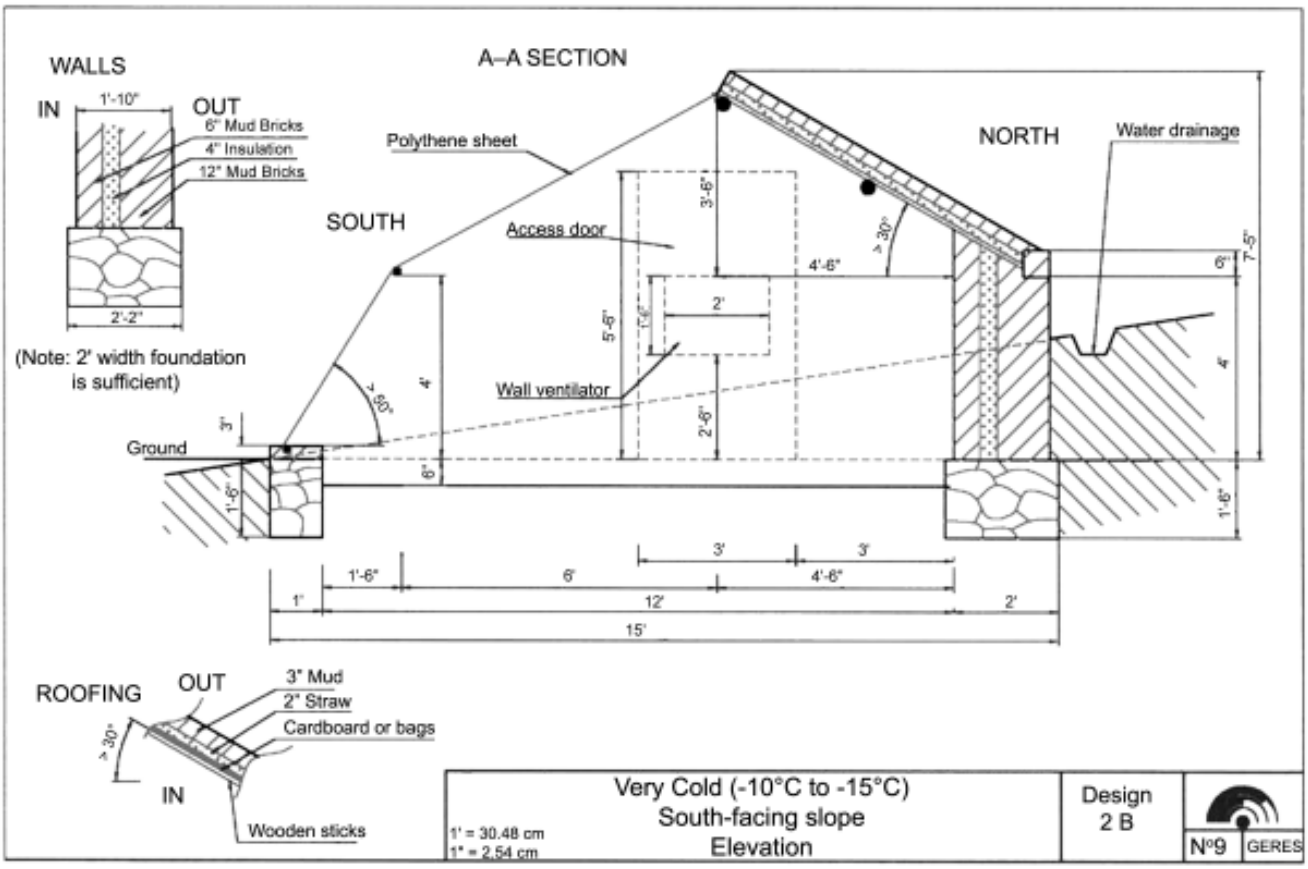


Figure 19: Design 2A - Greenhouse for very cold climate, flat land



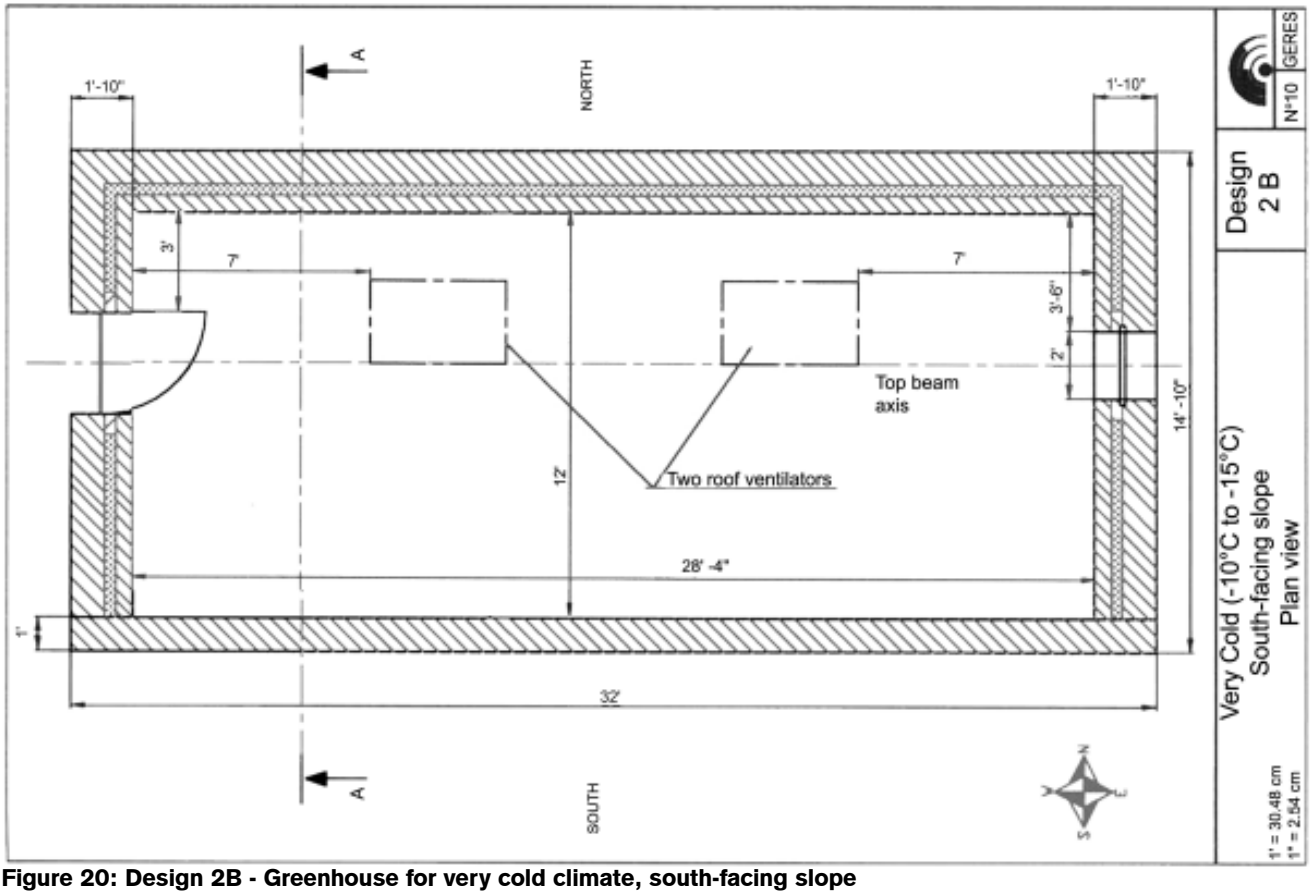
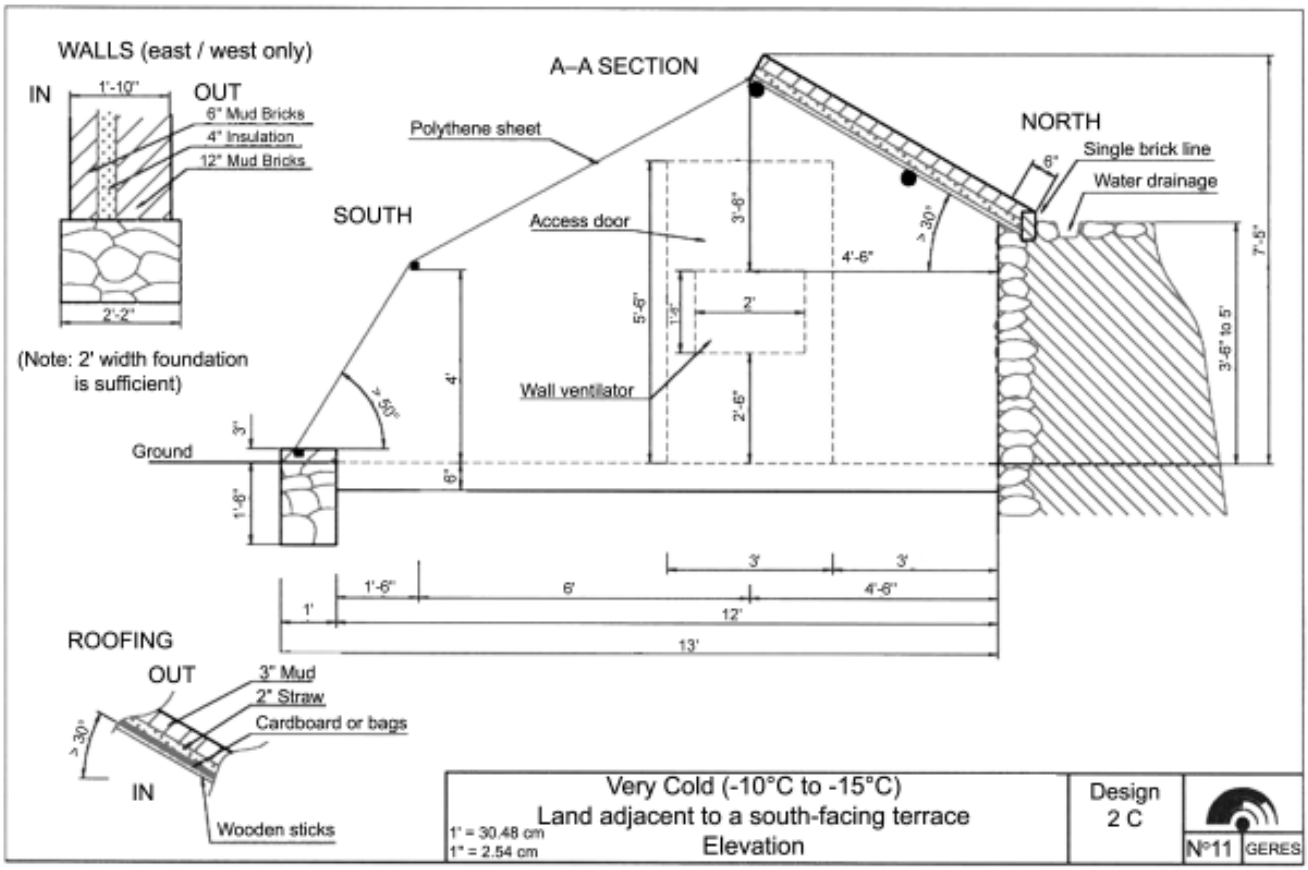


