SOLAR GREENHOUSES FOR MONGOLIA

Construction Guidelines

May 2012

Contents

Introduction

The project "Food Security and Innovative Farming Approaches for Mongolia" (2010-2013) is led by the French NGO "Secours Catholique", implemented by Mongolian NGO "Caritas Mongolia" with its technical partner French NGO "GERES" and in collaboration with Ministry of Food and Light Industry and Gobi-Altai province government.

The objective is to develop more efficient and diversified ways to **grow vegetables** at household level in order to reduce **food insecurity** which affects the most vulnerable families. The project targets 1,000 families in Ulaanbaatar and in Gobi-Altai province.

Given the harsh climate of Mongolia and the short growing period, growing vegetables is difficult and the current tunnel greenhouses can only be used for 3-4 months.
The project intends to diffuse **Solar Greenhouses** in Mongolia. Solar greenhouses exist in most of Asian cold areas (China, Central Asia and Himalaya). This type of greenhouse is mainly composed of three walls with a small roof and is oriented to the south. It enables **to extend the growing season** by providing a warm climate inside the greenhouse during cold periods.

This book targets farmers or organizations willing to build their own solar greenhouse. It gives them **practical guidelines** to construct the greenhouse. If they don't have construction skills, they should take advice from mason and carpenter.

The handbook presents step by step instructions to construct one design of solar greenhouse and gives plans and list of materials for 3 different sizes: 30m^2, 60m^2, 120m^2. This design has been developed by the project and experimented successfully since 2010. Alternative options for construction will be explained at each step, for example for walls, roof...
One other low-cost design, is also presented at the end.

Acknowledgments
This guide is funded by the European Commission with cofounding from Secours Catholique.

This handbook has been prepared by Anne Randall (Group for the Environment, Renewable Energy and Solidarity) and Tegshbayar Sandujav (Caritas Mongolia).

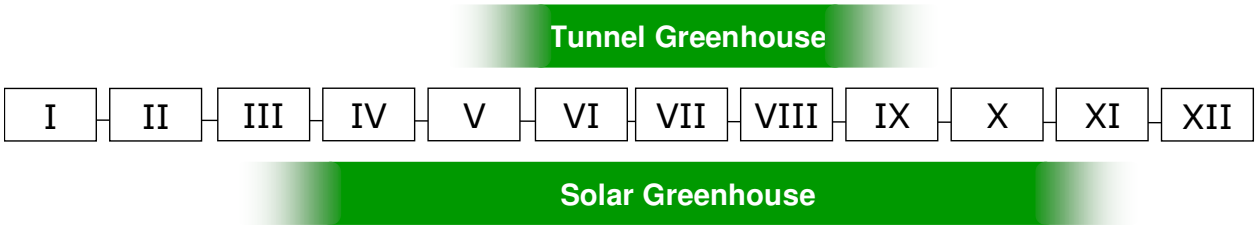
Units
1 cm= 1 centimeter/ 1 m= 1 meter / °C= Degree Celsius / Ø= diameter

What is a Solar Greenhouse and why to use it in Mongolia?

In Mongolia, most of the greenhouses are composed of a wood or metal frame covered by a layer of polyethylene sheet. These greenhouses are either hand-made or bought from company importing Korean tunnel kit greenhouses. This type of greenhouses provides a warm and protected climate to grow fruit vegetables such as cucumber and tomatoes during summer. However, they can only be used during the 3 to 4 summer months in Mongolia and they are often too hot during sunny days in summer.
A Solar greenhouse is a specific type of greenhouse. It has three walls, a half-roof and a polyethylene face oriented toward the South. This type of greenhouse is specially adapted to cold climate countries (Mongolia, Inner Mongolia, Himalaya region, Central Asia, Canada) where there is a lot of sunshine but the air is too cold for growing crops except in summer.

Tunnel polyethylene greenhouse
Growing season: 3-4 months

Solar Greenhouse
Growing season > 7 months

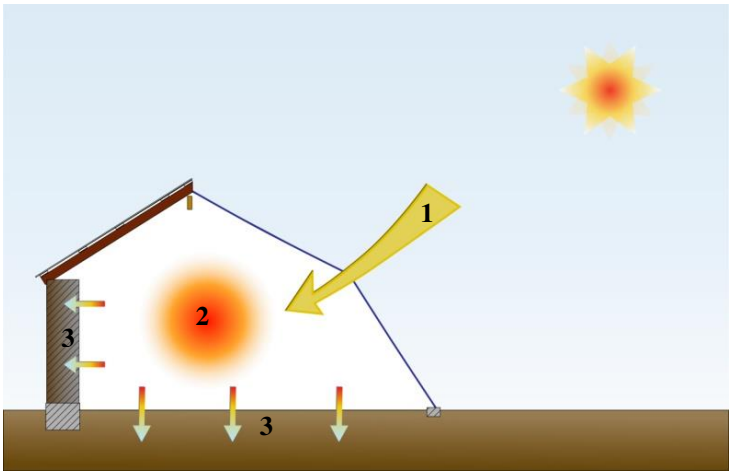


In Ulaanbaatar conditions, solar greenhouse enables to cultivate from mid-March to mid-November. In colder regions (Altai north Mountains region), growing season will be less. In warmer regions (Gobi and East region), growing season can be increased.

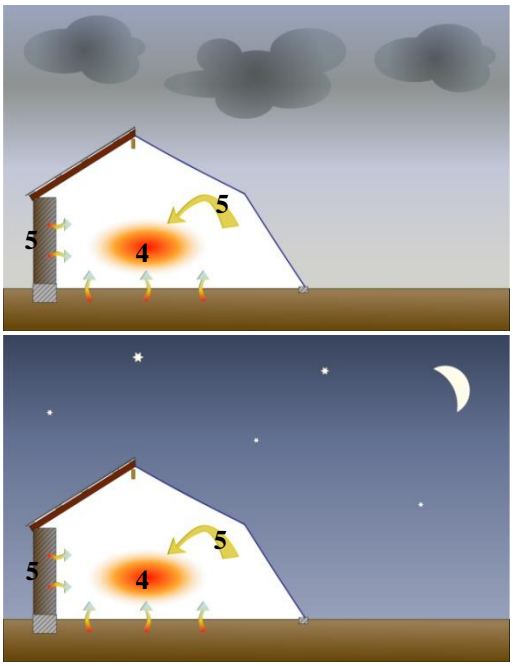
Opportunities with Solar Greenhouse:

- Extend the growing period and harvest period for summer fruit vegetables
- Grow seedlings in spring for open-field
- Grow seedlings in spring for greenhouse
- Grow leafy and root vegetables in early spring and late fall

How does a Solar Greenhouse work?



Side view of a solar greenhouse during a sunny day



Side view of a solar greenhouse during a cloudy day and at night

Explanation in five simple points:

- During the day, as the greenhouse is oriented to the south, it collects a maximum of solar energy (**1**)
- This energy heats the air inside the greenhouse (**2**). This heat is stored in the ground and in the walls (**3**). Ground and walls act as thermal mass (see below for more explanation)
- When there is no solar energy, during the night or a cloudy day, the heat stored in the ground and the walls is released inside the greenhouse (**4**). The air of the greenhouse is thus warmer than the outside air.
- This heat is trapped inside the greenhouse which is insulated (**5**).
  - ⇨ Solar greenhouse is warmer because it can store the excess of heat in the walls when there is sun and release it when there is no or little sun

The half-roof also provides shade in summer and avoid overheating. Natural ventilation is provided through several openings. It enables to control temperature and humidity and renew air in the greenhouse.

Two important concepts :

Thermal mass	Insulation
The thermal mass materials can store the heat and release the heat during cold periods. Heavy materials are good thermal mass: bricks, blocks, stones, soil, water. If the thermal mass has a dark color, it will store more heat.	Insulation material prevents heat to escape, it retains the heat. Light materials are good insulators: polystyrene, glass wool, felt, straw, air (if trapped). Wood is also an insulator but has a lower efficiency. Soil can not be considered as insulator except if the layer is very thick (more than 1m).

How to select a site for my greenhouse?

It is very important to know if the site for the greenhouse is convenient. Read these recommendations carefully.

A suitable site

A site is suitable if the land is flat or has a slope oriented to the south.
A site is not suitable if the site is not good for agriculture: marshy ground, sand, stones, chemical pollution or the slope is too high or oriented to the north.

Water supply

Growing vegetables in greenhouse requires water, especially in summer. Reliable **water supply should be accessible from spring to fall**. Transportation should not be too difficult to discourage farmers. Distance to water point, transportation, irrigation system and time spent for water collection should be taken into account carefully.

Water requirements for a greenhouse full of fruit vegetables during peak season:
30m^2: 200-300l/m^2/day
60m^2: 400-600l/m^2/day
120m^2: 800l-1,5 ton/m^2/day

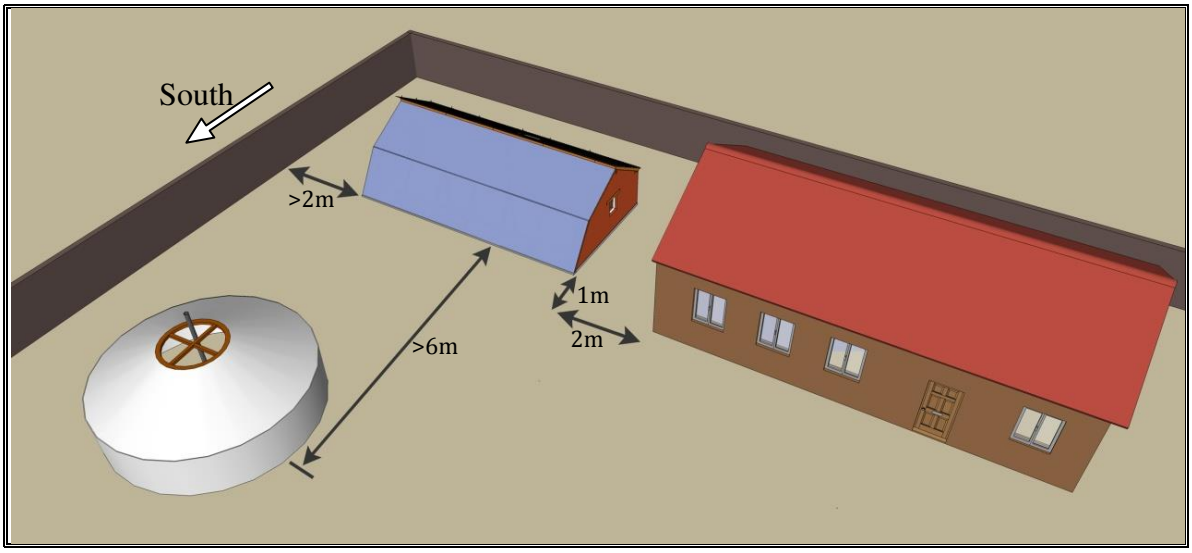
Good amount of sunlight and no shadow

Solar radiation is required for plant growth and for heating the greenhouse.

