Chapter 8
Greenhouse Components, Mounting, Installation and Maintenance

When the farmer has chosen a greenhouse structure, he has to observe the mounting and installation by the manufacturer very carefully. He should look around and check all components and connections of the structure, the fastening of the cladding material, the tightness of ventilators, doors and screens as well as the climate control systems. Even if the structure in principle fulfils the requirements and specifications, mistakes during the mounting can weaken the whole structure and can make the investment useless.

After the structure is ready for operation, the farmer has to take responsibility for continuous maintenance, so that the greenhouse can be operated as long as possible.

Examples of how to do and how not to do will be shown.

8.1 Foundation

The concrete foundation of a greenhouse should fulfil the following requirements:

1. It should safely sustain and transmit the loads of the greenhouse to the ground. These are pressure forces as well as uplift forces by wind suction.
2. The footing of the foundation should rest on undisturbed soil at a depth of about 500–600 mm below the ground surface. It is not necessary to build continuous foundations below the side walls and gables, but only stable concrete point foundations below the vertical stanchions.

The European standard for greenhouses EN 13031-1 (2001) gives some instructions for concrete point foundations and the possible tolerances (Fig. 8.1):

"The position of the prefabricated foundation block within the foundation hole shall be such that:

- Its centre lies within a circle with radius equal to D/5 or 100 mm, whichever is less, of the centre of the foundation hole.
- The distance between the face of the pile and the face of the foundation hole is at least 50 mm or D/8, whichever is larger".

C. von Zabeltitz, *Integrated Greenhouse Systems for Mild Climates*,
DOI 10.1007/978-3-642-14582-7_8,

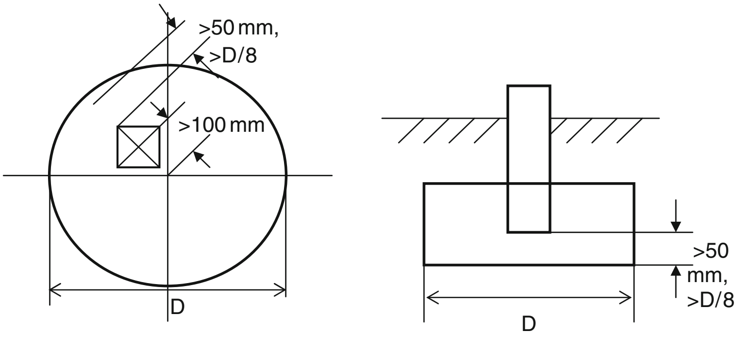

Fig. 8.1 Concrete foundation according to European standard EN 13031-1 (2001)

The concrete point foundation consists of the concrete base with the diameter D at a depth of 500–800 mm and the concrete pile as holder for the stanchions.

The Indian Standards IS 14462:1997 and ASAE EP460 DEC01 give average diameters of point foundations for greenhouses which can be taken also for subtropical and tropical conditions.

Greenhouse span (m)	Distance of stanchions (m)		
	2.4	3.0	3.7
	Diameter of foundation (mm)		
6 m	300	300	300
8.5 m	300	380	380
9.5 m	300	380	380

For windy areas, it is recommendable to install foundations with a diameter up to 500 mm.

Low-cost greenhouses often do not have concrete foundations. The steel pipes or wooden stanchions are very often inserted directly into the soil. This method is dangerous, because uplift wind forces can damage greenhouses very easily. This happens very often with round-arched tunnel greenhouses.

Figure 8.2 shows some well-designed concrete foundations (also see Figs. 8.3–8.5).

8.2 Connections and Clamps

All steel components of the greenhouse structure should be connected by screws or clamps. Welding is not recommended after galvanising the components.

The stable connection of the steel components by clamps is very important for the wind resistance of the greenhouse structure.

The clamps must not slide on the tubes, but have to be tightened firmly. After the mounting has been finished, one has to check whether all clamps, screws and bolts are screwed and fixed tightly.