Figure 20: Design 2B - Greenhouse for very cold climate, south-facing slope



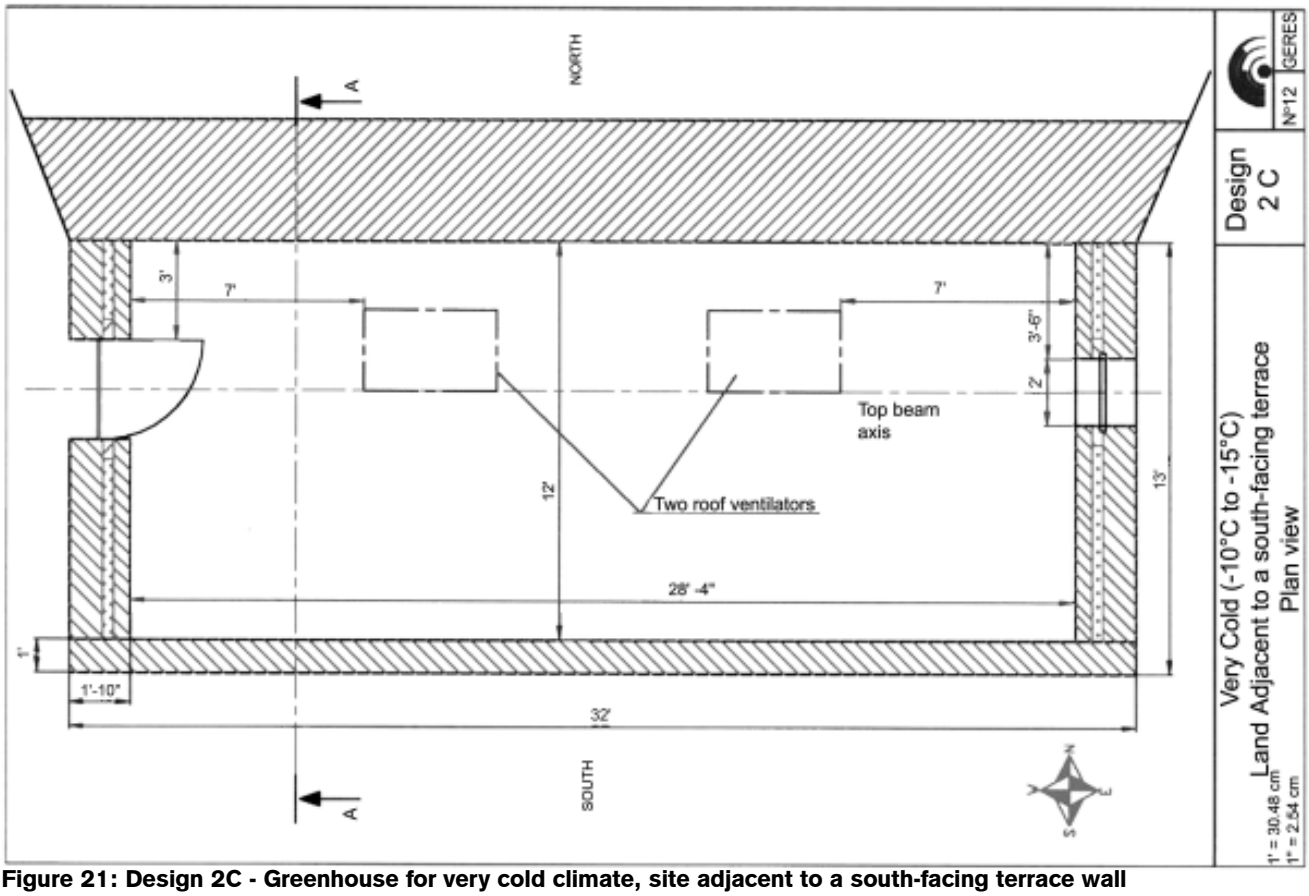


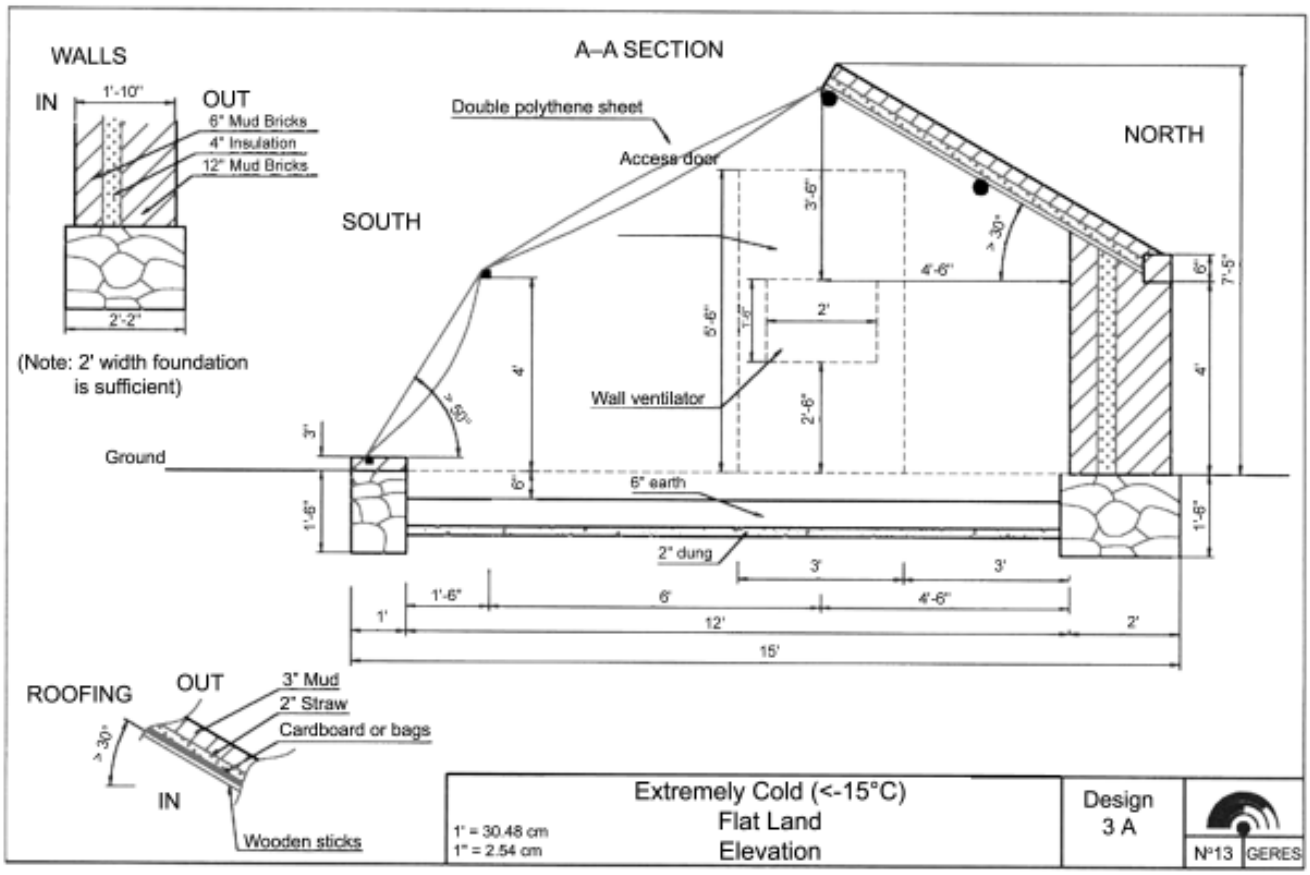
Figure 21: Design 2C - Greenhouse for very cold climate, site adjacent to a south-facing terrace wall

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	30°
	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).