From March to November, **sunrise must be before 10:00 and sunset after 16:00**, so that the greenhouse receives **at least 6 hours** of full sunlight.

It is also important to **take into account potential obstacles around the site which can create shadow**: far mountains, hills, nearby buildings, houses...

For example, if you construct greenhouse in the khasha, you should be put the greenhouse where there will be less shadow…If the fence is 2m high and parallel to the greenhouse, greenhouse should be at 2 meters minimum. If the fence is higher, distance should be more. An obstacle in front should be located at a distance twice its height:
Example: 3m high ger should be located at 6m, 5m house should be located at 10m…



Location of the greenhouse in the khasha

Design, sizes and material used

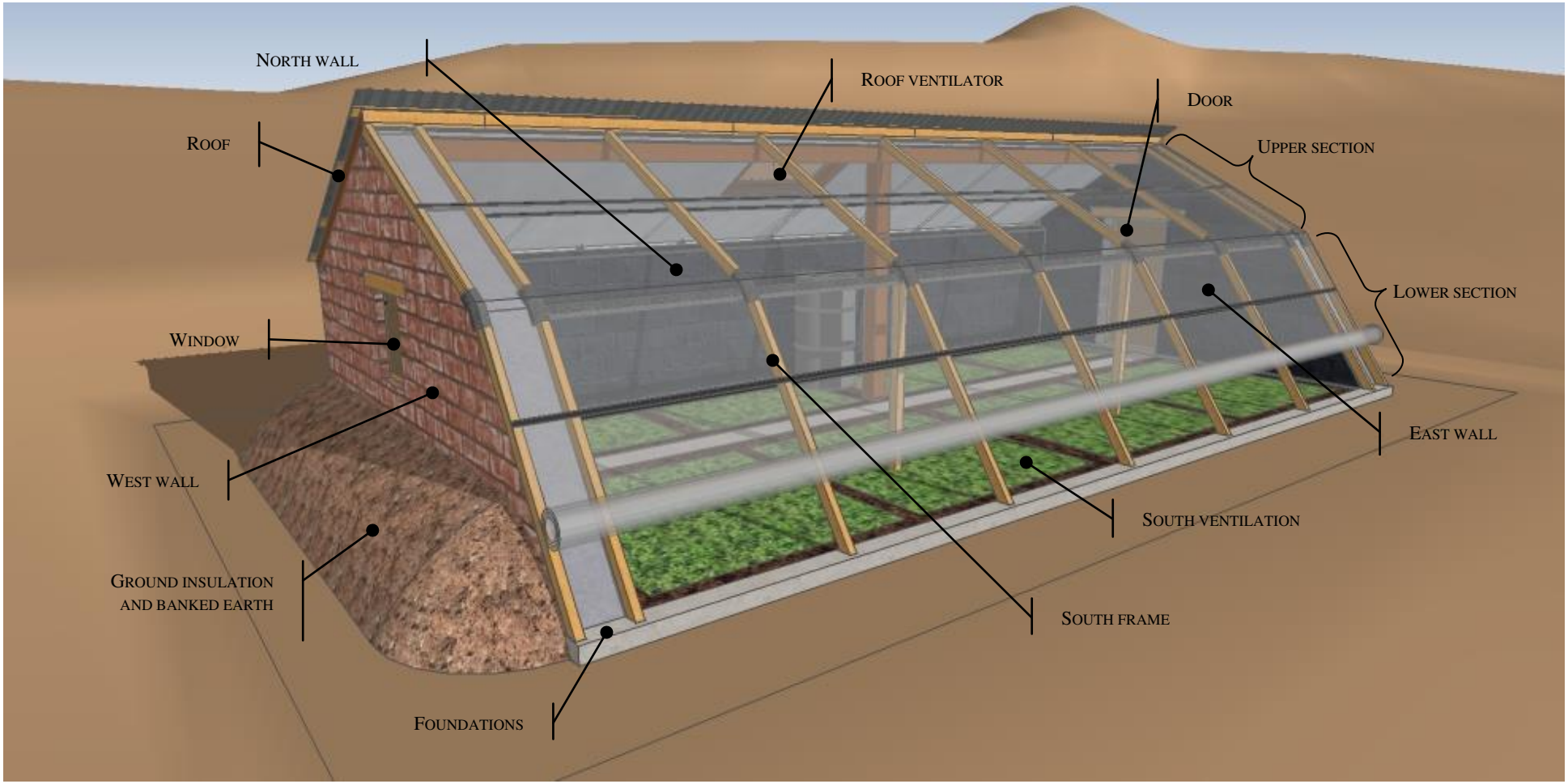
This chapter presents detailed plans, cost and materials for main design presented below in 3 different sizes.

	External size	Internal size	Growing area (m2)	Cost Materials (MNT) in 2012 in UB	Time for construction for 4 persons
Size 1	8,7m*4,5m	8m*4m	32 m^2	1 440 000 MNT	< 1 week
Size 2	13,8m*5,1m	13,1m*4,6m	60 m^2	2 160 000 MNT	1-2 weeks
Size 3	27,2m*5,1m	26,4m*4,6m	120 m^2	3 960 000 MNT	2-3 weeks

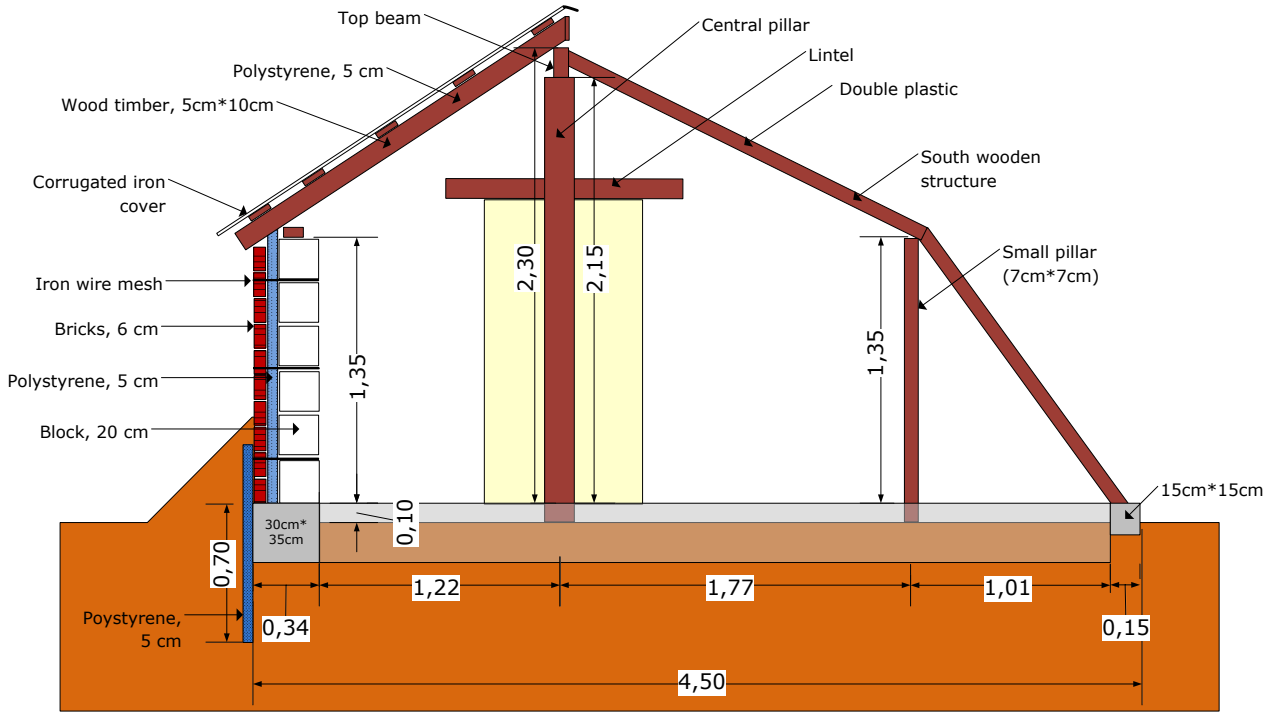
Before constructing a greenhouse and selecting the size of your greenhouse, think about your objectives:

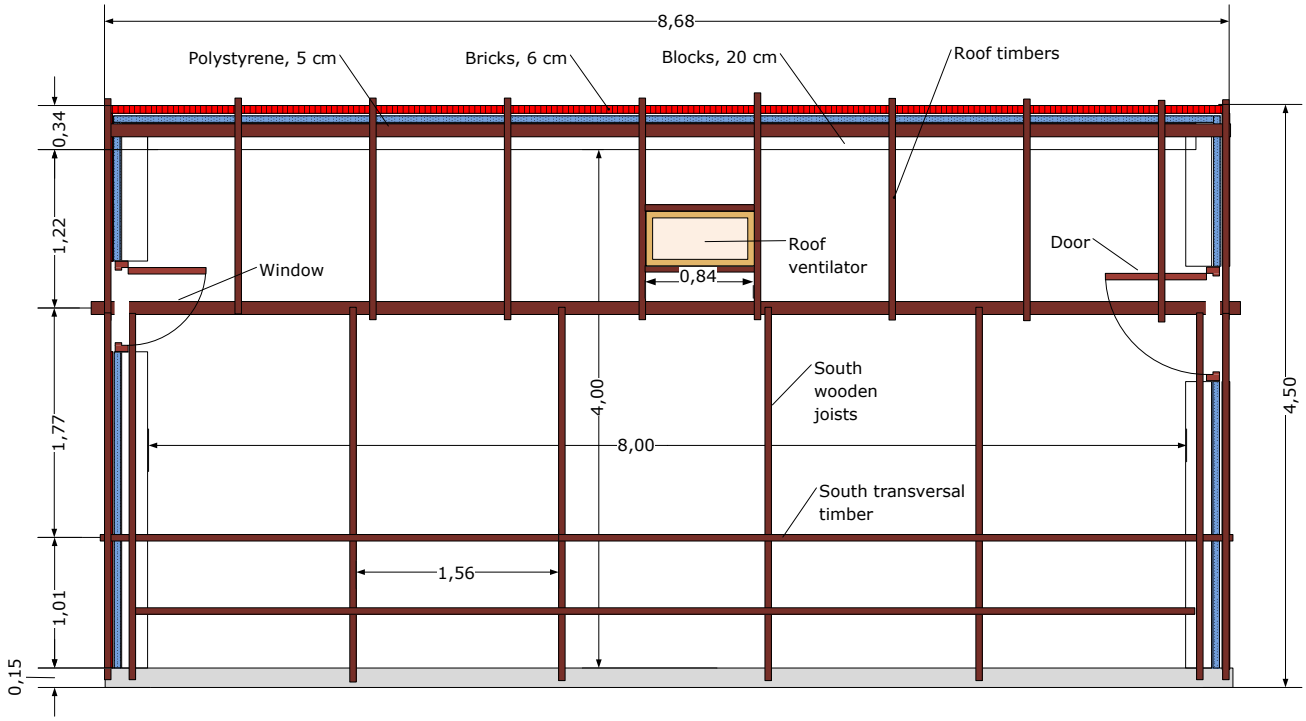
- Do you have skills in greenhouse vegetable growing?
- Who will take care of the greenhouse and how much time does he/she have every day?
- What are your water resources: distance, price, quantity available, possibility for irrigation
- What is your objective:
    - Produce vegetables for your family and relatives
    - Sell vegetables: who will buy your vegetables? What types of vegetable you want to produce? To which market you want to sell? Did you plan to process the vegetables?
- How much are you ready to invest to build the greenhouse? Are you able to get all the materials for the construction?

