

**Cesar Flores**  
Agribusiness Development Specialist  
East-West Management Institute  
575 Madison Ave  
25th Floor  
New York, NY 10022

*Phone:* 212-843-7660  
*Fax:* 212-843-1485  
*E-mail:* cesarflor@yahoo.com

# **A LOW-COST ENERGY EFFICIENT GREENHOUSE**

*Construction Manual*

*July 2006*



**EAST • WEST  
MANAGEMENT  
INSTITUTE**

The **Low Cost- Energy Efficient Greenhouse** is designed to create a controlled environment for the growing of cool season vegetables at dramatically reduced heating costs through energy saving advanced technologies. The Cultivable area of the greenhouse is 394 m<sup>2</sup>, sufficient for growing 1000 tomato plants.

The structure is a combination of custom manufactured polyethylene plastics and relatively inexpensive “off-the-shelf” materials. There are two covers of polyethylene 20 cm apart; an outer multilayer tear resistant polyethylene cover that diffuses light throughout the greenhouse and an inner infra-red radiation trapping, anti-fog polyethylene cover. Additional savings are provided by a lightweight aluminium thermal blanket. The blanket covers the crop during the night; adding additional insulation and reducing the heating area.

The greenhouse is lightweight, and easy to erect. Two rolling shades extending down each side of the greenhouse are an additional cost-reducing structural component,. A simple winding mechanism enables one person to adjust heat and humidity inside the greenhouse in less than one minute.

Growing media is locally available coarse construction sand. This avoids the expense and difficulty of sourcing Perlite or Peat. The media is bagged, allowing the flexibility to change the plant rows to meet the needs of the crop.

Construction can be completed in 10-12 days using 6 laborers. Prices for local materials should be USD \$ 2000-5000 depending on location. Manufactured polyethylene plastics materials cost approximately USD \$ 3700. Total greenhouse material cost is USD \$ **5700 – 8700**.

## Materials

The following materials are required to construct one greenhouse.

<b>Locally available Materials and Equipment</b>	<b>Unit(s)</b>
Metal angle, 40x40mm, 6m long	160 pieces
Galvanized pipe conduit, 20mm, 6m long	390 pieces
Metal pipe u-shaped connectors	459 pieces
Large wood boards, 70-80 x 25-40mm, 6m long	24 pieces
Small wood boards, 30 x 15-20 mm, 3m long	81 pieces
Galvanized wire, 3mm	120 m
Galvanized nuts and bolts, 6mm, 4cm long	100 units
Galvanized nails, 5cm	5 kg
Round (6 mm) rebar, 6 m long	9 pieces
Round (3mm) rebar, 6m long	1 piece
Copper electrical wire	5 m
UVA resistant nylon belt 50x2 mm	660 m
Anti-rust paint, grey	30 liters
Nylon rope for site marking	400m
Exterior White acrylic paint	20 liters
Polyethylene black pipe, 20mm	110m
Gravel	10 m <sup>3</sup>
Coarse construction sand	5 m <sup>3</sup>
Heavy polyethylene 4 liter bags	1000 units
Universal mechanical joint	2 units

<b>Manufactured Materials</b>
<b>External cover material</b> – Multilayer 6 mil UVA Diffused PE film 65 x 8.4 m (546 m <sup>2</sup> )
<b>Sidewall material</b> - Multilayer 6 mil UVA/ Diffused PE film 172 120 x 1.4 m (80 m <sup>2</sup> )
<b>Window material</b> - Multilayer 6 mil UVA /Diffused PE film 120 x 1.75 m (105 m <sup>2</sup> )
<b>Internal cover material</b> - Multilayer 4 mil UVA/IR/Anti-drip/Anti-fog PE film 63 x 11 m, (1600 m <sup>2</sup> )
<b>Thermal Blanket material</b> – Tenax Aluminet 60- 60 m x 11 m

## Selecting the Site

Site selection is determined by 4 factors:

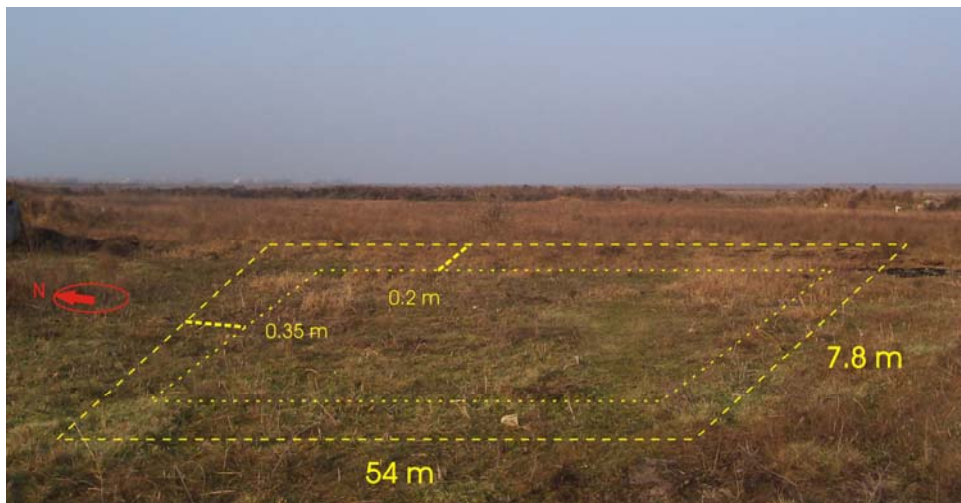
1. **North - South Direction.** The length of the greenhouse must align north-south to ensure that plants receive maximum exposure to sunlight.. Within the greenhouse, the seedbeds must also align to the north-south axis.
2. **Level.** The site ideally should be gently sloping to North or South, or alternatively, level.
3. **Unshaded.** It is imperative that no shade falls on the greenhouse at anytime during the day during all seasons of the year. Check for shade from even distant trees, buildings, fences or other structures during early morning, midday and evening.
4. **Infrastructure.** The site must have access to a
  - water source (as clean and fresh as possible)
  - an electricity supply .

## Marking the site

Once the site has been selected, measure and mark the greenhouse layout.

Tools for marking the site
magnetic compass
measuring tape (75m)
400m of thin nylon rope
4 wooden stakes
Hammer

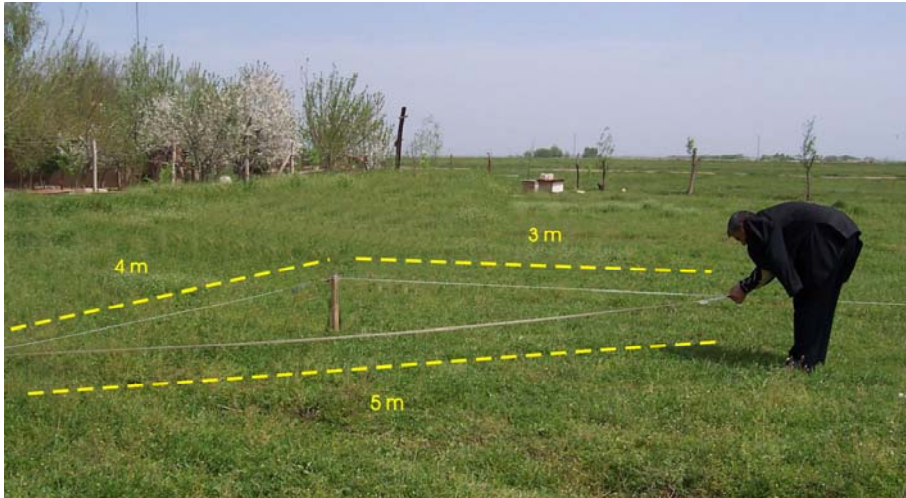
- Step 01** Determine the True NORTH/SOUTH line, this will be the greenhouse orientation.
- Step 02** Hammer the first stake vertically into the ground to establish the Northeast corner. Ensure that the stake is square to North/South.
- Step 03** Tie the nylon rope securely to the stake so the nylon rope runs along the outside edge of the stake.
- Step 04** Using the magnetic compass and the measuring tape, extend 54m of nylon rope due South, measuring from the outside edge of the first stake.



- Step 05** Hammer the second stake into the ground exactly 54m from the first stake along the North/South line. Ensure that the measurements are from the outside edge of the stake. Tie the nylon rope securely to the stake.

**Step 06**

Cut three exact lengths of unstretched nylon rope; 3m, 4m and 5m. At the Northeast corner, hold the 3m length of nylon rope along the North/South rope. Form a triangle with the 4m length of nylon rope along the East/West line and the 5m length of nylon rope along the hypotenuse. This will create a precise 90° angle.



**Step 07**

Measure 7.8 meters West from the Northeast corner along the East/West line. Hammer in a stake to establish the Northwest corner and tie on the nylon rope, passing on the outside of the stake.

**Step 08**

Mark the Southwest corner 54 meters South of the Northwest corner and 7.8 meters from the Southeast corner. Hammer in a stake and securely tie the nylon rope from both corners.

**Constructing the Arch Bending Jig**

Arches are bent cold around a jig. Two tracks of 4 cm angle iron form the jig. The jig is supported by truss work constructed from 20 mm conduit one meter high and sunk into the ground a few centimeters.