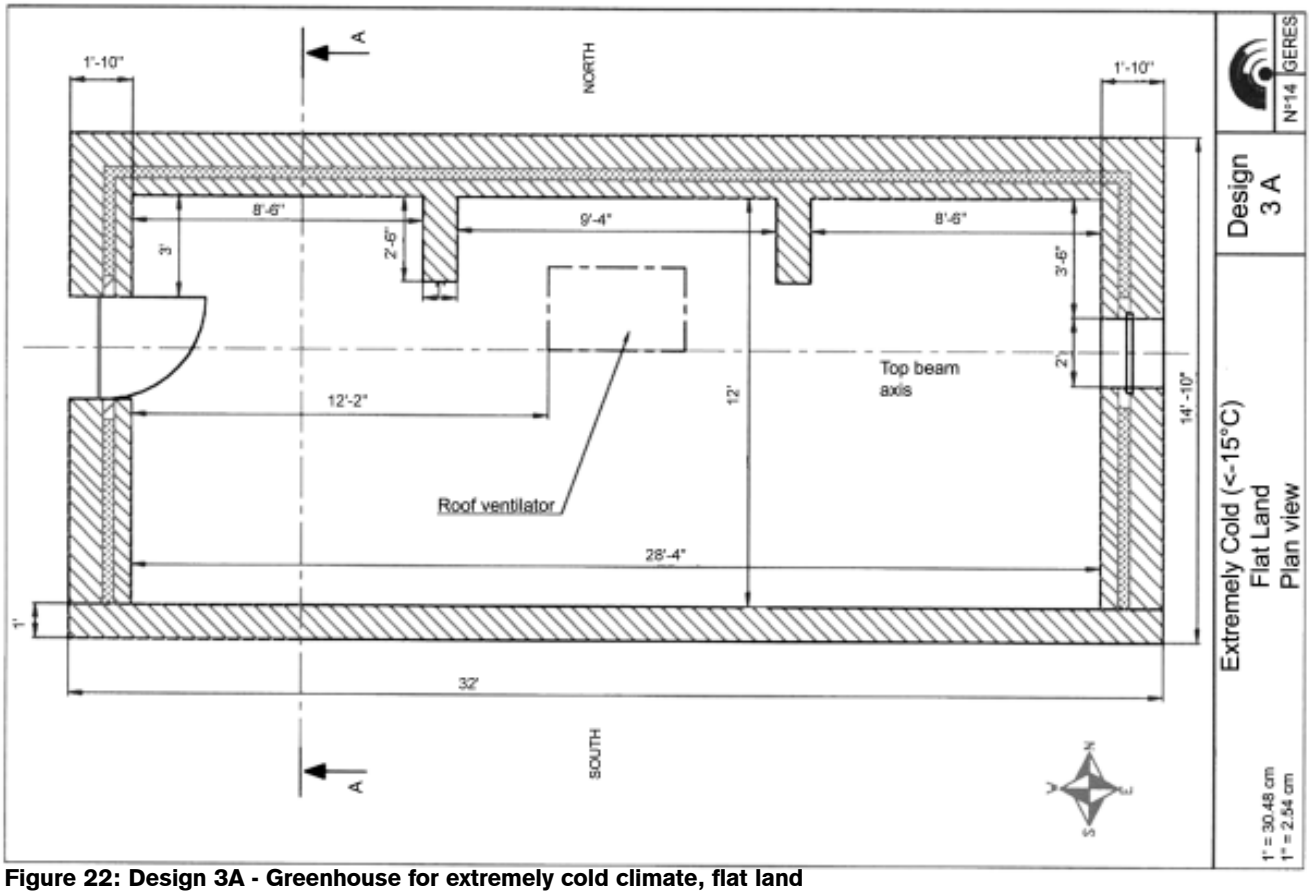
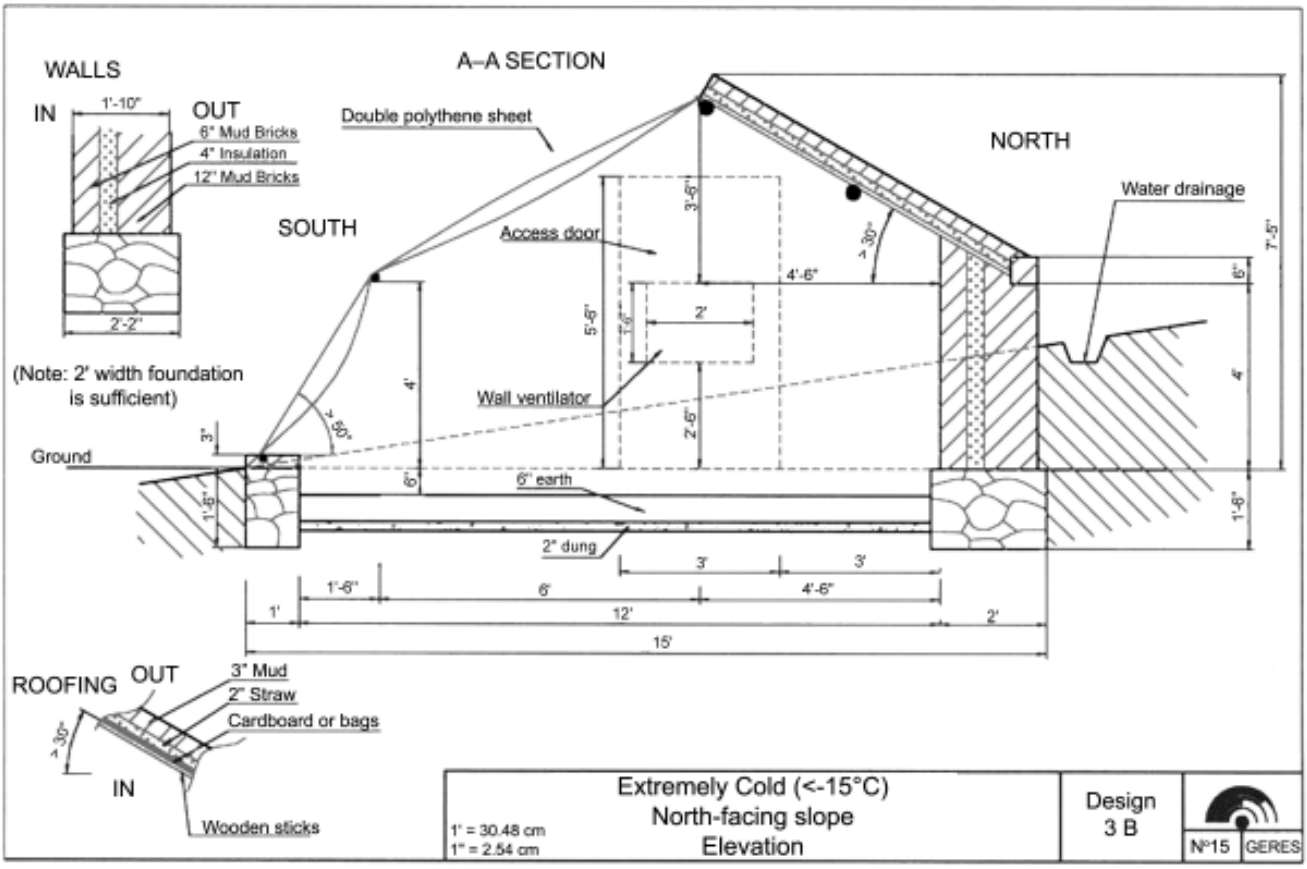