Some example of how to do and how not to do are shown in the following figures:

Fig. 8.2 Some well-designed concrete foundations. The vertical columns should be inserted on or in a pipe which is part of the concrete foundation block. The columns should be fixed by screws or bolts and not welded

8.2.1 How to Do and How Not to Do the Clamp Connections

(See Figs. 8.6–8.10)

Fig. 8.3 Vertical posts inserted directly in the foundation are not recommendable

Fig. 8.4 Even timber stanchions should be inserted in concrete foundations to stabilise the structure

8.2.1.1 Welding

All galvanised steel components of the structure should be connected by clamps, screws or bolts as far as possible and not welded. Welding destroys the protective galvanised surface, and the steel component starts to get very rusty quickly. If

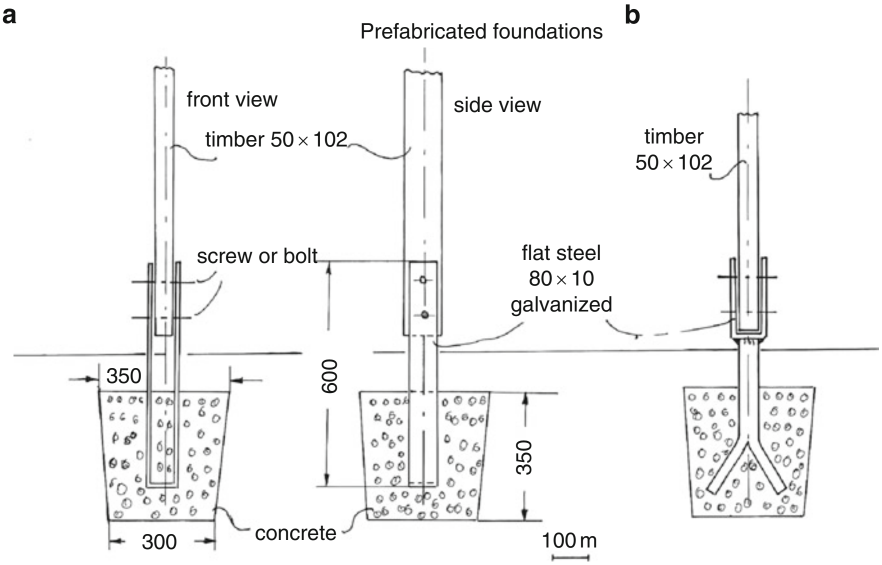

Fig. 8.5 Prefabricated foundations can be used for timber structures, for example. The timber stanchion should not be inserted directly into the soil or into the concrete footing, but should be fastened in a steel or wooden holder, which is inserted in the concrete footing. In that way, rotting of the structure can be avoided