Materials for the arch bending jig
4 pieces of curved 4 cm angle iron - 2 of 3.94 m and 2 of 3.59 m
4 pieces of straight 4 cm angle iron - 4 of 2.0 m
9 leg pieces of 1.0 m conduit
Approximately 15 m of conduit for truss work
Anti-rust paint

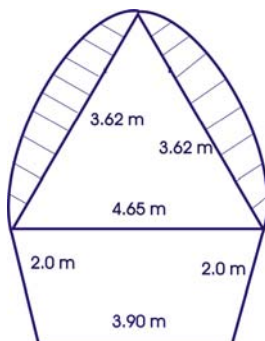
**Step 1** Using the nylon rope and a sharp stick, scribe an arc into the dirt with a radius of 3.9 m

**Step 2** **Large Arc** - Make 4 cm deep cuts every 10 cm along on one side of the 3.94 m angle irons

**Step 3** Bend the angle irons into curves matching the curved line in the dirt and weld to the ends of 3.62 m conduit

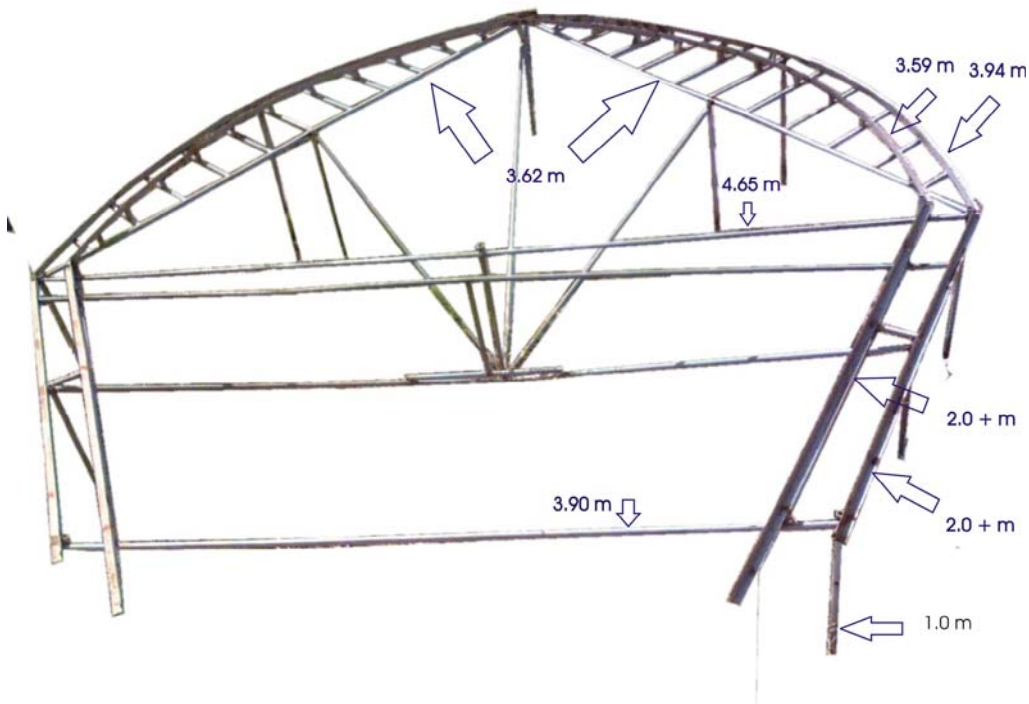
**Step 4** Weld in 10 conduit supports every 20 cm between the curved angle iron and straight conduit