Figure 22: Design 3A - Greenhouse for extremely cold climate, flat land



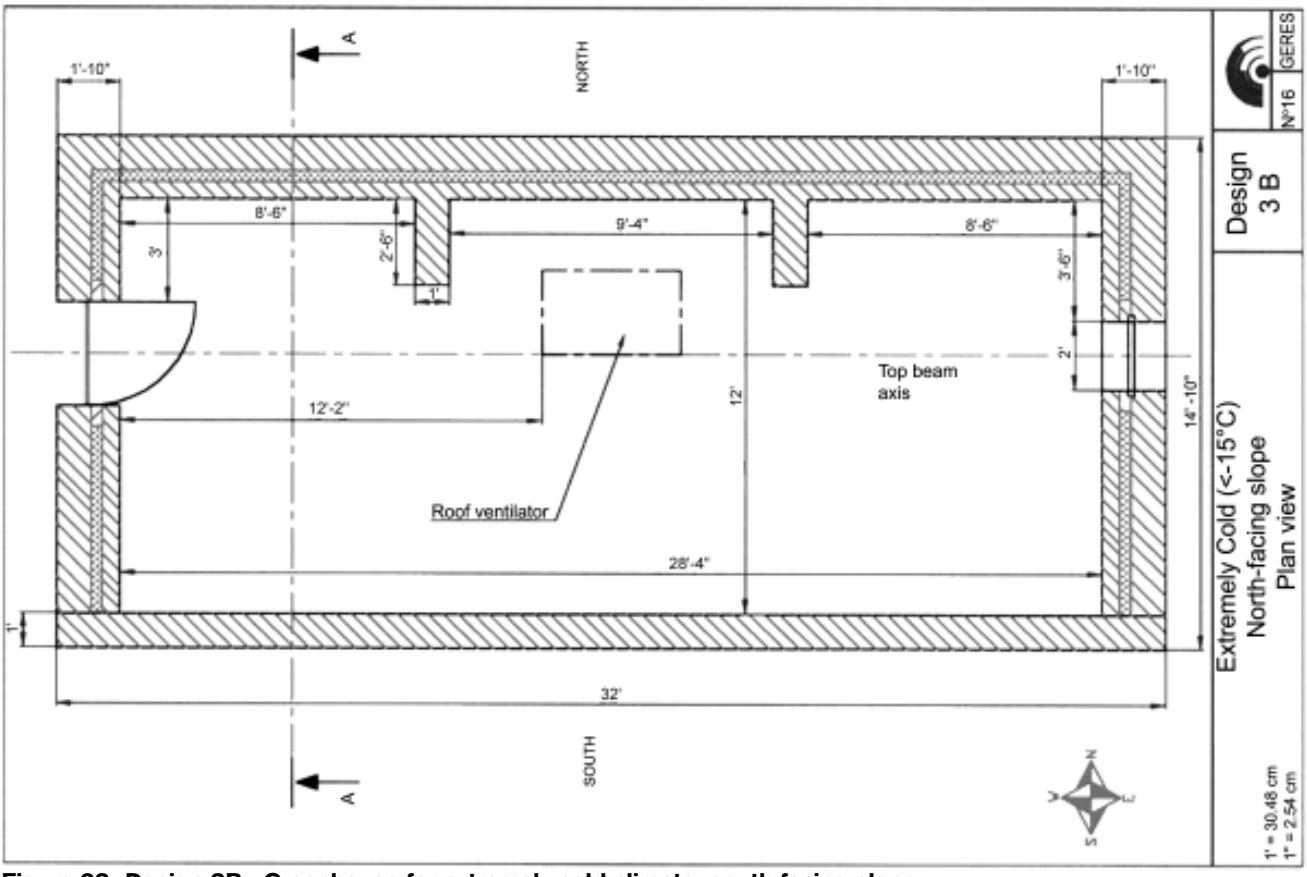
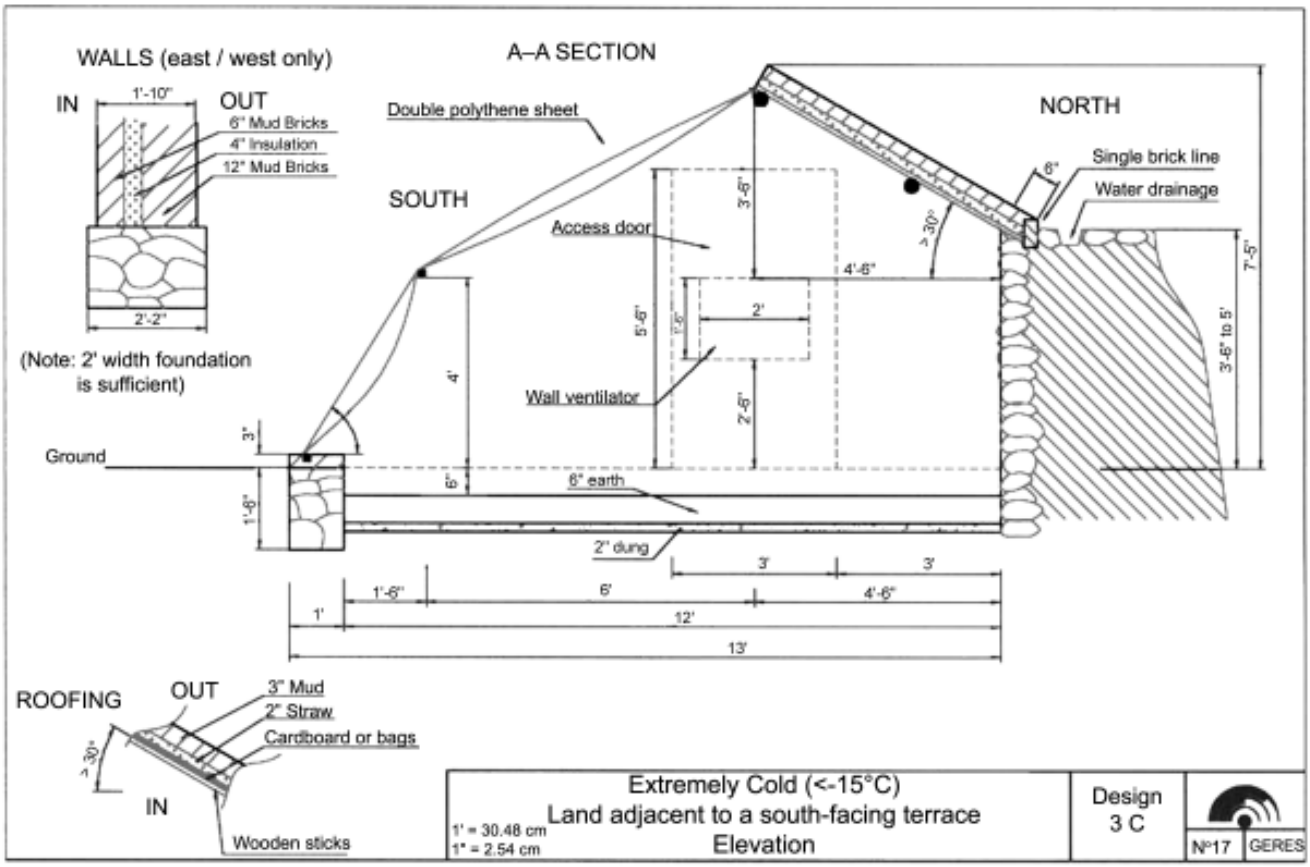