Terms used in the guide for construction

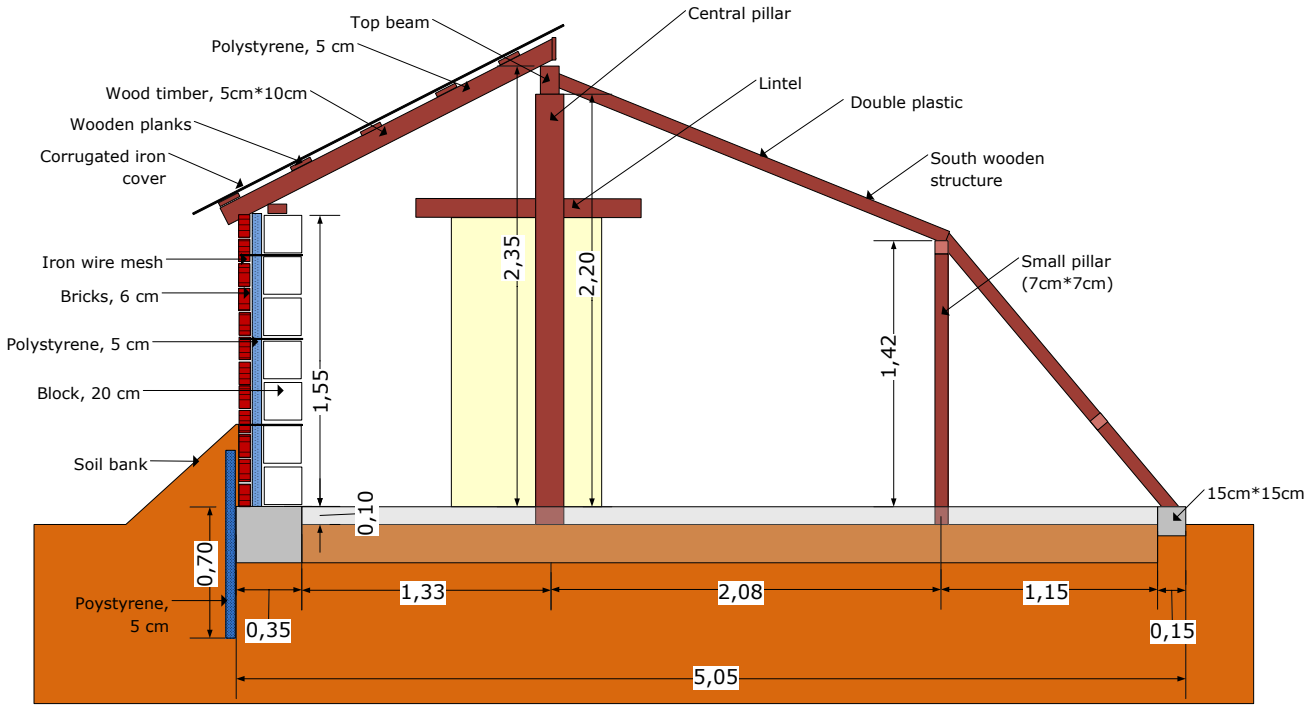


Main design/ Size 32m²: Side view and top view

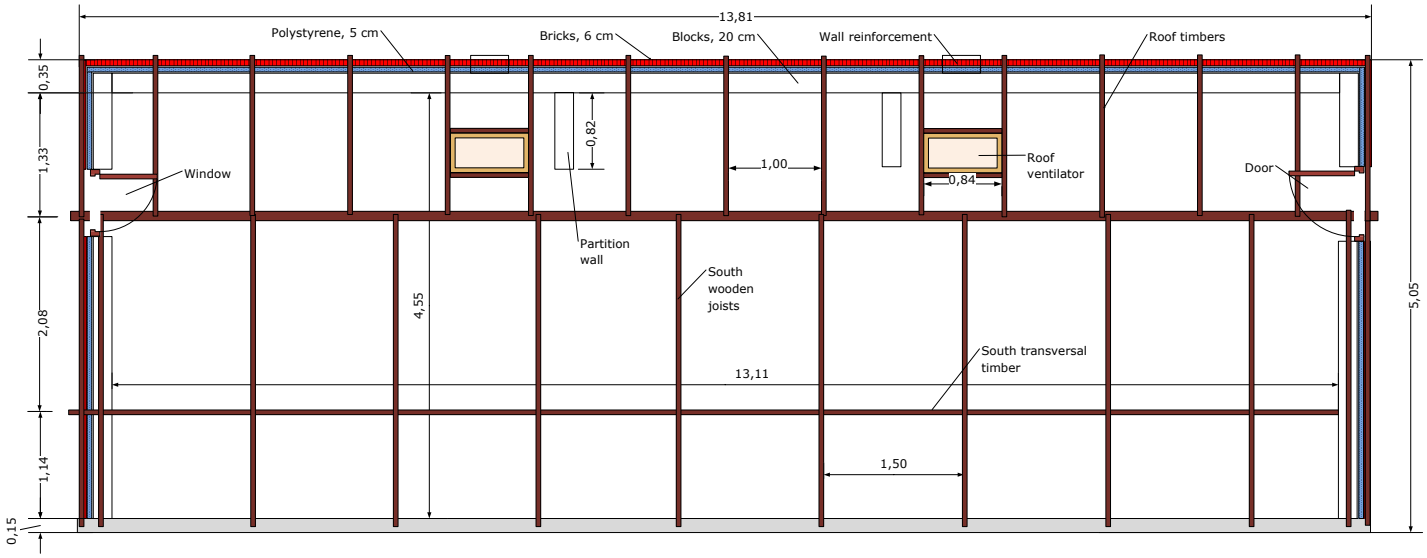




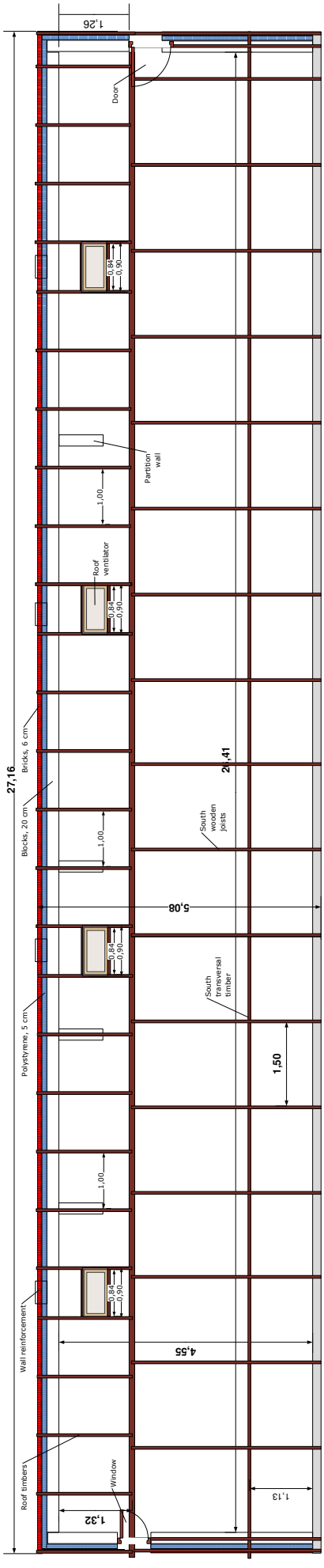
Main design /Size 60m² and 120m²: side view



Main design / Size 60m²: top view



Main design / Size 1200m²: top view *(next page)*


1,26
Door
0,84
0,90
Partition wall
1,00
Roof ventilator
0,84
0,90
Bricks, 6 cm
27,16
20,41
Blocks, 20 cm
South wooden joists
1,00
5,08
0,84
0,90
South laminated timber
Polystyrene, 5 cm
1,50
1,00
0,84
0,90
Wall reinforcement
4,55
Roof timbers
Window
1,13
1,32