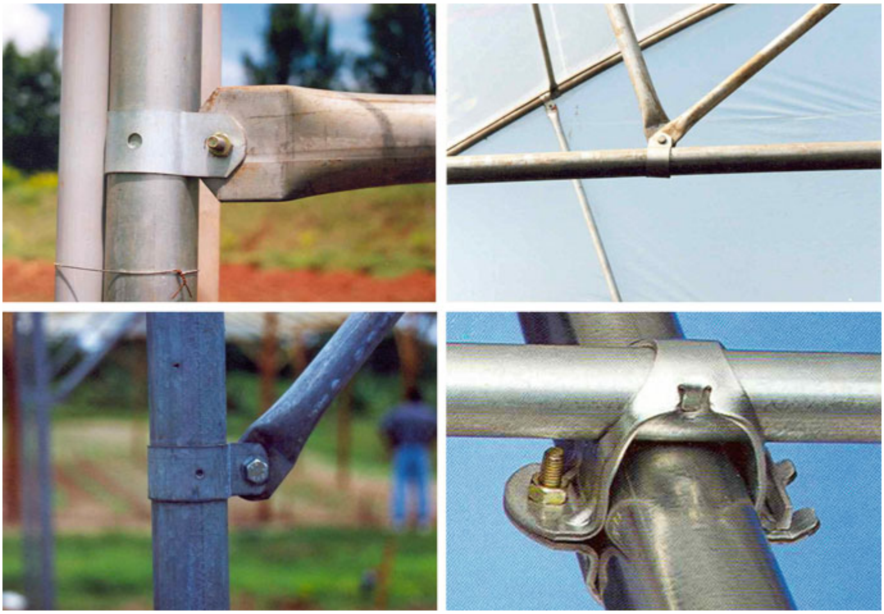

Fig. 8.6 Tight clamps for steel components

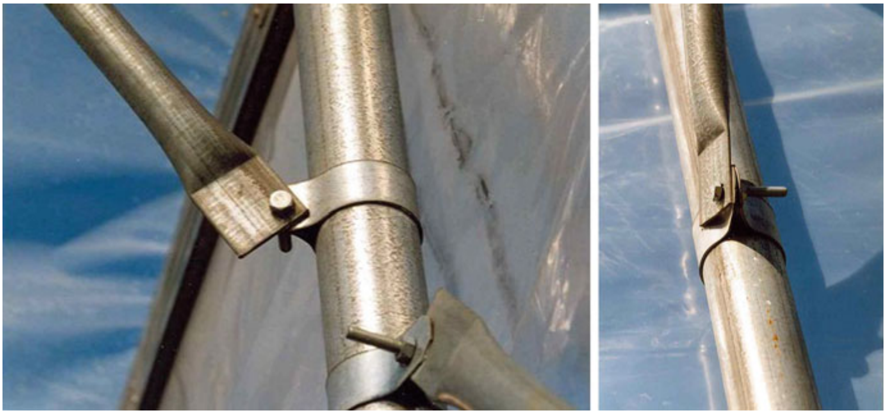

Fig. 8.7 The clamps are screwed tightly together, but the borehole in the brace is near the edge, so that the brace cannot be fastened firmly to the clamp. It is better to bevel the brace and to bore the hole in the middle

welding is unavoidable the welding, must be painted carefully. Otherwise, rust occurs immediately (Fig. 8.11).

8.2.1.2 Gutters

See Figs. 8.12 and 8.13.

8.3 Fastening and Stretching of the Cladding Material

Plastic film as cladding material on greenhouses has to be fastened to the structure and stretched tightly. The film must not be able to flutter due to wind forces. If the film starts to flutter, it will be destroyed quickly.

The plastic film has to be changed every 2–4 years, depending on the quality. This work is costly, and should be done quickly. That means the film should be fastened by detachable devices and not by nailing. Nailing is still used in several countries, in particular with wooden structures. If there is no other possibility, the plastic film should be fixed by screwing two laths together with the plastic film in between (Fig. 8.14).

Plastic film can be fastened by fastening devices made of plastic, aluminium, or steel (Fig. 8.15) or by rolling it up on a tube (Fig. 8.19). The film has to be fastened in a longitudinal direction at gutters and side wall as well as at the roof and gable ends (Figs. 8.16–8.23).