Figure 23: Design 3B - Greenhouse for extremely cold climate, south-facing slope



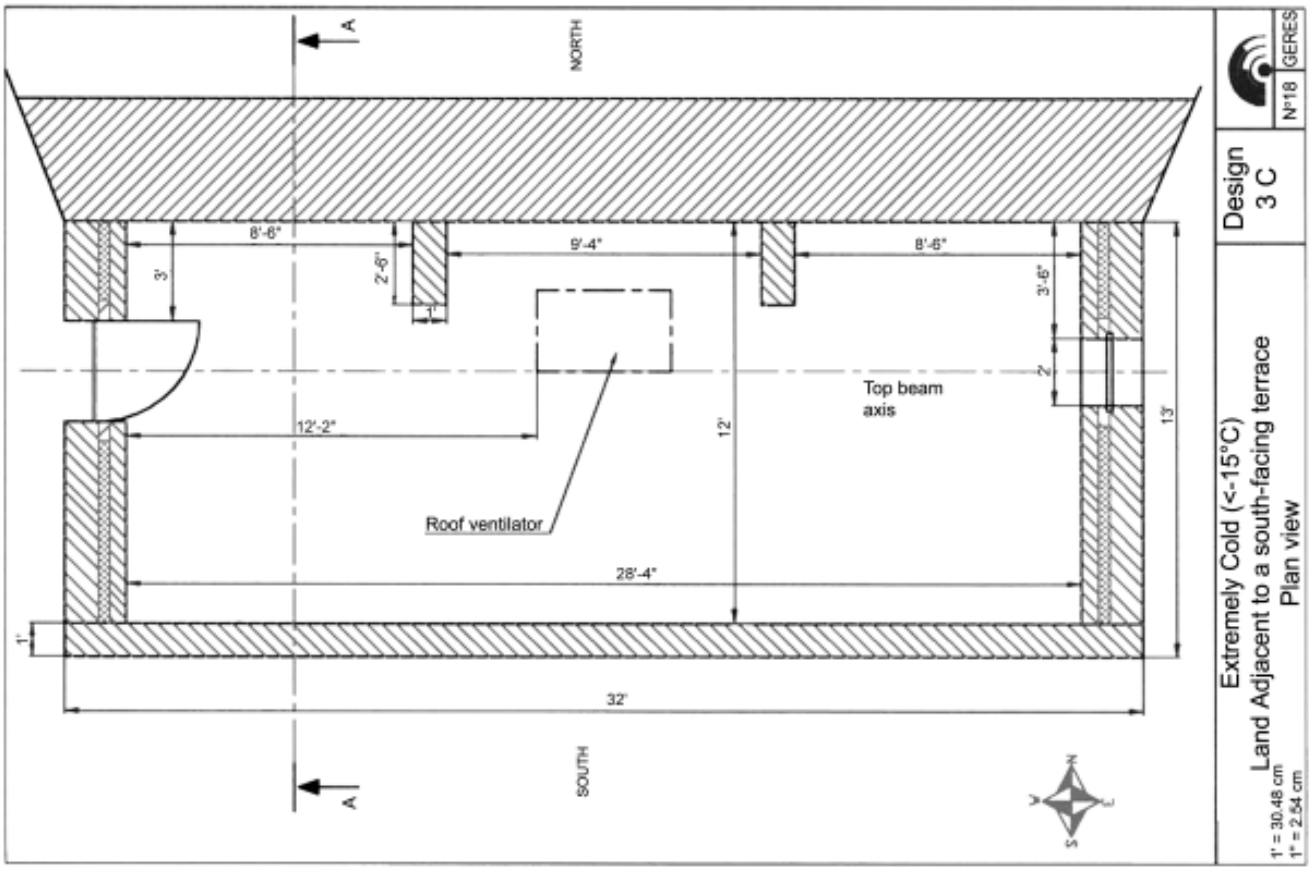


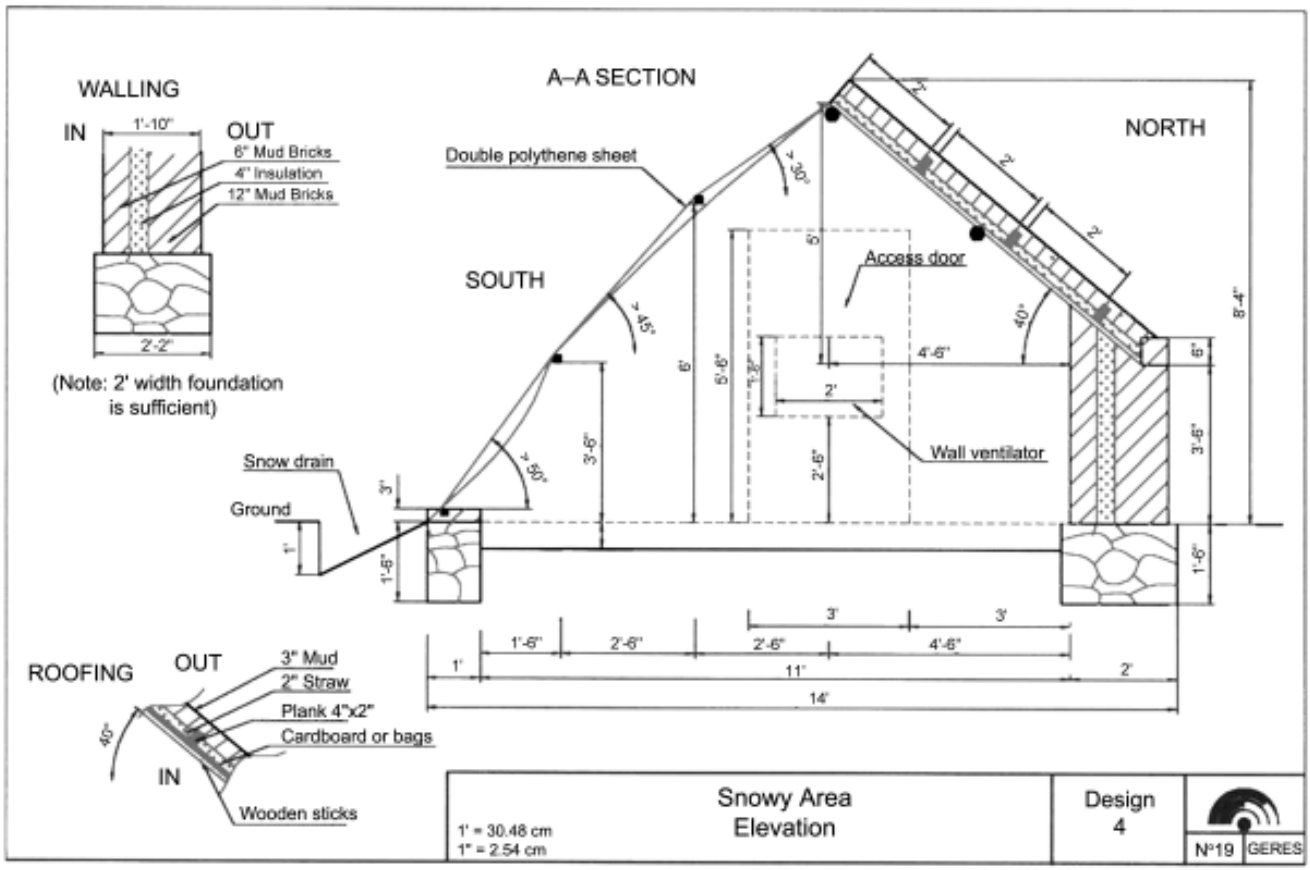
Figure 24: Design 3C - Greenhouse for extremely cold climate, site adjacent to a south-facing terrace wall

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	40°
	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.



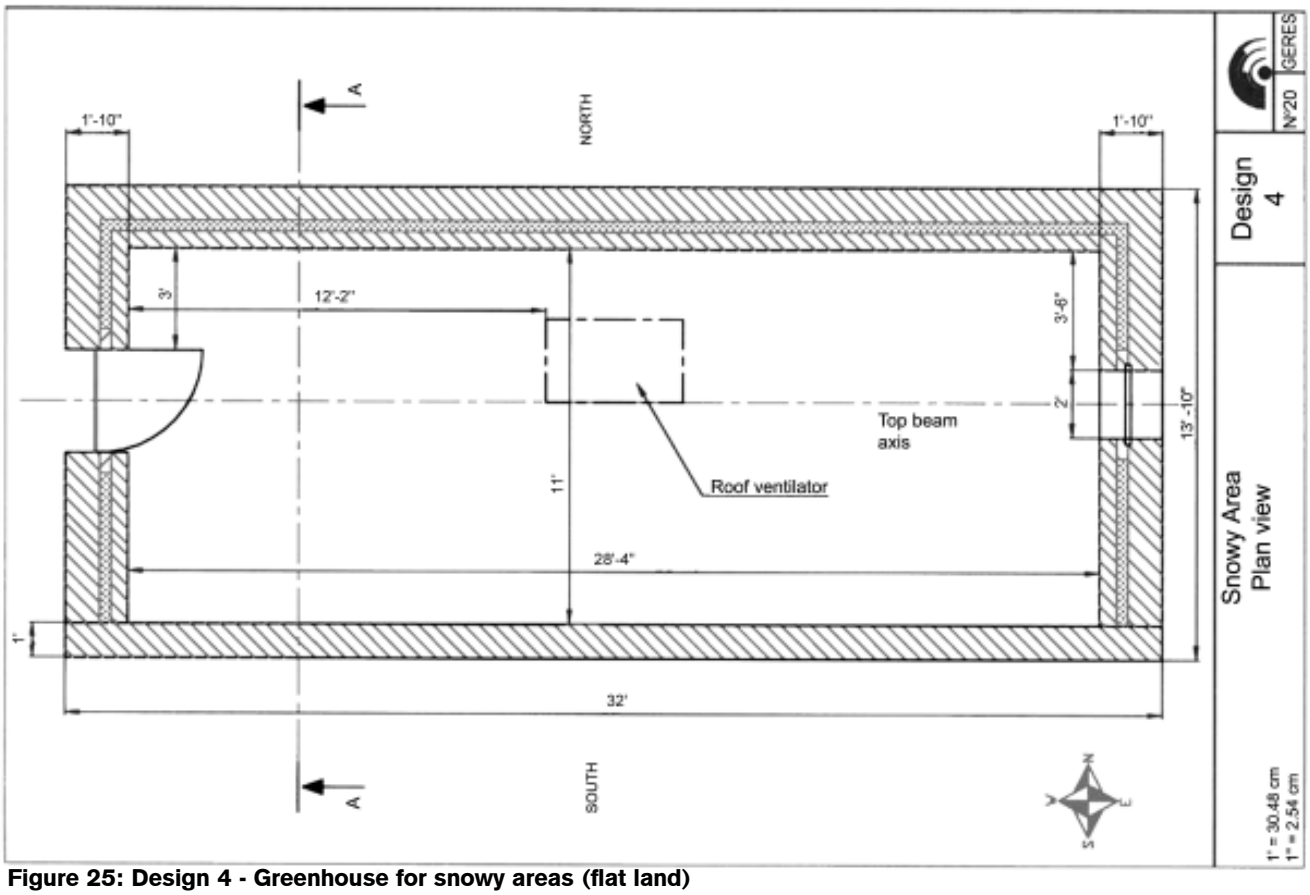


Figure 25: Design 4 - Greenhouse for snowy areas (flat land)

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).

  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.