List of Materials

Materials	Unit	Size 1: 32m2	Size 2: 60m2	Size 3: 120m2
Foundations				
Fondations	m3	2,0	2,7	4,4
Cement	bag (50kg), type 4.25	7,0	9,7	22,0
Gravel	porter car (0.5mm to 15mm)	1,0	1,4	3,1
Stones	porter car	1,0	1,4	3,1
Walls				
Cement hollow block	piece (20cm*20cm*40cm)	260	420	789
Cook brick	piece (6cm*12cm*24cm)	820	1300	2048
Cement	bag (50kg), type 4.25	9	14	22
Sand	porter car	0,7	1,0	2
Polystyrene 10kg/m3	piece (1m*2m*5cm)	15	22	38
Metal sticks mesh	piece (1m*40cm)	40	61	98
Roof				
Top beam	piece (7cm*15cm*5m)	2	3	6
Central pillar	piece (15cm*15cm*3m)	1	2	5
Wood timber	piece (5cm*10cm*2m), black wood, north	4	7	13,5
Wood timber	piece (5cm*10cm*2m), black wood, roof	10	15	28
Polystyrene 10kg/m3	piece (1m*2m*5cm)	9	14	27
Wood plank	piece (2cm*12cm*2m)	50	70	152
Corrugated Iron cover	piece (2,3m*0,9m*0,8mm)	10	16	31
Screw+Plastic for Corrugated Iron cover	piece	170	239	516
Aluminium foil	piece (1 m*1,2m)	17	27	54
Screw	box (10cm)	2	3	5
Wall Painting				
Black paint	kg	7	11	18
White paint	kg	4	5	5
Aceton	bottle	2	3	5
Roll brush middle	piece	2	2	4
Brush	piece	2	3	6
Ground Insulation				
Polystyrene 10 kg/m3	piece (1m*2m*5cm)	9	12	19
Door/Window/Roof ventilator				
Wood lintel	piece (7cm*15cm*3m)	1,5	1	1
Wood timbers for door/window/ventilator	piece (5cm*10cm*2m)	6	8	10
Wood door and window structure	piece (3cm*5cm*2,3m)	5	5	5
Wood for roof ventilator structure	piece (5cm*7cm*3,3m)	1	2	4
Polystyrene 10kg/m3	piece (1m*2m*5cm)	1	2	3
Handle	piece	5	6	8
Plywood	piece (8mm*1,2m*2,4m)	1	1	1
Plywood	piece (3mm*1,2m*2,4m)	1	1	1
Hinge small	piece	6	8	12
Metal sheet	piece (0,6mm*1m*2m)	0,3	0,7	1,3
Felt	m2 (1cm width)	2,5	2,5	2,5
Wood structure for plastic				
Wooden vertical small pillars	piece (7cm*7cm*3,3m)	1	4	8,5
Wooden timber	piece (5cm*7cm*2,1m)	22	22	40
Wooden timber	piece (5cm*7cm*3,3m)	2	9	18
South metal connectors between 2 walls	piece (U)	4	4	4
Wood laque	liter	7	14	28
Plastic				
Korean Plastic 0,1mm	m (10 m width roll)	9	14	28
Cheap Wooden stick	fagot (1cm*2cm*2,2m)	3	5	10
Plastic strap/wire	meter	40	60	150
Nails	kg (3cm length)	0,5	1,0	2,0
Others				
Expansed foam	bottle	3	5	10
Metal sticks	piece	20	35	70
Screw	piece (4см)	100	175	350
Nails	kg (length 7cm)	1	2	4

Foundations

Tools	Materials	Remarks
Sledgehammer, iron sticks and non-extendable rope Tape measures (5 meters minimum) Water tanks, shovel, trowel Spirit level	Cement Gravel Sand Water Stones	Good orientation of greenhouse is crucial, follow instructions carefully. Digging duration depends on soil type: Rocky soil: 1 day for Size (30m^2) Sandy soil: 0,5 day for Size 1(30m^2)

Main design

✓ Draw the foundation lines

The first step is to draw the external foundation lines of the greenhouse on the ground (see figure 1 below). The greenhouse faces south, which is the direction of the sun when it is the highest in the sky.

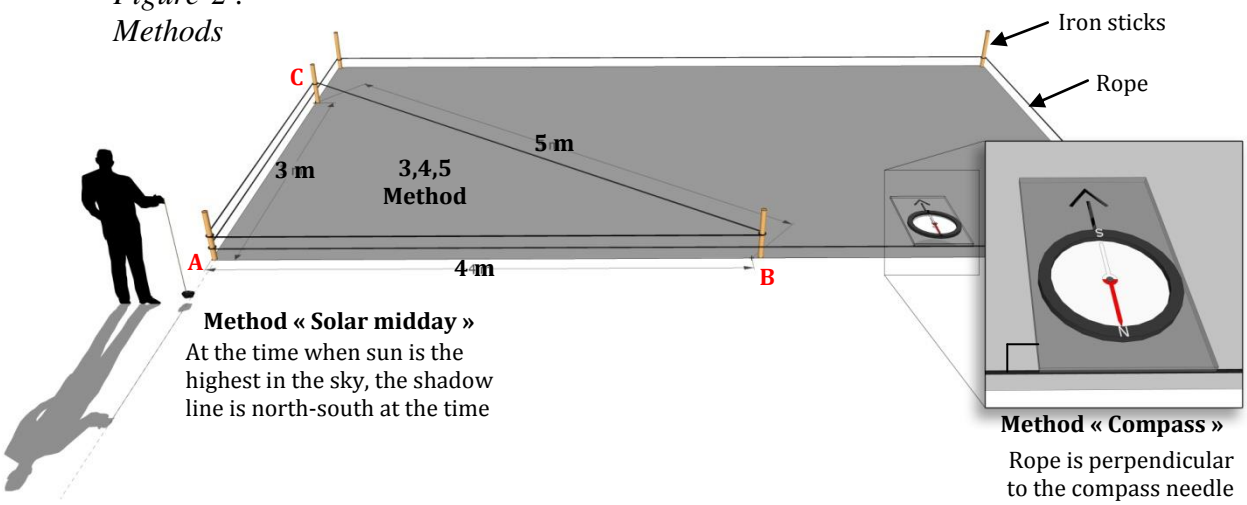
Figure 1: External foundation lines

Most of the people think they know where is south (usually the direction of the ger's door), but it is better to use one of these two methods to draw foundation lines.

Method 1: solar time (easy method)
Solar midday is the moment of the day when the sun is the highest in the sky. At this moment, sun indicates the exact South direction. If you know the solar midday of your location, you can know at what time the sun is exactly south. See Annex 1 to know solar midday of your location.
At solar midday time, position yourself at one of the corners of the greenhouse and hold in your hand a rope of 1,5m with a stone hanging at the bottom. Try not to shake (see figure 2 below).
Install a rope along the line of the shadow with iron sticks. This represents the North-South axis and the line of the West or East wall.

Method 2: use a compass (expert method)
Put a piece of wood plank flat on the soil, put the compass on it. Take care there is no metal around like nails. Position the rope so that the line is perpendicular to the needle of the compass which is oriented North-South (see picture). +/- 15° of difference with South is tolerated. This line represents the East-West axis and the line of the South or North wall.

Figure 2 : Methods



Depending on the method you used to find the south, you have only one line of the greenhouse drawn (either east or west wall, either south or north wall). You need to draw now all the foundation lines taking care they are perpendiculars and the right size.

Perpendicular: You can use the "3-4-5" method[1] to ensure that the lines are perpendiculars (see figure 2 above and figure (A) in Annex 5). Three persons are needed and a rope of 12 meters marked every meter. Form a triangle **ABC** of 3m, 4m, 5m on each side. Each person stands at each angle of the triangle. The triangle has a right angle at point A, which means that lines along AB and AC are perpendiculars.

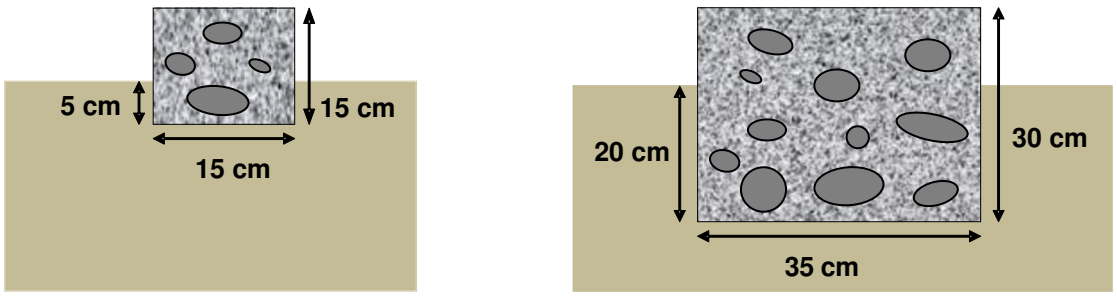
Size: see top view designs to know the size of external lines.

✓ Digging and construction of the foundations:

You have now drawn the external lines of the foundations. You should dig inside the lines the foundations. Foundation dimensions for main design are given below (same for Size 1, 2 and 3):

- Foundations width is 35 cm for West/East/North walls and 15cm for South wall
- Foundations is 20cm below soil and 10cm above soil for West/East/North walls (30cm height in total)
- Foundations is 5cm below soil and 10cm above soil for South foundation (15cm height in total)

Foundations are above soil to avoid infiltration of water and humidity.



South foundations East, North and West foundations

Figure 3: foundations dimensions

[1] The « 3,4,5 » method is a construction method based on the Pythagorean theorem…

Prepare boxing for the foundations footings wherever it is needed. Ask advice from a mason. Then, prepare the foundation mix with the following proportion:
Concrete: cement and small gravel, proportion 1:5

- 1 m^3 of small gravel (0,5mm to 10mm)
- 0,25 m^3 = 7 bags of cement = 350 kg
- 125 liters of water

  + Stones: variable

Pour the concrete in the hole with stones (5-10cm). Use your shovel to shake the concrete to ensure all the spaces between the stones are filled up. In lowlands where soil is not stable, use special metal sticks to reinforce the foundation structure. In sloppy area, you can use large stones to fill high foundations.
Use the spirit level to ensure that foundations are horizontal. The foundations should dry at least during 2 full sunny days.
For the south foundations, insert wood pieces (10cm*5cm*5cm) at the position where the wood timbers of south frame will connect to the south foundations (figure 5 and 20).

✓ Walls reinforcement for Size 2 and Size 3:

For size 2 and size 3, there are partition walls inside the greenhouse to reinforce the internal walls and increase storage of heat. Don't forget to add foundations below these extra walls.

Other options for foundations

If you the width of your walls is different from the main design, you will have to adapt the width of the foundations accordingly.
For example, for a wall composed of Blocks (20cm) + Straw (15cm) + Blocks (20cm), you will need to make a foundation of 55 cm width + 5cm extra, so in total 60cm.

Walls

Tools	Materials	Remarks
Level Shovel and trowel Container for mortar mix Rope and wood sticks for wall angles Iron angle square Cutter for polystyrene	Blocks Polystyrene Bricks Iron wire mesh Wood timber (10cm*5cm*4m) Wood top beam (15cm*7cm) Wood pillar (15cm*15cm) Iron sticks	All points are important, read instructions carefully. Select your materials for wall and insulation and adapt design if necessary Walls represent 50% of the cost of this main design presented

Main design: double walls and polystyrene

In the main design, the walls are built of 3 layers:

- INTERNAL WALL: 20 cm internal wall built with HOLLOW BLOCKS filled with compressed soil. The internal wall stores the heat and bears the load of the roof.
- INSULATION LAYER: 5 cm middle wall of EXPANDED POLYSTYRENE (EPS).
- EXTERNAL WALL: 6 cm external wall built with RED COOK BRICKS. The external wall protects the insulation layer.

Other materials can be used, either for walls, either for insulation: see the recommendations below Annex 3 and 4.

✓ Mark angles on East/West walls

Install wood sticks (5cm*5cm) tightly and form the angles of the walls with rope (see figure 4 below and figure (C) in Annex 5) according to the dimensions of the selected design. The top angle is above top beam.

✓ Mark the openings for the door and the window

The door is located opposite to the prevailing wind. In Ulaanbaatar, door is thus usually located on the East wall. The window is located to the opposite of the door.
It is easy to position the door and window openings using the number of blocks, as shown in figure 4 below.