**Step 5** Join both arcs with a length of 4.65 conduit m and weld.



**Step 6 Straight segments** - Attach 2 straight segments of 2.0 m angle iron to the arches. Join with a 3.90 m conduit.

**Step 7 Legs** – Weld in 9 legs of 1.0 m long conduit. Build the Supporting truss work from conduit as shown.



**Step 8 Small Arc** - Make 4 cm deep cuts every 10 cm along one side of the 3.59 m angle irons.

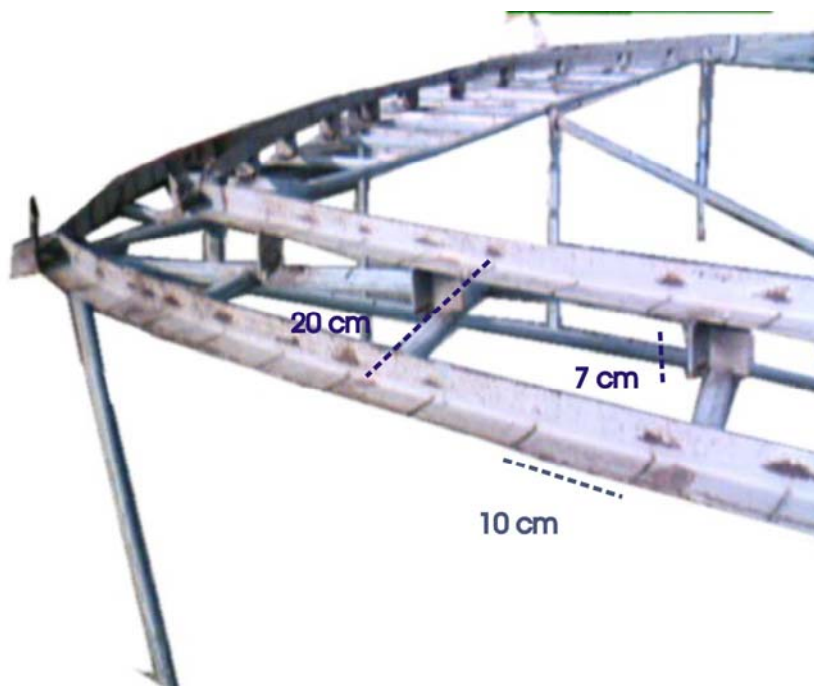
**Step 9** Bend the angle irons into gentle curves matching the curved line in the dirt and attach with pieces of angle iron 7 cm above, parallel and 20 cm inside the large arc using 20 pieces of 7 cm angle iron.

**Step 10 Straight segments** - Attach 2 straight segments of 2.0 m angle iron to the inside arches, 7 cm above and 20 cm inside the large arc

**Step 11** Attach 2 pieces of 15 cm angle iron at the arch vertexes to form guides for the bending track.

**Step 12** Paint the entire structure with anti-rust paint

**Step 13** Sink the legs into the ground a few centimeters on the site to stabilize



## Forming the Arches

<b>Materials for forming the arches</b>
306 pieces of 6 m (20mm) conduit
Antirust paint

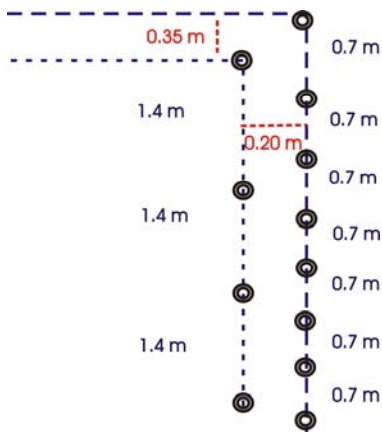
- Step 01 Weld 2 galvanized pipes (20mm, 6m long) together. Repeat to make a total of 153 pipes 12 m each.
- Step 02 Weld a 0.7 m piece of conduit onto each of 78 (12 m) pipes to make 78 pipes 12.7 m long.
- Step 03 Paint with the pipes with anti-rust paint.
- Step 04 Slowly bend the 78 long (12.7 meter) welded pipes around the **large** Jig.
- Step 05 Slowly bend the 39 short (12 meter) welded pipes around the **small** Jig.



## Erecting the Arches

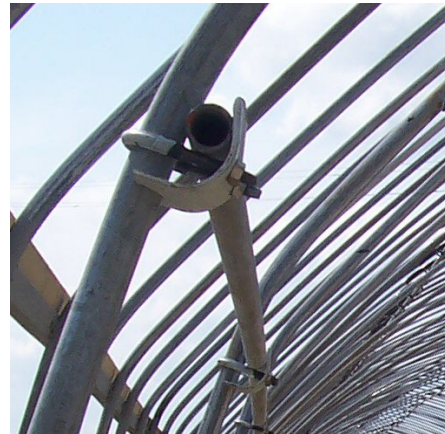
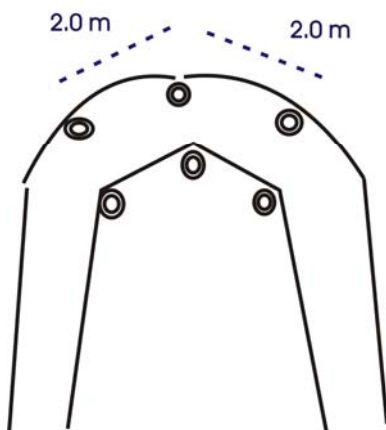
<b>Materials for erecting the arches</b>
54 pieces of 6 m (20mm) conduit
459 U-shaped connectors
12 pieces of 30 cm black (20 mm) polyethylene pipe
Antirust paint

- Step 01 Stand up the first large arch at the marked corners. Following the angles of the standing arch, make holes by hammering the 1 m rebar halfway into the ground every 0.7 m along the nylon rope line.
- Step 02 Stand up the first small arch 0.35 m inside the end and 0.20 m inside the side of the marked space. Hammer a 1 m rebar halfway into the ground (0.5 m) aligning with the angles of the standing arch. Continue making holes for the internal arches every 1.4 m along and .20 m inside the rope line
- Step 03 Erect the 39 internal arches and then the 78 external arches by simply inserting them into the holes.