Figure 27: Finding south with a plumb line

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

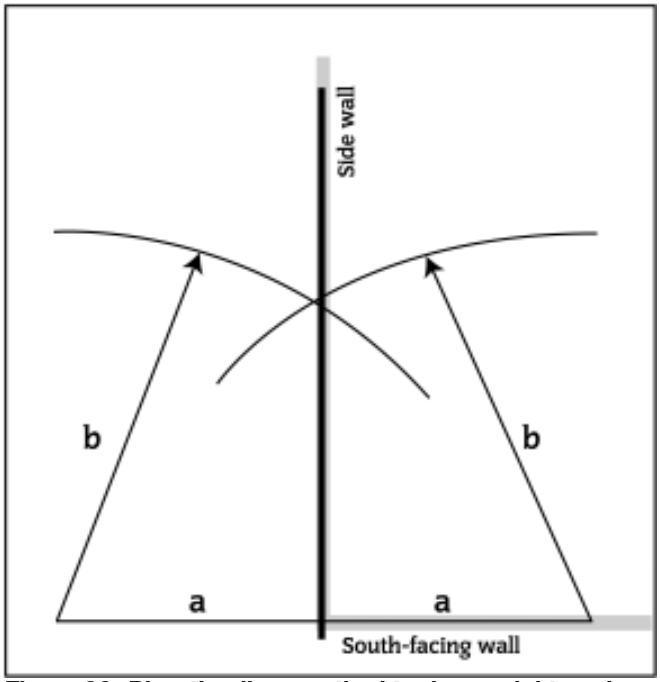


Figure 29: Bisecting lines method to draw a right angle

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 side-wall, 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.

- **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.

Figure 31: Marking the position of the walls

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.

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**

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

Fill the trench with medium-sized 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.

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 wall). 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).

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

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.

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

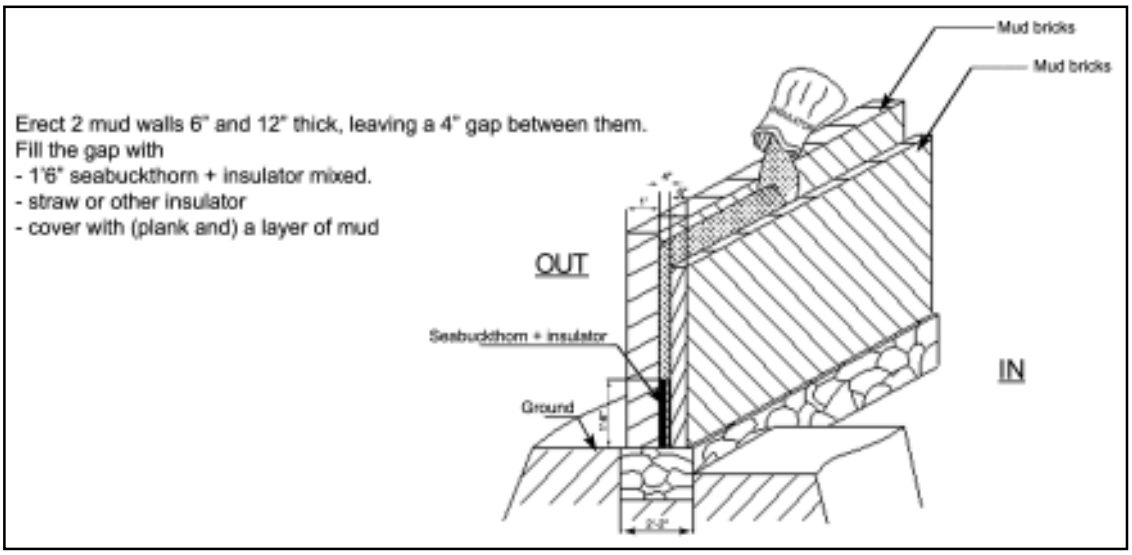


Figure 35: Plan of double wall construction

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.

Building the wall

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

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.

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

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

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

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 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

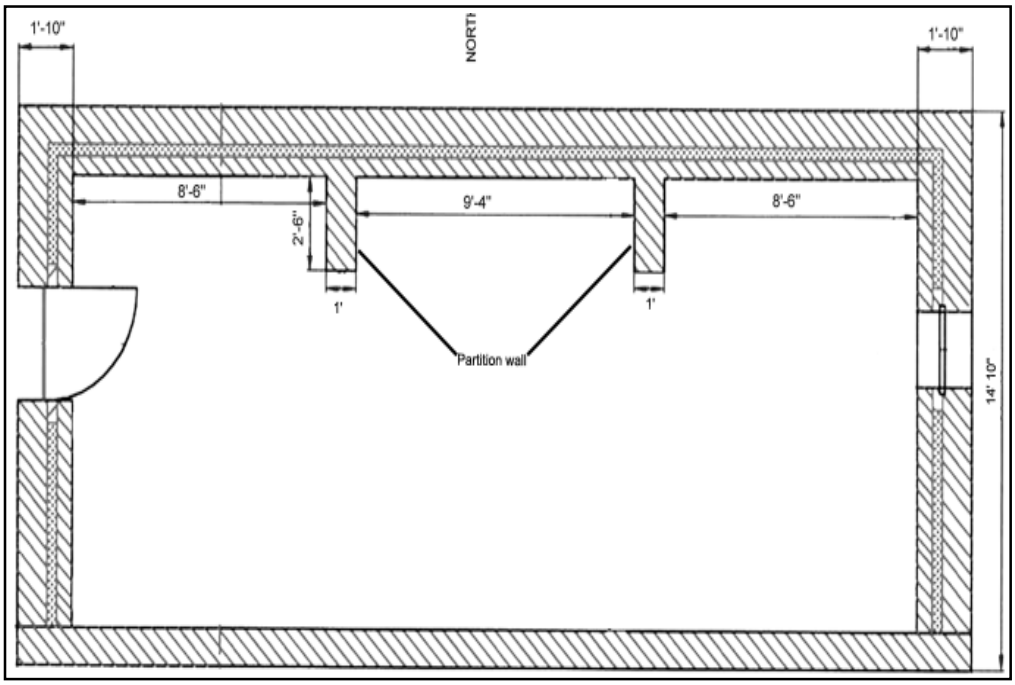


Figure 40: Plan view of greenhouse partition walls

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.

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.

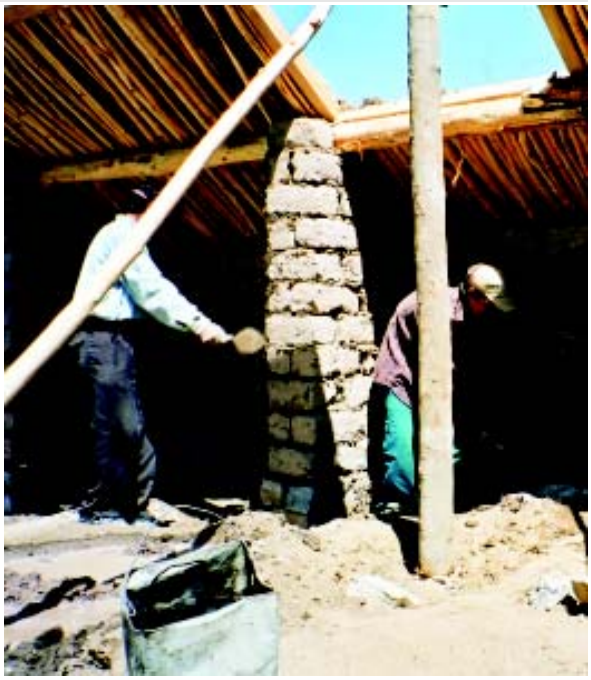


Figure 41: Finishing off the partition walls

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.

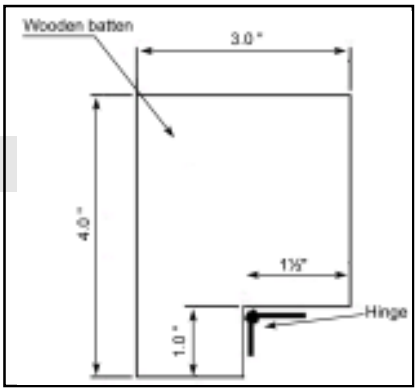


Figure 43: Framework for door

Carpentry

The door frame

- Prepare four wooden beams cross-section 4" x 3" and impregnated 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.

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.