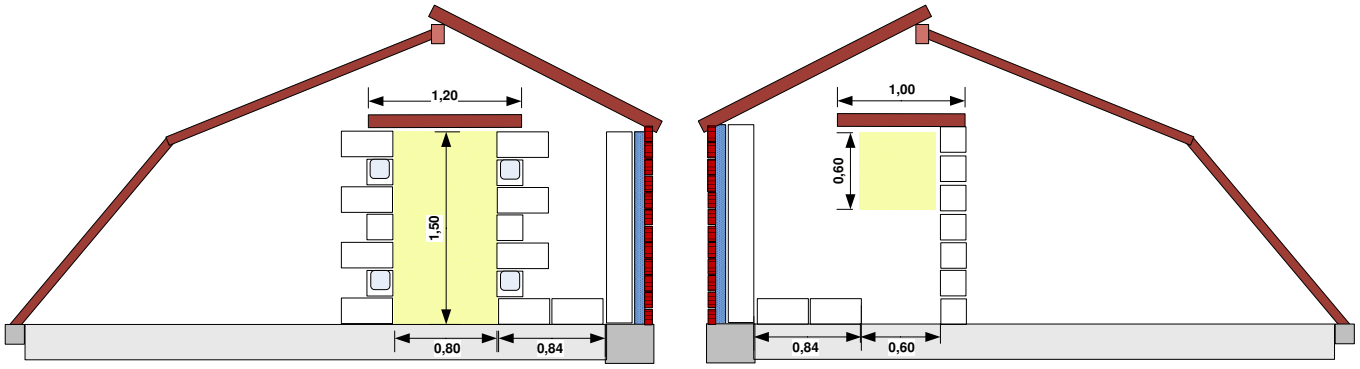


Figure 4: Position of the door and the window on the side walls

✓ Build internal East/West/North walls

Prepare the mortar (sand and cement, ratio 3:1). Mortar should be around 1 cm high. The side of the block with holes should be upward so that you can fill them with soil (the type of soil is not important). Then, the soil is compressed by hand.
Install iron wire mesh that will keep the block wall and the cook brick wall together (see figure 5 below and figure (B) in Annex 5). The part with sticks should be pointing outward (towards polystyrene and cook brick walls). Install mesh after 1st, 3rd, 5th layers of blocks and after 7th layer on East/West walls. On each layer, install a piece of iron wire mesh letting two blocks between each piece.

For the door, fill the second and sixth level blocks with concrete instead of soil, so that the door frame can be connected to the walls easily (see figure 4 above with blocks filled concrete in gray). Install the lintel on the top of the openings for the door and the window (see figure (B) in Annex 5).

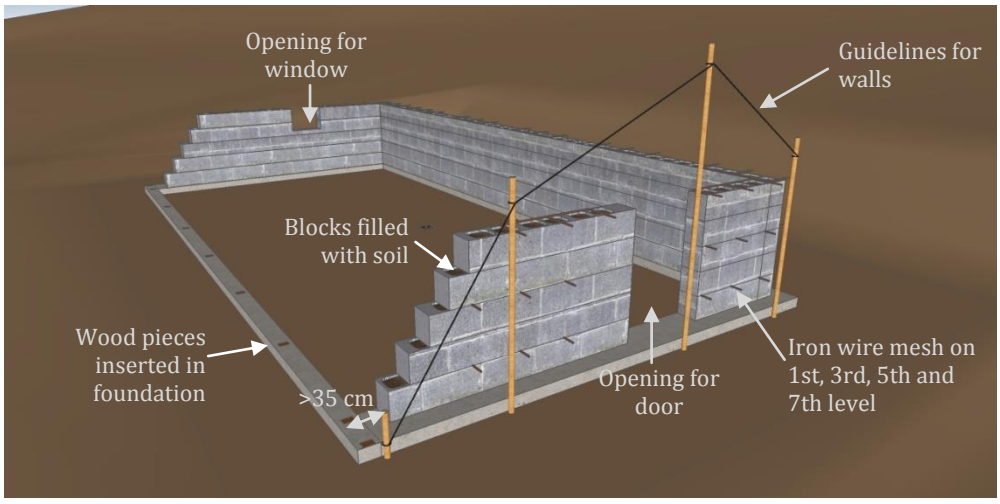
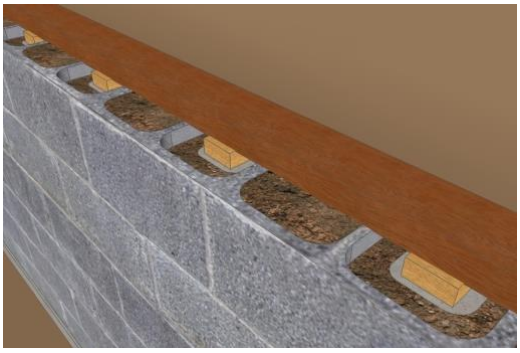


Figure 5:Wall angles and construction of internal wall

Stop the first layer of blocks 35cm minimum before the south foundations. Wait until you have finished all walls to make the slope of the walls nicely. Continue the block wall until the blocks come next to the guidelines. You should not finish the wall until you have installed polystyrene and brick walls.

✓ Extra blocks on north wall

On North wall, you can add perpendicular blocks to increase the storage of the heat. You can also use them as shelves IF the blocks are strong enough. Every two blocks, one block is placed perpendicularly to the wall.
Don't put extra blocks on the first and the last layers of blocks of the north wall.



Install a line of wood timber (10cm*5cm*2m) on the top of the last layer of the north wall.
Two possibilities:
1) You can nail the timbers to the blocks below. For this, install wood pieces with concrete in the holes of the blocks (as shown on the figure on the left).
2) Attach the timbers to the last layer of blocks with iron wire which goes under the last layer of blocks.

Figure 6: Wood timber on north wall

✓ Extra walls for design 2 and 3

For Size 2 and 3, you must reinforce the external walls with hollow blocks to support the brick walls. Partition internal walls should also be added to increase thermal mass (see design plans)

Figure 7: Inside partition walls for large greenhouse

✓ Install the central pillar(s) and the top beam(s)

Figure 8: Central pillar: making foundations and leveling

Figure 9 : Block walls, pillar and top beams and timber on north wall

Install a rope from the east to the west wall to mark the bottom of the top beam (see figure (C) in Annex 5).
Cut the pillar at the good size taking into account the extra piece into the soil. Use the spirit level to ensure that the pillar is vertical. Protect the part of the wood that will go in the soil with tar (see picture (D) in Annex 5)
Dig and make foundations for central pillars and install the central pillar (see figure 8 above). Foundations should dry for one day before installing the top beams.
Install the top beams and nail them together and to the pillar with iron sticks: minimum 6mm diameter (see picture (E) in Annex 5). Before installing, be sure that the beams have the correct size.
Protect wood beam and pillar with wood laque.

✓ Install Polystyrene and built the brick wall

Polystyrene panels are installed vertically and pushed on the iron wire mesh that comes out of the block wall. Cut extra polystyrene but make sure the polystyrene overlap the block walls by 15 cm (see picture 10 below).
It is time to build the cook brick wall. The iron wire mesh will keep the brick wall connected to the block wall (see picture 11 below and picture (F) in Annex 5). The extra part of the iron mesh should be cut after the wall is erected.
It is easier to install the last layer of bricks after the roof is installed.

Figure 10 : Polystyrene layer installation

Figure 11 : Brick wall construction

Other options for walls :

✓ Wall insulation with straw

Straw is also a good insulator; you can use straw instead of polystyrene between two walls. Be sure to use straw and not hay (see Annex 4). In this case, the insulation layer should be 10-15cm. Walls are thus larger and require larger foundations.

Figure 12 : Insulation with straw

Built the entire internal wall, then start to built the external wall, letting a 10-15cm space between the two walls. After 60cm, stop and fill the space with two layers of emptied and closed plastic bottles. Plastic bottles will limit moisture problems arising from groundwater or rains. Then, add the straw and compress it with your hand (see on left). Then, continue to alternate building the wall and filling with straw until you reach the top.

!! Be sure to fill the gap correctly between roof and walls, so that no humidity or rodents can enter the straw layer.

✓ External protection of polystyrene

This technique is already used in most of new buildings in Ulaanbaatar. Polystyrene density should be high (16kg/m^3) to be resistant. Polystyrene panels are screwed to the block wall using protecting discs to avoid damaging the polystyrene. Then, a synthetic mesh is added plastered with a special render (see picture 13).
This solution may be less durable because of rodents entering and building easily galleries in the polystyrene and possible damaging caused by chocks (children, dogs…).

Figure 13: Protection of polystyrene with plastic mesh and plaster.

✓ Other materials for double walls:

According to the materials available in your area, you can use other types of bricks or blocks that the one presented in the main design. Please refer at Annex 3 on Materials for walls.
Here are some few points to consider carefully.

- Internal wall should be at least 15cm to make a good thermal mass
- Humidity is high inside the greenhouse, so blocks or bricks should be resistant or plastered
- External wall is exposed to bad weather and wind. If the material is less resistant, it will require plastering and regular maintenance.

✓ **Other materials for insulation between two walls:** Refer to Annex 4 on Insulation materials to see what material can be used for insulation

✓ Single wall:

Single wall can be an option if it is very thick (<1 meter) because it will act as a thermal mass and insulator at the same time. If the wall is thin, the efficiency of the greenhouse will be less. However, it will still be able to extend the growing season at some point.

Three possibilities can be considered:

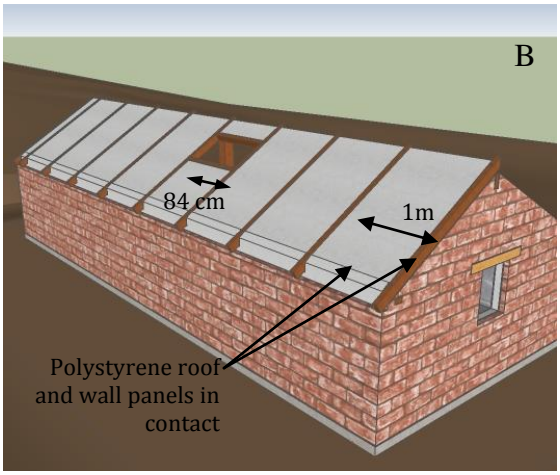
- A large amount of soil is added behind the single wall in case the greenhouse is dug into a south-facing slope. The risk is that the wall collapse under the load of soil.
- The greenhouse is partly underground (see Alternative design below). In this case, the single wall is not high and can bear the load of soil.
- The greenhouse has high but thick wall (several layers of bricks/blocks or large stone wall)

Roof

Tools	Materials	Remarks
Electrical screw gun if possible (or hand screw driver) Hammer Wood saw and cutter Ax Metal scissors	Wood timbers (10cm*5cm*2m) Polystyrene panels (2m*1m*5cm, 10kg/m3) 8 mm corrugated iron cover (2,3m*0,9m) Screw for iron cover + cap Wood planks (2cm*12cm*2m) Wood sticks (3cm*1cm*2m) Aluminium foil Nails	Don't break the polystyrene panels Be careful to gaps between insulation Polystyrene from roof and walls should be well connected Screwing iron roof is difficult by hand.