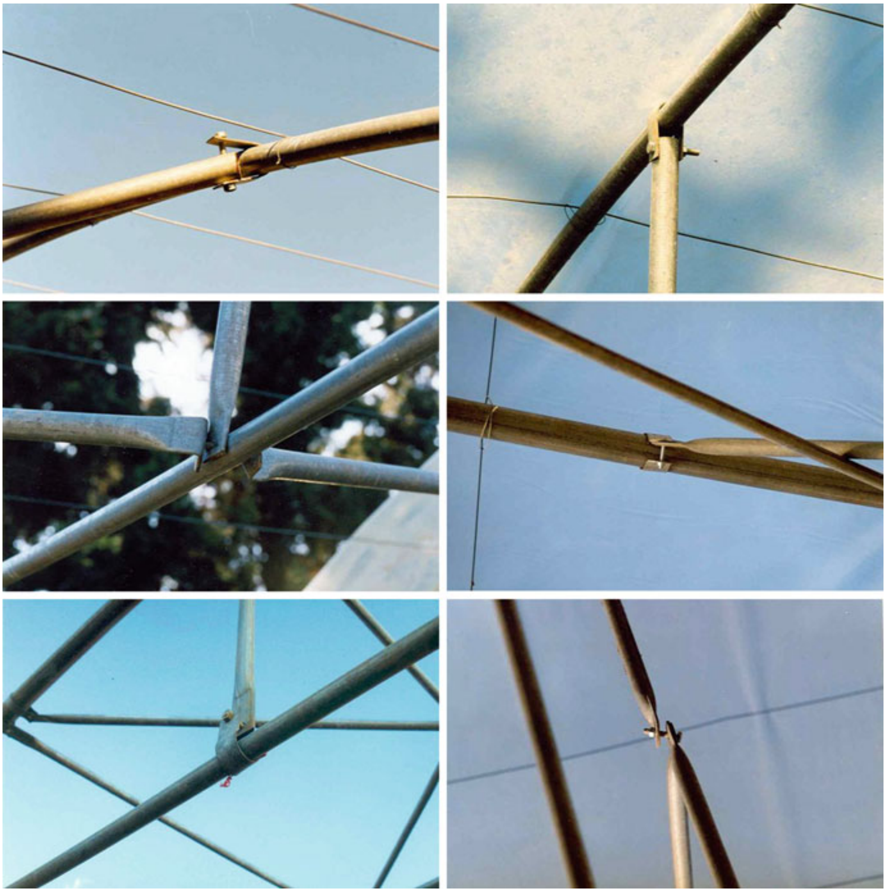

Fig. 8.8 The connectors are absolutely not acceptable. This is not only a matter of the design, but is caused by the mounting at the farm. The workmen worked badly

After having been fastened to the structure, the films have to be stretched tightly to prevent fluttering by wind forces. This can be done by the following methods:

- Fastening devices
- Rolling up the film on a steel pipe in the gutter and at the side wall
- Stretching additional plastic ropes over the structure (Fig. 5.20)
- Inflated double film

Double-inflated film is a very favourable method to stretch the film on the structure, with good resistance to wind and snow. Two plastic films will be fastened airtight on all sides and inflated by small fans with a pressure of 40–50 Pascal (4–5 mm water column). Double-inflated film can save 30–40% of heat in case of heating. The small fan can inflate side wall and roof elements at the same time. It

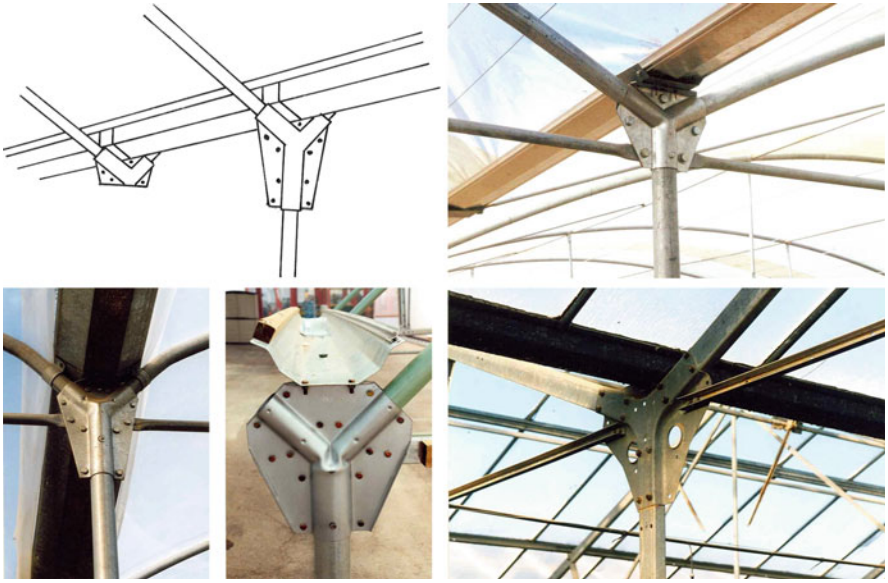

Fig. 8.9 Connectors for stanchions and roof pipes. The connectors are pressed or punched and screwed together