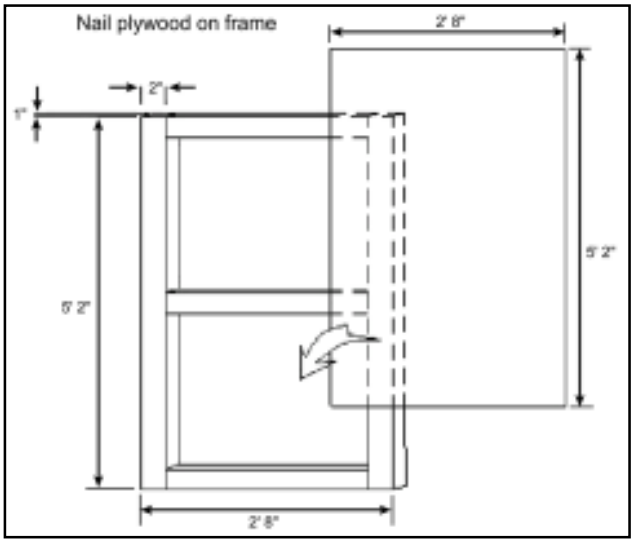


Figure 44: Plan for the door


Figure 45: Assembling the door

Masonry – Installing the Door

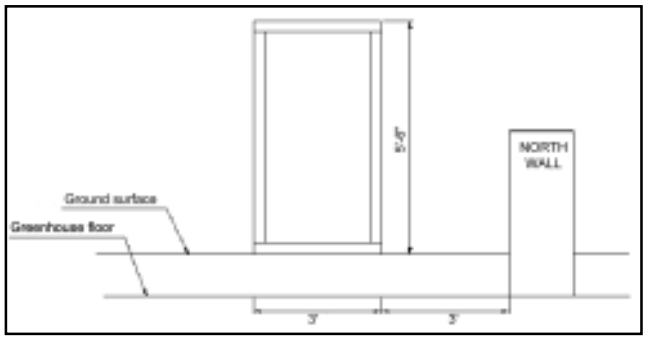


Figure 46: Position of door

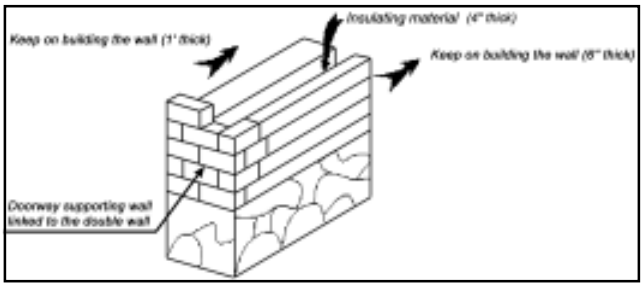


Figure 47: The masonry procedure for building the wall supporting the doorway

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

- 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.)
- 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 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.

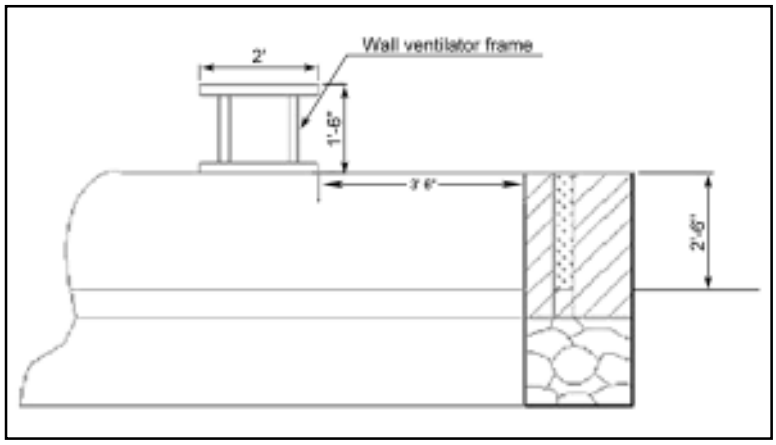


Figure 50: Diagram of shutter frame installation

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

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.

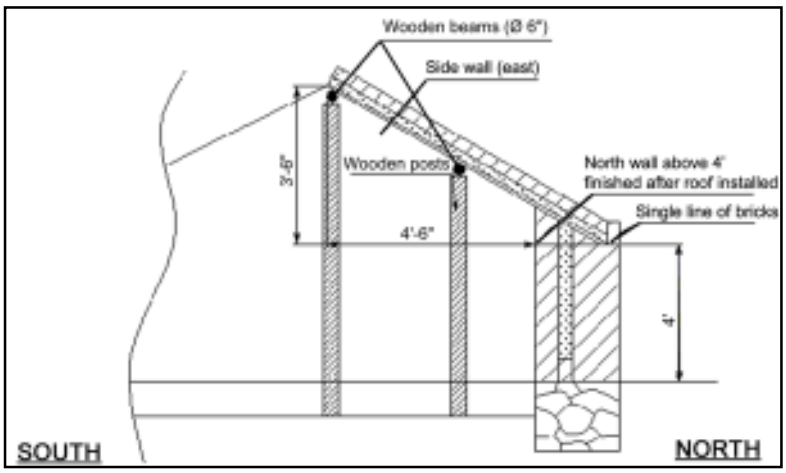


Figure 55: Position of roof and supports

- 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).

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

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

- 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 cross-beam 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).

Figure 58: Cross beam to the north

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

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 58 and 59).

Figure 59: General view of greenhouse structure

Constructing the Roof

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

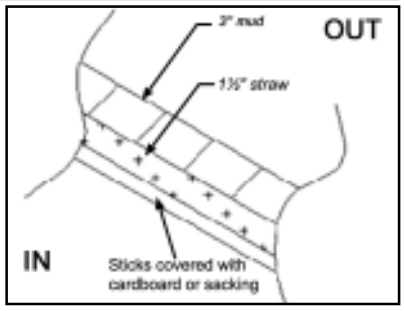


Figure 60: Roof composition

- 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.

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

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).

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. 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.

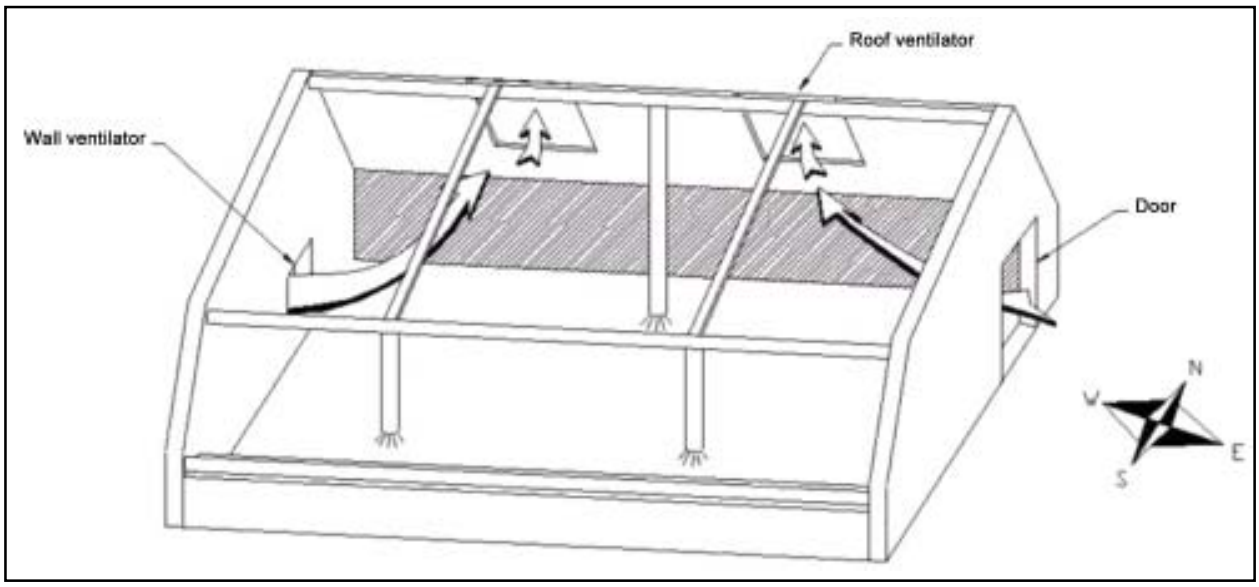


Figure 67: View of air circulation through roof ventilator

Figure 68: Inside view of the roof shutter propped open

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.

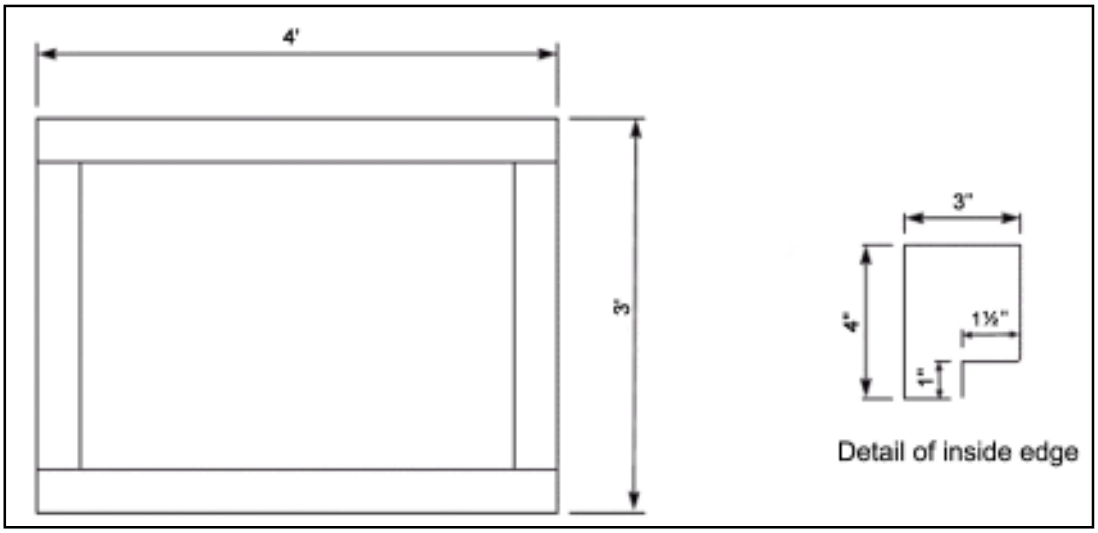


Figure 69: Construction of the frame

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 side-wall, 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).
- 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).