- Step 04** Make a 54 m longeron by welding 9 pipes 6 m each, end to end. Repeat twice to make a total of 3 external longerons.
- Step 05** Make a 53.7 m longeron by welding 9 pipes 6 m each, end to end and cut to 53.7 m. Repeat twice to make a total of 3 internal longerons.
- Step 06** Paint all longerons with anti-rust paint.
- Step 07** Using the metal u-shaped pipe connectors, hang the central longeron from the apex of the external arches. Loosely tighten the connectors.
- Step 08** Using the u-shaped connectors, hang the lateral external longerons 2 m to each side of the apex of the external arches. Loosely tighten the connectors.



- Step 09** Hang internal longerons on the inside arches at the apex and at both “elbows”. Loosely tighten the u-shaped connectors.
- Step 10** Weld the longerons to the end arches only. Line up the longerons using a tightly pulled rope as a guide and then fully tighten all u-shaped connectors.
- Step 11** Cover all of the connectors and all the sharp edges at the front and rear, inner and outer arches of the greenhouse with 30cm long pieces of split black polyethylene (20mm) pipe to prevent tearing the polyethylene covers.

### ***Building the End Walls***

<b>Materials for End Walls</b>
2 pieces approximately 7 m angle iron for crossbar
4 pieces 2.2 m angle iron for vertical supports
4 pieces approximately 3.0 m angle iron for sides

6 pieces approximately 2.0 m conduit (20 mm) for roof support
6 pieces of 6 m large wood boards, 70-80 x 25-40mm, 6m long
12 Galvanized nuts and bolts, 6mm, 4cm long
Antirust paint

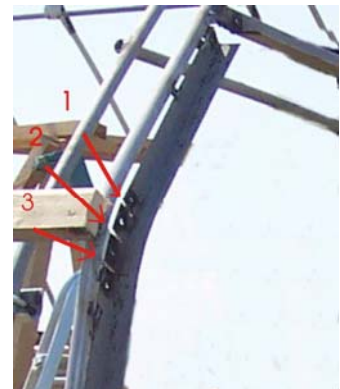
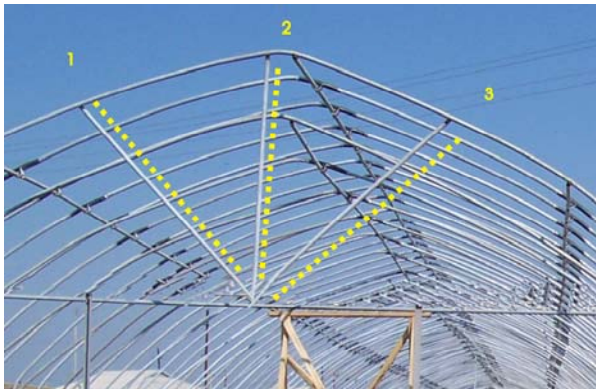
**Step 01** Weld a metal 4 cm angle iron crossbar horizontally across the entrance 2m high, cut to fit.

**Step 02** Stand 2 metal angle irons 2m apart (1m from center) vertically against the crossbar



**Step 03** Weld the vertical supports to the crossbar. Bury the angle iron supports 20cm deep.

**Step 04** Cut to fit and weld 3 lengths of galvanized pipe from the upper center of the door to the end arch to form arch supports.



**Step 05** Weld angle iron to the arch pipe from the ground up to the crossbar along both sides of the door arch. A bend can be made at the elbow by making 3 cuts 4 mm each into one side of the angle iron before bending.

**Step 06** Drill 8 mm holes every 2 m into the angle iron along the crossbar, door supports, and sides.

**Step 07** Bolt Wood boards, (70-80 x 25-40mm) 6m long to the angle irons on the crossbar, door supports and sides, cut to fit.