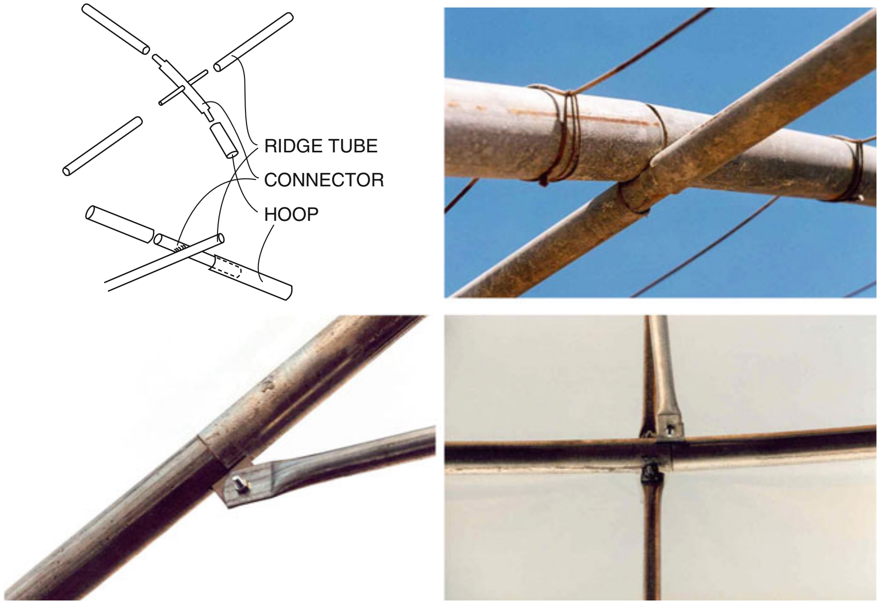

Fig. 8.10 The crossing of ridge tubes and hoops can be connected by special connectors inserted into the tubes, and screwed tightly

Fig. 8.11 Galvanised steel components welded together (see Sect. 8.2.1.1)

Fig. 8.12 All parts of the gutters have to be connected tightly by rubber tapes or by silicon to avoid dripping of rainwater

Fig. 8.13 Leaky gutter connection, bare holes or rusted-through holes cause water penetration into the greenhouse, flooding, and destruction of the crop

Fig. 8.14 Nailing the plastic film onto the structure is time-consuming and not recommendable

is very important to draw the air from outside. If humid air is drawn from inside, drop condensation occurs on the colder outside film. Light transmittance will be reduced remarkably, and algae will grow (Figs. 8.24–8.25). For protection of film see Figs. 8.26–8.27.