Main design: polystyrene and iron cover

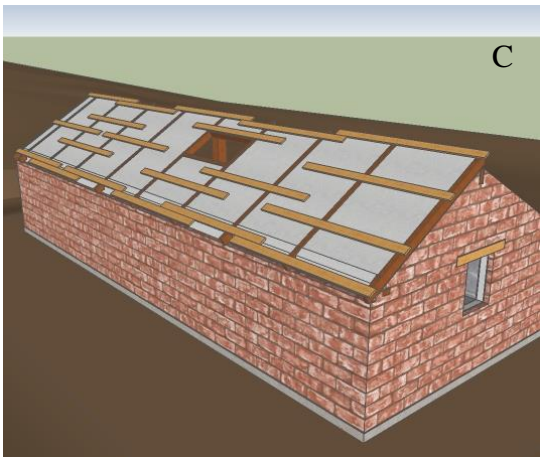
Install the first roof timber (10cm*5cm*2m) on one extremity. Nail the top part to the top beam and the bottom part to the wood timber fixed on the north wall. Cut a hole in the wall polystyrene panels to insert the roof timber. Then, install the first polystyrene panel (5cm*1m*2m). Avoid polystyrene panel to be taken away by the wind. Use half-nailed planks on the panels.



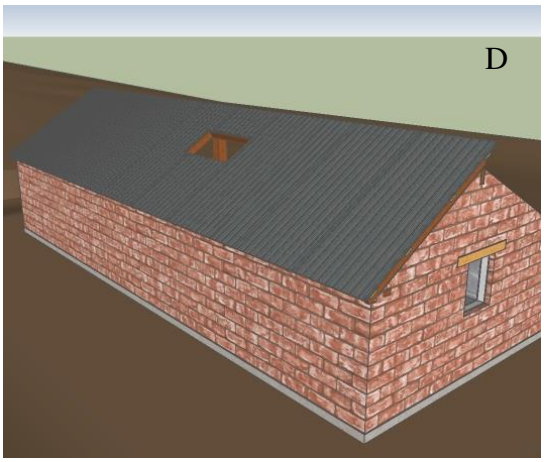
Continue one after the other.

The crucial point is that the roof polystyrene panels connect well with the vertical polystyrene panels of north, east and west walls. The panels should be in contact.

After 3 to 5 panels (depending on design), install roof ventilator frame and cut polystyrene at correct size. Inside distance between the two a roof ventilator timbers is 84cm (see roof ventilator dimensions)



Wood planks (2m*12cm*2cm) are nailed on wood timbers to support the iron cover. You don't need to use to much wood planks. Be careful when climbing on the roof.



Fix corrugated iron cover bands using special roof screw and plastic tops. 1 m^2 of roof requires 8 screws. Iron cover should overlap on each side of the greenhouse, protecting the brick walls from rain.

Figure 14: Steps on roof construction

Aluminum foil is installed below the roof and pinned up with wood sticks (3cm*1cm*2m). It will protect the polystyrene of the roof and reflect more light to the plants below (see figure 19).

Bevel the roof timbers edges above the top beam. Nail wood planks all along the roof timbers ((see figure 20). Fill the gaps between the roof and the top beam with expanded foam from inside the greenhouse before installing polyethylene sheet.

Other options for roof

According to your local climate, roof should be resistant to spring rains, wind and heavy snow falls. Roof takes a lot of moisture coming from the greenhouse, it should be resistant to humidity. There should be no air gap through the roof.

Tarfelt can also be used as a roofing material, instead of iron cover. Roof should be fully covered by wood planks before installing the tarfelt, otherwise holes will appear.
Two possibilities can be considered:

- tarfelt+ full wood planks + polystyrene. But, the cost compared to iron cover option is not very different and iron cover is more durable.
- tarfelt+ isolative layer foam of 1 cm (easily found in market in roll)+ full wood planks. Wood planks should be well protected with laque to avoid quick rotting (Annex 5, picture (I))

Wood sticks in forms of triangle should be nailed on the tarfelt.

A common practice seen in Mongolia consists in wood planks covered with a layer of yellow mud mixed with straw. As the roof is sloped, this is not a good solution because the mud will be washed down quickly.

Door, window and roof ventilator

Tools	Materials	Remarks
Saw	Wood (10cm*5cm*2m)	Require carpenter skills to
Screw driver, Hammer	Wood (5cm*3cm*2m)	prepare frames and to install

Level Carpenter square, Wood plane Tape measure	Plywood 8mm and 4mm Expanded foam Screw (10cm and 4 cm) Polystyrene Hinges, Handles Iron bar, Locks Felt	correctly. Be sure that roof ventilator(s) is/are water-proof and have a good opening system

Door and window should open toward inside greenhouse. Roof ventilator should open toward the outside.

✓ Prepare and install the door and window frames

First, measure the opening size of the door and window:

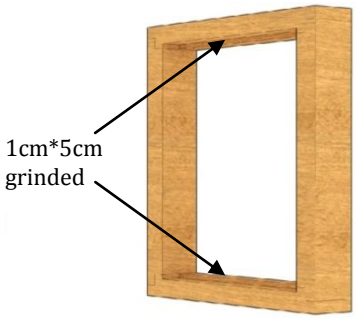


Figure 15: window frame

Then, one frame for the window and one frame for the door:

Prepare four wooden beams cross section 10cm*5cm: take out a piece 2,5cm*5cm*10cm from each extremity of the bottom and the top frame's beams.

Grind the bottom and top beams cross section on 1cm*5cm.

Assemble the four wood beams together and check if angles are perpendicular with a carpenter square. If ok, screw the beams together. Protect the frames with wood laque and let it dry.

Install the frames in the space left in the walls: half of the frame at polystyrene level, half of the frame at block wall level.

Screw (10cm screw) the door frame on the level of the blocks filled with concrete (figure 4). Then, screw to the lintel. Fill the space between the wall and the frame with expanded foam.

✓ Make and install the door and the window

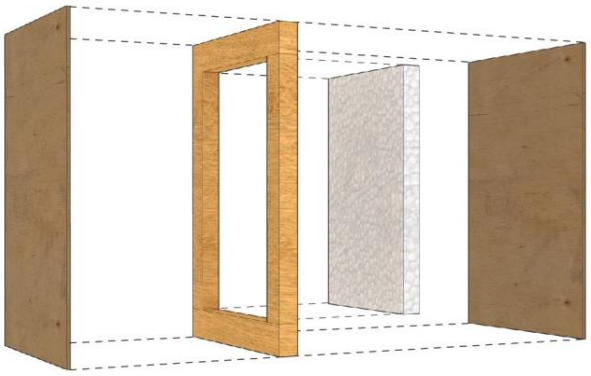


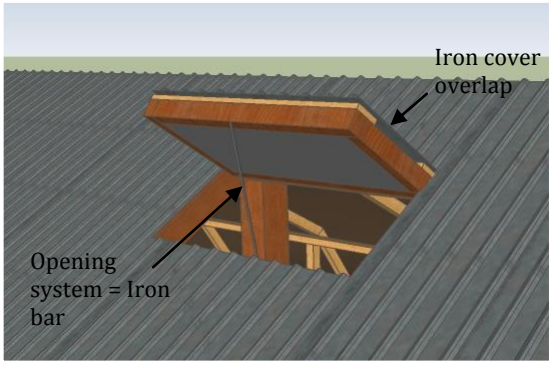
Figure 16: window structure

Build a rectangular framework using wooden battens cross section 3cm*5cm. Dimensions should be adapted to the wood frame. Insert a piece of polystyrene and inside the framework and then nail plywood on each side. Indoor plywood (8mm) should overlap the frame to avoid air infiltration (see picture (H) in Annex 5). Outdoor plywood (3mm) is same size of the frame.

Protect door and window with wood laque and let it dry. Install the door and the window in their frames with two hinges.

Place felt cover on the external openings of the door and window to protect them and decrease air infiltration. Install locks.

✓ Make and install roof ventilator



Picture of side view of roof ventilator fixing

Figure 17 : roof ventilator

The roof ventilator is composed of a rectangular wood framework (10cm*5cm cross section), filled with polystyrene and covered with corrugated iron on the external face and metal sheet on the internal face. Fix the roof ventilator inside his framework with two hinges. Be sure the iron cover overlaps the roof to avoid water infiltration (see picture (J) in Annex 5).
A moveable iron bar with holes is installed to open the roof partially or totally. Hammer a nail into the center of the frame of the ventilator in such a way that it can slip into the holes of the iron bar and keep the ventilator opened (45° maximum).

Ground insulation

Tools	Materials	Remarks
Shovel and ax Cutter	Polystyrene	Difficulty of digging depends on soil type.

Figure 18 : Ground insulation: trench and banked earth on greenhouse side

Dig around the East, North and West walls a trench of 15cm width and 70cm below the top of the foundations (see picture 18 above).
-If the soil is too rocky, you should dig a minimum of 30cm.
-If it is really impossible, you may at least put soil on the walls, until the bottom of the window

Install polystyrene panels in the holes. The panel should go 30cm above the top of the foundations and 70cm below. Then, polystyrene panels should all be covered with soil: we should see no white (see picture 18 above), otherwise, the polystyrene will be damaged quickly. You can plant grass on the banks to avoid erosion of soil.

Painting

Tools	Materials	Remarks
Brush and roll brush	White paint	Not difficult
Gloves	Black paint	½-1 day for all walls
Containers for paint mix	White spirit	

Figure 19 : inside greenhouse view

East and North walls are painted in black (see figure 19 on left) to absorb and store more heat (black color absorbs more heat).

West wall is painted in white to reflect sunlight on the plants in the morning (figure 20).

Mix the paint with white spirit and use gloves.