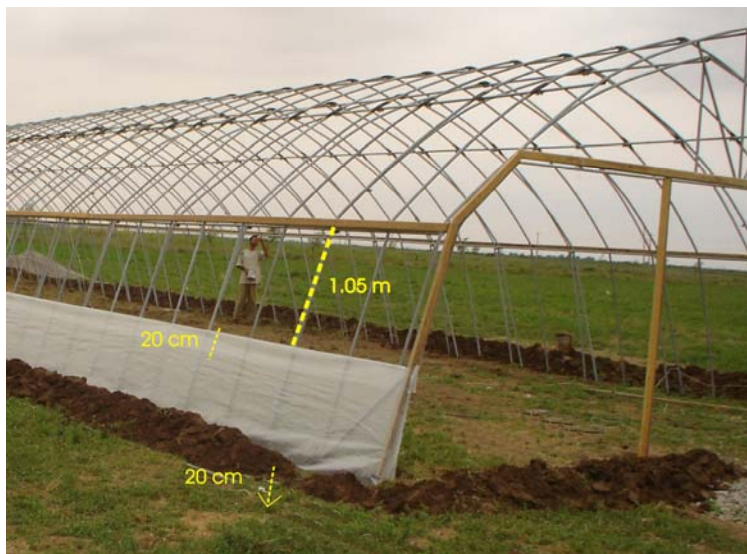
**Step 08** Paint all wood surfaces with white exterior acrylic paint to prevent heat degradation of the UVA resistant material

**Step 09** Build a similar end wall and door at the other end of the greenhouse

## Building the Side Walls

Materials for Side Walls
18 pieces of 6 m angle iron for horizontal Window support
18 pieces large wood boards (70-80 x 25-40mm) 6m long
54 nuts (6 mm) and 54 bolts (6 mm), 4 cm long
115 m galvanized cable (3 mm)
2 pieces Multilayer 6 mil UVA Diffused PE film 55 x 1.4 m (80 m <sup>2</sup> )
Anti-rust paint
Exterior white acrylic paint

- Step 01** Tie the nylon rope to the outer arches the full length of the greenhouse at “elbow” level. Level the rope with a bubble level. Weld 2 metal angle irons (40x40mm, 6m long) together. Repeat until you have a total of 18 angle irons, 12 m long each. Spot weld the 12 m angle irons to the arches, level with the nylon rope. Recheck the full length is level and make corrections before fully welding to the arches. Do both sides of the greenhouse.
- Step 02** Drill 8mm diameter holes every 2m along the length of the angle iron on the vertical side beginning 5cm from the end of the greenhouse.
- Step 03** Drill 8 mm diameter holes through the wooden boards (70-80 x 25-40mm), 6m long matching the angle iron holes. Bolt the boards to the angle irons the full 54 m length using galvanized nuts and bolts (6mm, 4cm long).
- Step 04** Paint all wood with Exterior White acrylic paint. This will prevent heat degradation of the UVA resistant material.
- Step 05** Attach a 3 mm galvanized cable to the end arches 1.05 m below the elbow angle irons on both sides of the greenhouse. Adjust the cables to level with a bubble level and tighten with turnbuckles.
- Step 06** Dig a 20 by 20 cm trench along the sides of the greenhouse at the base of the outer arches.
- Step 07** Fold 55 m long 1.45 m wide “ 172” material over the galvanized cable. Leave 20 cm of material folded on the inside of the cable. Fasten the material to the galvanized cable at each arch, using short pieces of copper wire punched through the material. Bury the material 20 cm deep in the trench, fill and tamp with dirt .

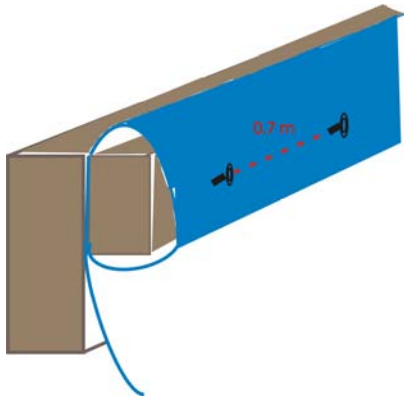


## Building the Windows

Materials for Windows
36 pieces wood boards (30 x 15-20 mm), 3m long
Galvanized 5 cm large head nails
18 pieces 6.0 m conduit (20 mm) for rollers
6 pieces of 6 m Wood boards, 70-80 x 25-40mm, 6m long
115 m galvanized cable (3 mm)
2 pieces Multilayer 6 mil UVA Diffused PE film 60 x 1.75 m (105 m <sup>2</sup> )
Anti-rust paint
Exterior white acrylic paint

### Step 01

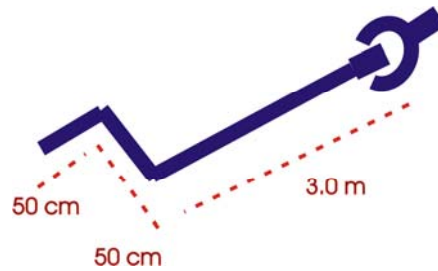
Wrap the top edge of the 60 x 1.75m " 172" material around 18 narrow wood boards (30 x 15-20 mm, 3m long) and nail the wrapped boards to the UPPER HALF of the large bolted wood boards with galvanized 5cm nails every 0.7m along both sides of the greenhouse. Ensure that the **'this side up'** message is facing outwards. Do both sides of the greenhouse.