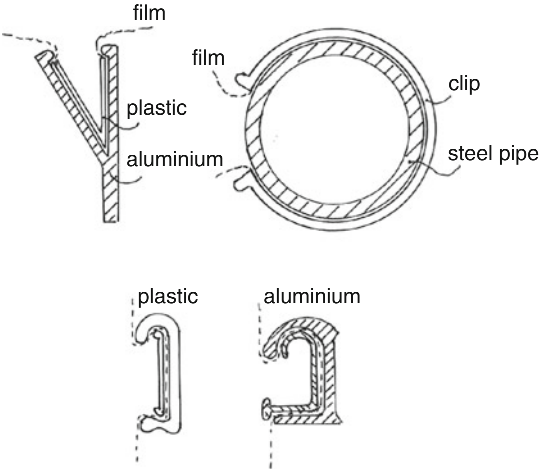

Fig. 8.15 Examples of fastening devices for plastic film

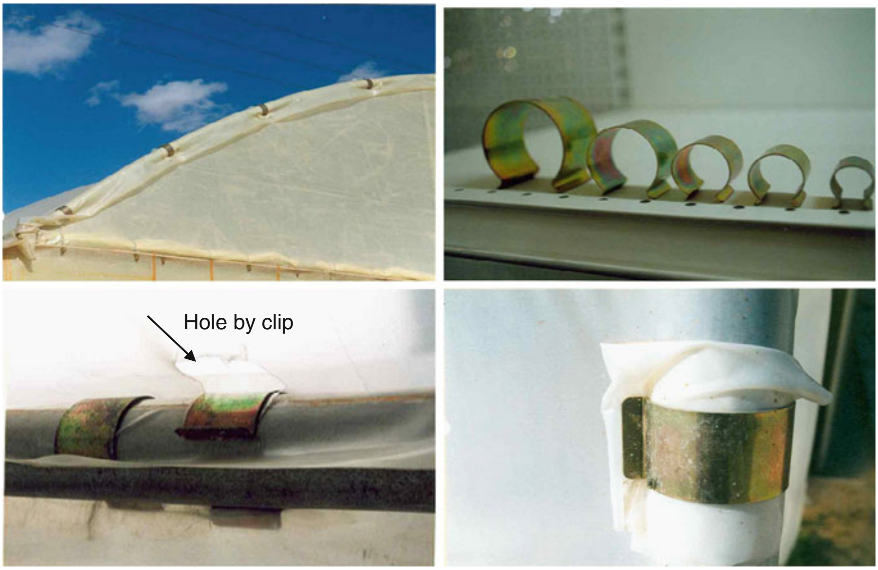

Fig. 8.16 A simple solution to fastening the film by commercial clips of spring steel. There is a danger that the plastic film can be destroyed by sharp edges of the clip. A tape of plastic should be put between the clip and the covering plastic film to protect the cladding film from destruction

8.4 Leaks

Leaks in the greenhouse structure must be avoided, wherever they occur at doors, ventilation openings, plastic-film fastenings, etc., for the following reasons:

Fig. 8.17 Prefabricated plastic clips

Fig. 8.18 Self-made clips for fastening of film or nets. One can use pieces of plastic water tubes which are cut open in a longitudinal direction and put over the construction component with the film or net in between, if no commercial fastening clips are available. This can be done even with timber profiles

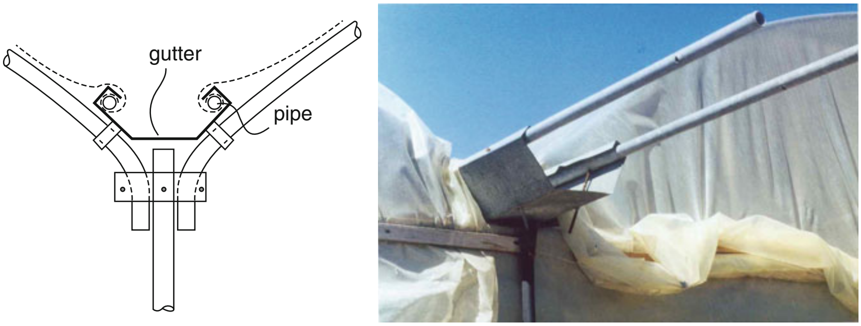

Fig. 8.19 Fastening and stretching of plastic film by rolling it up on a tube in the gutter. Either the gutter is formed especially for this reason, or a special holder can be fixed in the gutter. The sharp edges of the gutter should be protected by small plastic profiles to prevent cutting of the film. The advantage of this method is the fastening and stretching of the film at the same time

Fig. 8.20 One can fasten and stretch the plastic film from the roof side and side wall by rolling them up on one tube only. This method is a very elegant one

1. Solar energy will be stored in the daytime and will keep the air temperature in unheated greenhouses some degrees above outside temperature at night. If the warm air can escape through leaks, the temperature drops very quickly in the evening.
2. If there are holes in the plastic film caused by installation of the fastening clips, those holes are the starting point for damage to the plastic film by wind forces.