South frame

Tools	Materials	Remarks
Saw	Wood timbers (5cm*7cm)	Require carpenter skills
Screw driver	Wood pillars (7cm*7cm)	Protection of wood with laque or tar is very important for longevity of the greenhouse
Level	Cement and gravel for foundations for small pillars	
Hammer	Screw and nails	
Tape measure	Iron U-shape nail	
Shovel	Angle brackets	
	Wood laque	

Main design : wood frame

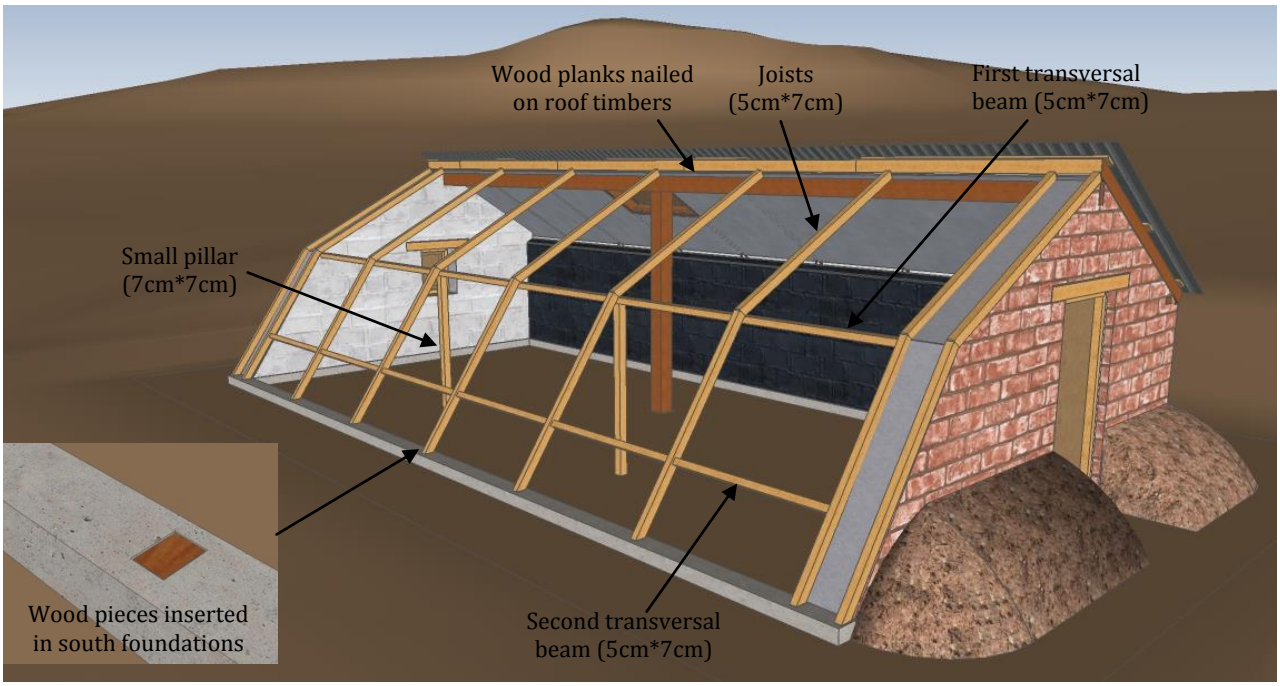


Figure 20 : South wood structure

Tighten a rope between the East and West walls at the junction of the upper and the lower section.

- Cut small pillars (7cm*7cm) and install them with small foundations at the right distance according to the design chosen.
- Install the first transversal beam (5cm*7cm) which rest directly on the pillars (picture (G) in Annex 5) and the East and West walls.
- Cut the joists at the right length and nail them to the top beam (picture 21 A), the transversal beam (picture 21 B) and wooden pieces inserted in the south foundations (picture 20). All joists should be aligned. On side walls, there should be two joists connected with four metal U-shape nails.
- Install small second transversal beams between the joists using angle brackets (picture 20 and 21 C).

Picture 21 A: wooden joist junction on top beam

Picture 21 B: Joists junctions between lower/upper section

Picture 21 C: Angle brackets for south ventilation

Distance between two joists is around 1,5m (see pictures (O) and (P) in Annex 5). If there are heavy snow falls or harsh wind, you may decrease the distance between joists to 1m.
Wood junctions, angles and edges shall be smooth. In other case, polyethylene cover will be damaged.
Paint all wood pieces with wood laque (or other protecting liquid) to protect them for humidity (humidity in the greenhouse is very high).

Other options for south structure

✓ Metal structure

It is possible to install iron structure instead of wood structure. It is more durable but more expensive and requires specific skills for installation. You can use iron curved tubes (second-hand tubes or tubes from tunnel greenhouse), inserted into the top beam and cast in south foundations.


Figure 22: Curved iron south structure

Three transversal metal beams are required to reinforce the structure and to enable bottom ventilation. They can be either attached with iron wire or welded. Polyethylene should be attached on each side walls using T-iron bar and attach system found on Tunnel greenhouse (see picture (L) on Annex 5). Vertical black straps can be fastened to keep the polyethylene tight (as on tunnel greenhouse).
Iron structure shall not be black painted (then it is too hot and polyethylene may be burnt) but white or grey.
Polyethylene should not be attached at the bottom level on 50 cm to enable ventilation.

With simple iron tubes, you will be able to put only one single polyethylene sheet.
It is possible to built double iron structure, which enables to attach two polyethylene but it is very complex (welding skills) and expensive (see picture (N) Annex 5)

Polyethylene and south ventilation

Tools	Materials	Remarks
Stepladder Scissors Hammer	Polyethylene sheets Rope/Strap (non extendable) Wood sticks, foam stripes and nails Bags filled with sand Adhesive tape Wood plank	Less than ½ day for 4 persons (Size 1 and 2) Installing polyethylene requires being careful and meticulous.

Quality of polyethylene and quality of installation are very important. If the quality is poor, polyethylene will have to be renewed after one season only!

Main design: Double layers of polyethylene sheet

The air between the two polyethylene sheets plays the role of an insulator. Comparer to a single polyethylene, air inside the greenhouse can be 2 to 5 °C warmer at night during spring and fall.
This space should be tightly closed all the time: no air gap, no holes. If the air can enter this space or inside the greenhouse, the insulation effect will be less.

It is very important to ensure that the polythene sheet is stretched tightly. Polyethylene expands with heat, so polyethylene should be fixed during the warmest hour of a sunny day when it is well-expanded so that it becomes tight as it cools. If it is fixed when the weather is cold, it will later expand and become loose, be more susceptible to damage from wind and heavy snowfall. If polyethylene is loose, the two polyethylene sheets may stick together and insulation will decrease.

Polythene sheet is usually 10 meters width. You can cut the sheet at the length you want depending on the length of the greenhouse. Then, cut again the sheet in two, so that you have two pieces of 5 meters width each; and use one part for the external face and the other part for the internal face. You will thus have little waste and no gap.

Figure 23 : Installing external polyethylene sheet

Ropes and polyethylene are fixed little by little, moving from one side to the other side of the greenhouse, one timber after the other. Four persons are required: 2 persons are keeping the polyethylene tight while 2 other persons are fixing the ropes/straps and the polyethylene. In total, 6 ropes/straps must be installed horizontally: two ropes for the first section and one rope for the second section on the external face and same on the internal face (see picture (M) in Annex 5). These ropes or straps should be non-extendable. The ropes/straps will help to keep a good space (5-7cm) between the two polyethylene sheets.

To fix the polyethylene to the wood structure, put a foam stripes (or tissue) between the wood timber and polyethylene (see picture (K) in Annex 5), otherwise, the polyethylene will be torn up quickly at the point of nailing. Then add the wood sticks and nail them to the timbers.

Install the polyethylene on the external face first, then on the internal face. Don't attach the bottom part to the timbers, because the polyethylene sheets will be rolled up to let air enter from the bottom.
To install the internal polyethylene, the small pillars are a problem. You will need the cut the polyethylene in two large stripes and fix each of them to the transversal beam.
The two polyethylene sheets should be kept as clean as possible (inside, between the two polyethylene sheets and outside). Other wise, sun light entering the greenhouse will decrease a lot.

Figure 24: South ventilation and attach system

For the bottom ventilation, you must install a simple system to attach the rolled sheets to the timber (see picture on left). Ventilation is crucial to regulate temperature and humidity inside the greenhouse and renew air for plants.

To close the ventilation, prepare cement bag half-filled with sand, to put on the plastic sheets inside and outside and keep the sheets tight down (see picture (O) in Annex 5)
When the weather is cold, there should be no air entering in the greenhouse.
You can also use ventilation windows (see picture (M) in Annex) if you have good carpentry skills

Other options:

✓ single layer of polythene and night insulation

Instead of adding a second polyethylene, it is possible to install a cloth (curtain) below the single polyethylene during cold nights of spring and autumn (night below 0°C). This technique is little more difficult, requires skills for installation and provides more shade on the crops. But, the temperature at night in the greenhouse is same as a double polyethylene and more sun is entering the greenhouse during the day as there is only one polyethylene sheet.

Figure 25: Inside night curtain

The thin cloth should be water resistant and easy to fold.
To be effective, there should be a space between the polythene and the cloth (5-10cm) so that the air inside the space is trapped. The cloth is attached at the top, middle and bottom by rings sliding on horizontal tightened metal cables (see figure 25). You should buy water-resistant and soft cloth that can easily be folded.
Prepare curtains: the curtain is cut in separate pieces to fit between the pillars supporting the wood frame. Then, make holes on the curtains every 25 cm at bottom, middle and top part, then punch grommets (metal eyelets) using a grommet hand kit.

Outdoor night insulation can also be added on the polyethylene at night. In this case, the cloth should be thick and isolative (pieces can be found in market and should be stitched together). The cloth will be rolled up or down at night with a mechanical system. Most Chinese solar greenhouse use this technique but it requires good skills to make easy system.

Alternative design: semi-underground solar greenhouse

This design is different from the design explained above.

- Growing area is dug on 60cm underground with a space all around so that foundations can
- single block wall 20cm + banked earth
- roof with wood planks, isolative layer (example: synthetic foam) and tarfelt
- double layers of polyethylene sheets
- 1 door, 1 window and south ventilation

This design is cheaper but requires digging.