### Step 02

Weld 9 pieces of 6 m conduit end-to-end to make 2 winding poles, each as long as the greenhouse.





- Step 04** Construct 2 cranks from conduit (20 mm), 2 pieces 50 cm and one piece 3 m. Weld the universal joints and crank to the front end of both poles.
- Step 05** Support the both poles above the ground so that they reach the level of the window material.
- Step 06** Roll the bottom edge of the material tightly onto the window winder pole and attach every 1m with clips made from split black polyethylene pipe cut into 20cm lengths.

### ***Building the Corner Walls***

<b>Materials for Corner Walls</b>
12 pieces of 30 cm black (20 mm) polyethylene pipe
1 m copper wire
Galvanized 5 cm large head nails

- Step 01** Cut 4 pieces 2.5 m long each from the surplus cover material (60 m – 54 m) and cover the first 3 arches at each greenhouse corner, inside the external arches and below the wood window top edges. Ensure that the **'this side up'** message is facing outwards
- Step 02** Wrap and nail the material to the top side of the wood window top and wood door corners.
- Step 03** Fold and clip the material to the 3<sup>rd</sup> arch from the end with clips made from split black polyethylene pipe cut into 20cm lengths.
- Step 04** Tie the bottom edge of the material to each of the 3 arches with copper wire punched through the material.



### ***Laying the Internal Cover***

<b>Materials for the Internal Cover</b>
Multilayer 4 mil IR/Antidrip/Antifog PE film
63 x 11m, (1600 m <sup>2</sup> )

- Step 01** Cover the internal structure first. Work in the early morning with absolutely NO WIND. Plan to lay both the internal and External covers the same day.
- Step 02** If the material is on a roll, insert a piece of conduit long enough to support it on 2 stands at the entrance. Stands can be simply constructed by welding "X" shapes from either conduit or angle iron and burying them in the ground.
- Step 03** Pass 2 long ropes (60 m minimum each) over the entire length of the top of the greenhouse. Tie the ropes to the corners of the material.



- Step 04** 2 people pull the ropes from the far end of the greenhouse. 1 or 2 people feed the material from the roll. 4 people push and guide the material with 3 m poles from below as it passes over the internal roof of the greenhouse
- Step 05** Everyone then unfolds the material by pulling gently and evenly from the sides.

## ***Laying and attaching the External Cover***

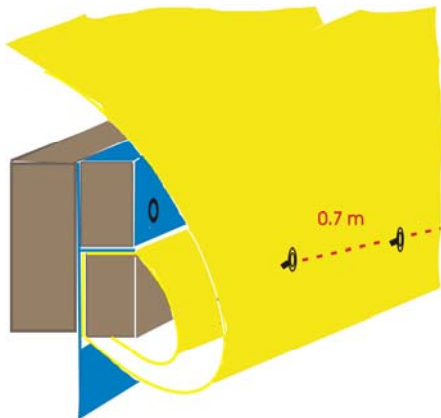
<b>Materials for the External Cover</b>
1 piece Multilayer 6 mil UVA Diffused PE film 65 x 8.4 m (546 m <sup>2</sup> )
36 narrow wood boards (30 x 15-20 mm), 3m long
Galvanized 5 cm large head nails

- Step 01** Work in the early morning with absolutely NO WIND. If the cover material is folded, 1 lightweight person stands on the top of the greenhouse and walks to the end gently pulling and laying the material as it unfolds.



**Step 02** 6 or more people on each side of the greenhouse pull and guide the material slowly and evenly from one end to the other.

**Step 03** Wrap the edge of the cover material around 18 narrow wood boards (30 x 15-20 mm), 3m long and nail every 0.7 m to the LOWER HALF of the large wood boards along the entire greenhouse on one side. Pull the material tightly over the top of the greenhouse and wrap and nail the other side. Air temperature should be warm during stretching operations.



## ***Attaching End Walls and Doors***

<b>Materials for End Walls and Doors</b>
12 pieces of 30 cm black (20 mm) polyethylene pipe
1 m copper wire
Galvanized 5 cm large head nails

**Step 01** Cut the extra roof material to the size of the front side.

**Step 02** Wrap the end wall material around 3 narrow wood boards (30 x 15-20 mm, 3m long, cut to fit). Nail the material to the UPPER HALF of the wooden door crossbar.

**Step 03** Wrap the roof cover material around 3 narrow wood boards (30 x 15-20 mm, 3m long, cut to fit) and nail to the LOWER HALF of the wooden door crossbar.

**Step 04** Wrap the material around 3 narrow wood boards (30 x 15-20 mm, 3m long, cut to fit). Nail the material to the wood side corners of the greenhouse.