Fig. 8.21 A special method for fastening the film is to push the film into steel profiles using plastic profiles, spring steel or even rubber or plastic tubes

Fig. 8.22 Sometimes the plastic film is stretched across the structure with overlapping at the film ends. The possible fluttering of the film edges by wind is a danger. The film has to be fixed very tightly, for example by ropes

3. Leaks in the structure, vents and insect screens are not permissible when integrated production and protection (IPP) is used, with useful insects inside the greenhouse and when pest insects must be kept out.
4. Leaks in gutters and cladding material cause rainwater penetration, crop flooding and disease infestation (Fig. 8.28).

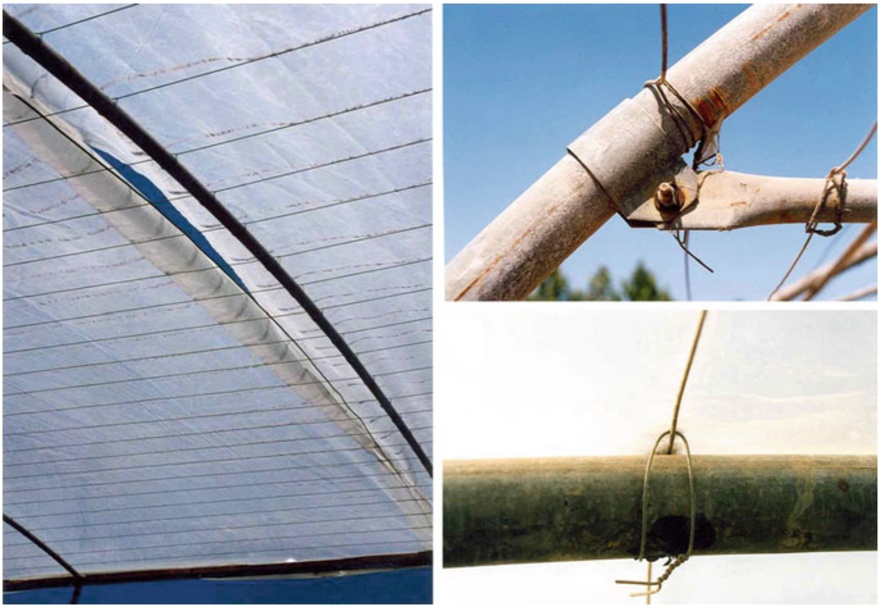

Fig. 8.23 Wires are fastened in a longitudinal direction at the roof components, very often to stabilise the plastic film, but the plastic film rubs on the wire and those points are the beginning of early destruction. Therefore, wires should be avoided if possible, even to prevent dripping from the roof (see Sect. 7.3.5)

Fig. 8.24 Double-inflated plastic film is a recommendable method for stretching and stabilising the film as well as for saving energy

Fig. 8.25 Double-inflated film can also be used to repair and to use old structures, for example old glass houses. The old cladding material will be removed and double-inflated film installed