Figure 70: Fixing the frame of the roof shutter

- 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.

Figure 71: Open roof shutter from outside

- 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).

Figure 72: Open roof shutter from inside

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.

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.

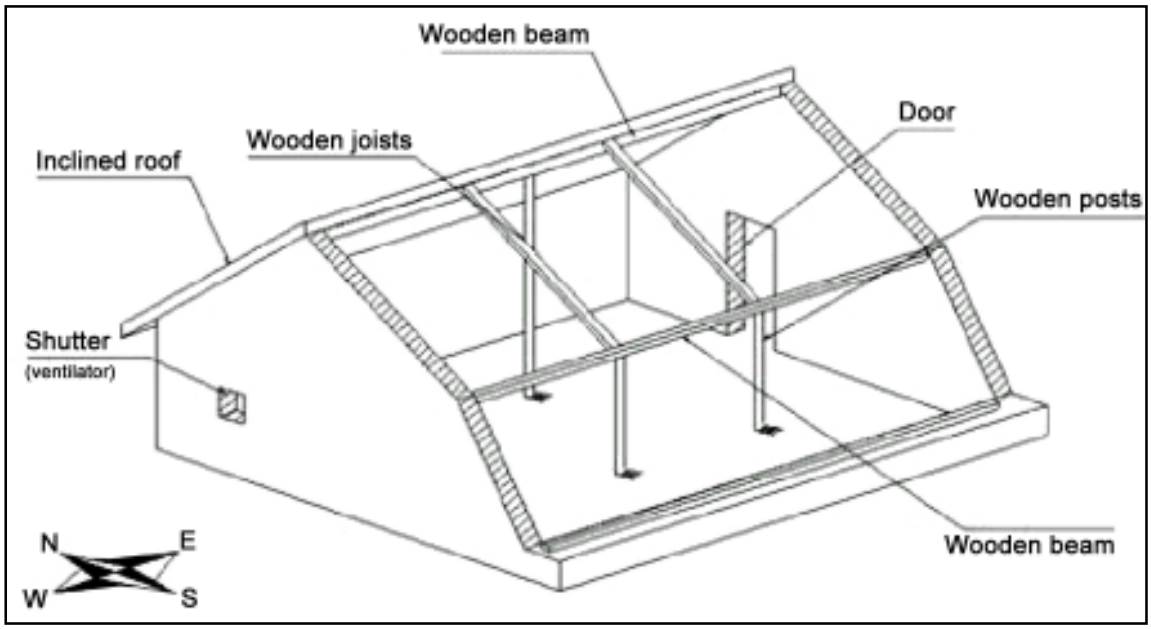


Figure 73: Wooden support structure for the polythene sheet

- 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.)

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

- 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 side-wall, 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).
- Other methods preferred by local builders are also possible, see for example Figure 42.

Appropriate Technology for Asia

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

- 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.

- 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

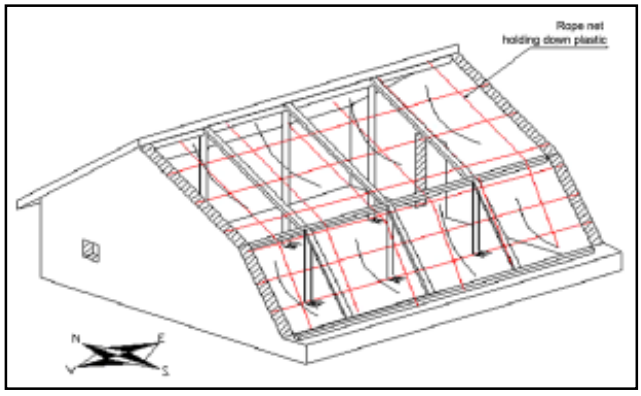


Figure 78: Rope net securing the polyethylene sheet against wind

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).

Recommendations for areas with a hot climate in summer

Figure 79: South face of polythene lifted to improve cooling

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.

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

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.

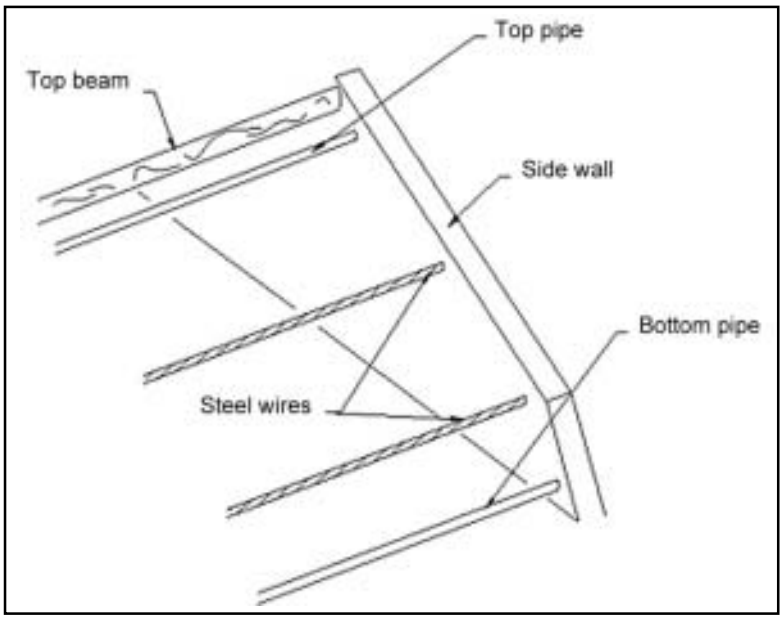


Figure 80: Diagram of framework for supporting the insulating material

- 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.

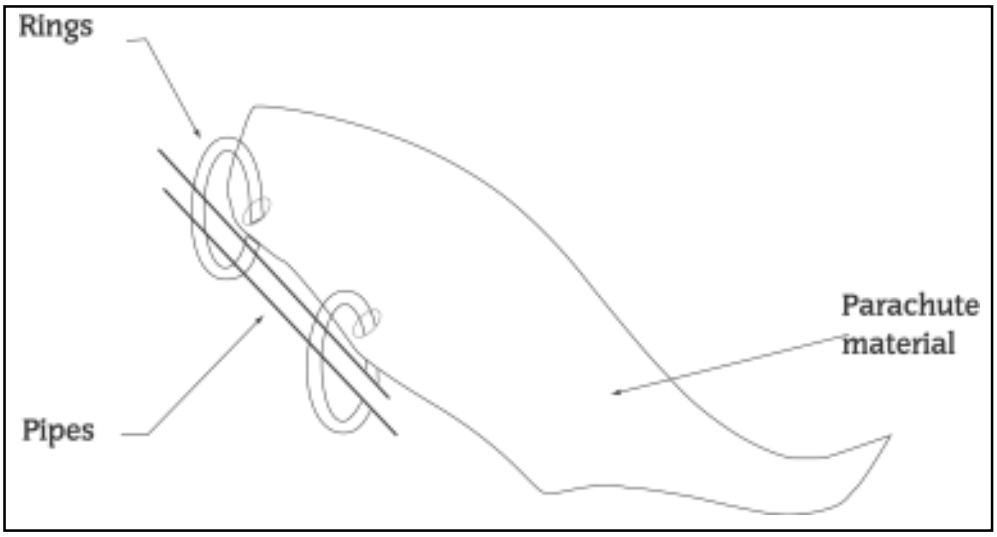


Figure 81: Attaching the cloth to the pipe (sliding device)

- 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
	Construction				
	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 pieces			
	mud	154 cu.ft			
	sticks ∅ 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 pieces*			
	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
	Door Frame and Door				
	wooden timber 4" x 3" for frame	17'			
	wooden timber 2" x 1½" 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 ∅ 4"	8'			
	plank 1" thick	3'6" x 1'10"			
	or sticks ∅ 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 1½" 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 amount			
	hinge 2"	2 pieces			
	chicken mesh	1'8" x 1'6"			

	Material required	Quantity*	Carpenter person days	Mason person days	Unskilled labour person days
5	**Roof**			2	8
	Support Structure				
	beam ∅ 6", 32' (*16' or 11*) long	2 (*4 or 6*) pieces			
	post ∅ 6", 10' long	2 pieces			
	post ∅ 6", 9' long	2 pieces			
	cross support ∅ 6", 12'6" long	1 piece			
	Covering				
	sticks ∅ 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 two, half amounts for one only)		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			
	or galvanised metal sheet (25 gauge) 4' x 3'	*2 pieces*			
	straw	0.4 bags			
	hinges 3"	4 pieces			
	hinge 2" (for iron bar)	2 pieces			
	iron bar 4' long, 1" wide, ¼" (5mm) thick	2 pieces			
7	**Transparent plastic covering**			1	1
	Support Structure				
	pillar post ∅ 4", 5'6" long	2 *(3)* pieces			
	beam ∅ 4" or 3" x 2", 11' *(16')* long	3 *(2)* pieces			
	wooden joists ∅ 2" or 3" x 2" or ∅ 4" bamboo, 10' long	5 to 7 pieces			
	iron or plastic wire (∅ 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' wide, 10'8" long	3 pieces			
	metal wire (∅ 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.