**Step 05** Dig a 20 x 20 cm trench and bury the bottom 20 cm of the material in the ground.

- Step 06** Cut the material vertically along the side of the door support closest to the wind.
- Step 07** Wrap 1 narrow wood boards (30 x 15-20 mm, 3m long cut to fit) and nail it to the vertical wooden door support on one side of the entrance door. Attach it to the side closest to the prevailing wind direction.
- Step 08** Cut a piece of the material 2.3 m x 2.3 m wrap 2 narrow wood boards (30 x 15-20 mm, 3m long, cut to fit) and nail it to the wooden door crossbar and side to form an outer door layer opening from the opposite side of the outer layer.



## ***Installing Internal Cover Ventilation Hangars***

<b>Materials for Ventilation Hangars</b>
9 pieces of 6 mm round rebar, 6 m long

- Step 01** Cut 80 lengths of 0.7m each from round rebar (6mm, 6m long), bend them into an 'S' shape and paint with anti-rust paint.



- Step 02** Hang the "S" shaped hangars on the side internal longerons at both sides of each internal arch.



## ***Installing Tension Belts***

<b>Materials for Tension Belts</b>
9 pieces of 6m galvanized conduit (22 mm)
64 iron rings (6 mm)
48 m of UVA resistant webbing (50 x 2 mm)

- Step 01** Cut 64 lengths of 0.8 m conduit. Cut iron rings from the 6 mm iron pipe. Weld the iron rings at the top and side of each piece of conduit.
- Step 02** Hammer the ringed conduit pegs into the ground every 1.4 m aligned with the internal arches, along and as close as possible to both sides of the greenhouse. Orient the pegs so that rings face the greenhouse.
- Step 03** Tie 32 UVA resistant webbed belts (50 x 2 mm) 14 m long each, to the rings on one side, stretch over the top of the greenhouse and tie to the ringed conduit pegs on the opposite side.



## ***Installing the Seedbed***

<b>Materials for Seedbed Installation</b>
10 m <sup>3</sup> of gravel
1000 heavy Polyethylene bags (4 liter)
4 m <sup>3</sup> of coarse construction sand (3-4 mm sand diameter)

### ***Test the Porosity of the growing media***

- Step 01** Cut the top off and fill a 2 liter plastic water bottle with a measured 500 ml. of the growing media.
- Step 02** Slowly pour a measured quantity of water until the water rises to the top of the media. This quantity is the TOTAL POROSITY.  $xx \text{ ml}/500 \times 100 = \text{PERCENT POROSITY}$
- Step 03** Punch holes in the bottom of the bottle and catch all the drainage water for 5 minutes. Measure this quantity, it is the TOTAL AIR.  $xx \text{ ml}/500 \times 100 = \text{PERCENT AIR}$
- Step 04** TOTAL PERCENT POROSITY – PERCENT AIR = **PERCENT WATER**
- Step 04** Acceptable range = **AIR SPACE = 20-30%**  
**WATER SPACE = 30% +**



### ***Install the Seedbed***

- Step 01** Lay a 2 cm layer of gravel inside the growing area of the greenhouse
- Step 02** Fill 1000 heavy polyethylene bags with approximately 4 L of coarse construction sand. Punch drainage holes in the sides of the bags 2 cm from the bottom.
- Step 03** Lay the bags of sand in 10 rows of 100 bags each. Space plants 0.4 m apart and 0.5-0.8 m between the rows. Place the end bags in plastic crates to stabilize the rows.

### ***Completed Greenhouse:***



### ***Manufacturers of Polyethylene cover materials:***

Kibbutz Ginegar  
Ginegar Plastics  
ISRAEL, 30053  
Tel: 972-4-6544220  
Fax: 972-4-6547947  
<http://www.ginegar.com>

Covalence Plastics  
1401 West 94th Street  
Minneapolis, MN 55431  
USA  
800-873-3941  
<http://www.covalenceplastics.com/site/content/agricultural/agricultural.asp>

AT Plastics Inc.  
142 Kennedy Road S.  
Brampton, Ontario L6W 3G4  
CANADA  
Tel:(905) 451-9985 Fax:(905) 451-1677  
<http://www.atplas.com/products.htm>

### ***Manufacturer of Thermal and Shade material:***

TENAX International B.V.  
Via Ferruccio Pelli, 14 • CH-6900 Lugano  
SWITZERLAND  
Tel. +41+91.9233412 • Fax +41+91.9237517  
<http://www.tenax.net/>

---

<sup>i</sup> ***Special thanks*** to Yosi Galon of East-West Management Institute, Elnur Sofiev and Rose Wellington of International Rescue Committee for providing explanations and some of the photos.