Figure 26: Inside view of semi-underground greenhouse

Figure 27: Outside view of semi-underground greenhouse

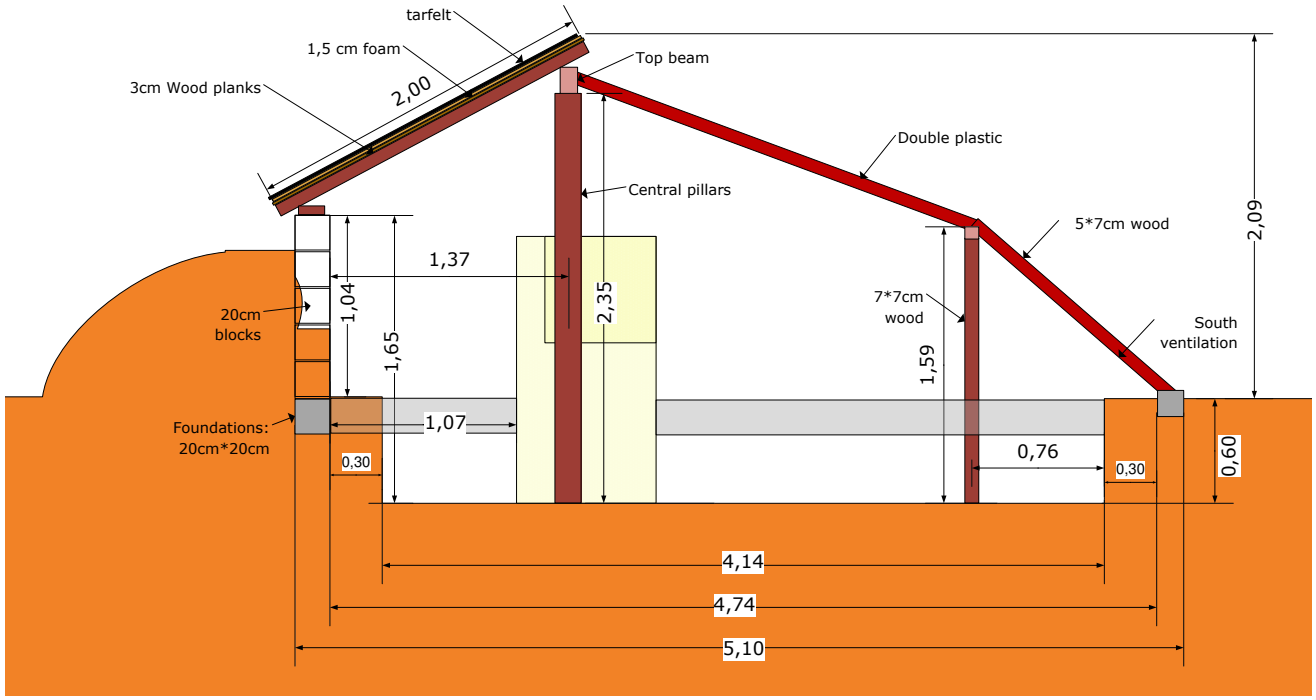


Figure 27: Side view design of semi-underground greenhouse

CONGRATULATIONS !

THE GREENHOUSE IS FINISHED

Please report now to the running manual to learn how to use the greenhouse and grow fresh and healthy vegetables

Annex 1: Find south with the solar midday time

The table gives the solar midday from April to August in every aimag capital of Mongolia. Select the nearest capital to your location and use the solar midday to know when the south is the highest in the sky and indicates south.

Aimag Capital	Solar Midday
Arkhangai	1:15
Bayan-Ölgii	1 :00
Bayankhongor	1:20
Bulgan	1:05
Darkhan-Uul	12 :50
Dornod	12 :20
Dornogovi	12 :35
Dundgovi	12 :50
Govi-Altai	1 :35
Govisümber	12 :40
Khentii	12 :35

Aimag Capital	Solar Midday
Khovd	12 :50
Khövsgöl	1 :20
Ömnögovi	1 :05
Orkhon	1 :00
Övörkhangai	1 :10
Selenge	12 :55
Sükhbaatar	12 :25
Töv	12 :50
Uvs	12 :45
Zavkhan	1 :30
Ulaanbaatar	12 :55

Annex 2: Materials logistics

In Ulaanbaatar, all materials are available easily in market.

Names	Location	What materials can be found
100 household market	Sukhbaatar district, Construction materials place.	Paint, brush, nails, screws, metal mesh, specially iron cover, iron big nails and plywood.
Khangai wood market	Songinokhairkhan district. Khanii material area.	All size of wood, paint, nails, screws, metal mesh and wood laque, aceton and Aluminium foil.
Gurvaljin 44 market.	Songinokhairkhan district, Gurvaljin bridge area.	Woods, paint, polystyrene, nails, paint and cement.
Evergreenland Co.,Ltd	Bayangol district, 10th khoroolol opposite of Stella center.	Plastic sheet, GH tools, black strap, shadow cover and water pipe.
Mon Dun LLC	Bayangol disrtrict, 1st khoroo, old wood industry fence.	Polystyrene
Terguun Zam LLC	Songinokhairkhan district, 7th khoroo, Bayankhoshuu	Hollow blocks
Mongol Keramic LLC	Songinokhairkhan district, 7th khoroo	Cook bricks
Narantuul market	Bayanzurkh district.	Felt and night cover.
Seruun Selbe LLC	Khan-uul district, back site of 3rd Pilot plan	Gravel and sand

In countryside, you need to make a market survey before the construction to see what materials are available and plan which materials to import from Ulaanbaatar or nearby cities. If you can, use material manufactured locally.

Annex 3: Materials for walls

Ash coal block		Ash coal waste chips or dust from the local coal plant. + cement in variable proportion Quality is very variable Check the quality and resistance. If the quality is good, plaster is not required
Volcano block		Volcano small stones (in volcanic areas) + cement in small proportion Blocks are usually light. If they are very light, they should not be used for internal wall because they store little heat.
Mud brick		Mud with sufficient clay content Local and natural material Usually cheap but not resistant. Check quality and resistance and use plaster to protect from rain or humidity of the greenhouse
Wood beams		It can only be used for <u>external walls</u> as wood can not store heat. Vertical or horizontal depending on the local technique. If wood is used, insulator can not be straw as it will rot easily.

Hollow blocks		Cement and small gravels There are factories of hollow blocks in most of urban centers. These blocks are generally resistant and durable. For internal wall, hollow blocks should be filled with compressed soil tp be heavier and store more heat.
Stone		Flat stones from river beds. Collection and construction takes lot of time. Local and cheap solution. Stones have good capacity to store the heat. More difficult to install polystyrene because the wall is not homogenous.
Red fire bricks		These bricks are made from clay with specific composition fired in large oven. They are generally resistant, but not found everywhere.

Annex 4: Materials for insulation in double walls

✅ **Expanded PolyStyrene (EPS)**		Polystyrene is an excellent insulator and easy to install. Polystyrene is made from petroleum. It is toxic if burnt. Be careful when handling the panels and pick up all small parts around the construction site to not pollute environment Width required: 5cm
✅ **Straw**		Straw is the stalks from cultivated grain crops (wheat, barley…) after the grain heads have been taken off. It's yellow, thick and the stalks are hollow like a drinking straw. Straw is great for insulating and is water resistant. It can be used for insulating the walls but not the greenhouse roof. ! Don't mistake straw with hay. Hay has been cut in the pastures and left to dry. Hay stalks are thin and greenish. If used as insulator, hay will rot and become dust. Width required: 15cm
❗ **Saw dust, wood shavings**		Dry wood shavings can be used for insulation in the walls but not for the roof. However, compression on the long-term makes it not a good solution. Width required: 15cm
❗ **Plastic bottles**		Recycled plastic bottles can be used for walls insulation. Use small bottles and close the caps. Arrange the bottles so that there is few spaces between the bottles This type of insulation will be twice less efficient than straw or polystyrene. Width required: 15cm
❌ **Glass wool**		Glass wool has a good insulation value and is widely used in Mongolia for insulation of the house. But, glass wool shall not be used in greenhouse because it will rot/ be spoiled with moisture and damaged by frost. It is also composed of very small fibers and can cause irritation.
❌ **Soil**		Mud is not an insulator and shall not used between double walls.

Annex 5: pictures of construction

(A) Method 3-4-5 to make perpendicular lines for foundations

(B) Block walls, iron sticks and lintel

(C) Rope for wall angles and top beam

(D) Protection with tar of main pillar

(E) Central pillar and top beam

(F) Polystyrene layer and starting brick wall

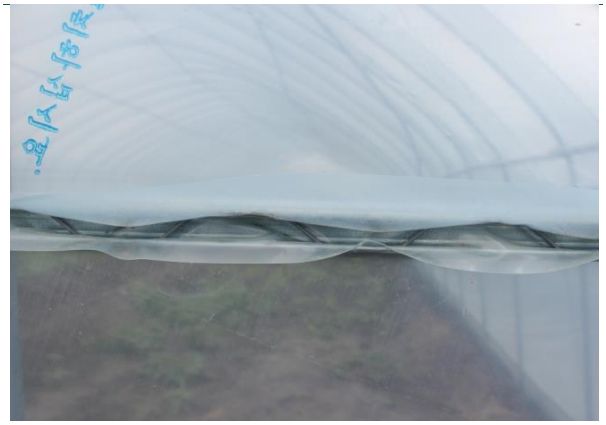
(G) Small pillar and transversal wood timber

(H) Window details

(I) Tarfelt roof and insulative thin foam layer below

(J) Roof ventilator

(K) Polystyrene connection between wall and roof (left). Foam below wood sticks to fix polyethylene (right)



(L) Lock wire system to fix polyethylene

(M) Wood structure and rope to support polyethylene

(N) Double metal structure on large chinese greenhouse

(O) Cement bag filled with sand to close south ventilation

(P) Ventilation window on south

About the organizations:

Secours Catholique/Caritas France

Founded in 1946, Secours Catholique/Caritas France is a service of the Catholic Church, and a member of Caritas Internationalis Confederation. It is a non-profit organization managing an annual budget of 130MEuros. Secours Catholique emphasizes the role of communities affected by poverty in determining their own development. It is committed to fighting side by side with them against the causes of poverty and exclusion; seeking active partnerships with organisations that share its objectives. Livelihoods/agriculture are an essential part of the work of Secours Catholique throughout Asia, Africa and Latin America.

Contact: Delphine Cournet: delphine.cournet@secours-catholique.org

Caritas Mongolia

Caritas Mongolia was founded in 2001 in response to the *dzuud* in 1999-2000 that directly affected 450,000 herders and killed about 3 million animals. Projects undertaken during the period from 1999 to 2003 were food relief, medical assistance (especially medicines and medical equipments provided to hospitals in the disaster areas), educational assistance (especially repairing dormitories where children of herders traditionally sent their children for board and lodging) and repair and rehabilitation of 17 deep wells. Based on this experience Caritas Mongolia maintains capacity for future emergency response. Food security and sustainable agriculture are key developmental project areas. The organization provides further support to anti-human trafficking, reintegration of Mongolian returnees and skills training.

Contact: Gandolgor Sainkhuu: fsproject.cm@gmail.com

GERES:

GERES, "Group for the Environment, Renewable Energy and Solidarity" - is a French non-profit NGO created in 1976 after the first Oil Shock. Environmental conservation, climate change mitigation and adaptation, reducing energy poverty, and improving livelihood of the poor are the main focus areas for GERES. The GERES team is particularly involved in the implementation, in partnership with local stakeholders and communities, of engineering solutions for development and providing specific technical expertise.
GERES has been a leading organization in disseminating solar greenhouses in cold Asian countries: Afghanistan, Tajikistan, India, Nepal, Mongolia.

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