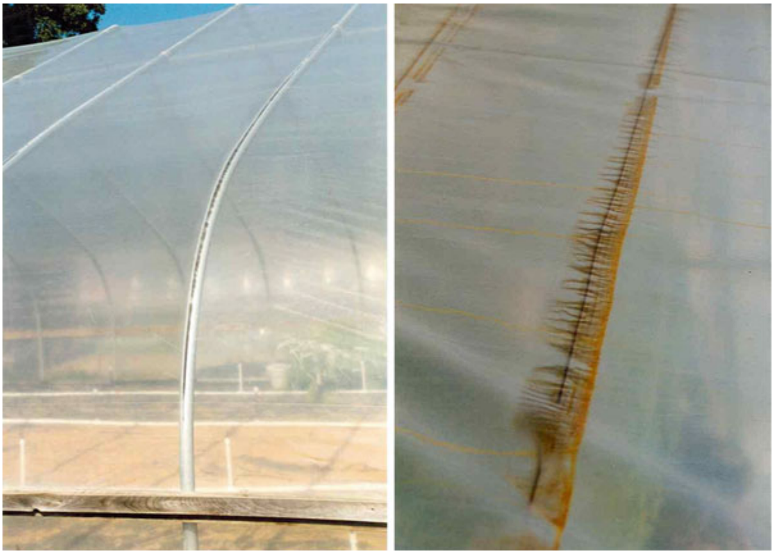

Fig. 8.26 Direct contact of the plastic film with steel tubes is a problem, in particular on hot days. The steel pipes can be heated up to 70°C by direct solar radiation. The plastic film can be destroyed earlier. In addition, the plastic film rubs on the steel tubes and the wires, and becomes black. This causes destruction of the film. It is recommendable to put some plastic tapes between film and steel pipes (Fig. 4.4). Another possibility is to paint the plastic white at the contact point to the steel pipes to prevent them from becoming too hot

If nails or screws are forgotten in the gutter during mounting of the structure, then the galvanised layer of the gutter will be destroyed and holes occur within a very short time so that rainwater can flow through. A corroded hole may be closed by a wooden stopper in one of the gutters (Fig. 8.29).

For leaks in insect screens, see Chap. 10.

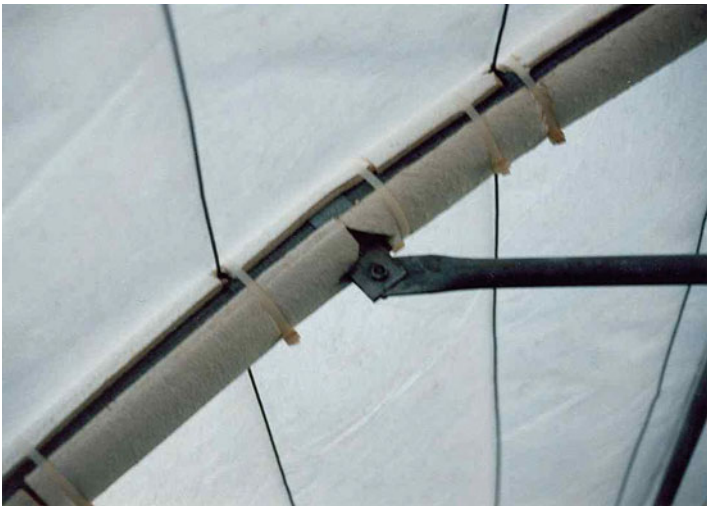

Fig. 8.27 Protection of the plastic film above steel tubes and wires by plastic tapes

Fig. 8.28 Leaky doors where insects can penetrate and heat energy will be lost at night

8.5 Windbreaks

Wind action by high wind speed can cause damage to structure and plants, erode uncovered soil, and transport sand and soil through leakage into the greenhouse. The heat loss of a greenhouse also depends on the wind speed. Natural windbreaks by hedges and shelterbelts, as well as artificial wind screens, reduce the wind speed and thereby the impact of wind. Various rows of trees and hedges as well as fences

Fig. 8.29 Forgotten nails and screws cause rusting-through of the gutter. One corroded hole is closed by a wooden stopper

of plastic material can be used for protection from too high wind speeds. Windbreaks should not be completely airtight, but must have a certain permeability (Fig. 8.30) (Dierickx et al. 2001a; von Zabeltitz and Baudoin 1999).

The major factor influencing the wind speed reduction is the open area of the windbreak or screen. The open area is:

$A = \Sigma A_i / A_{\mathrm{tot}}$ (%)

ΣA_i (m^2) = sum of single hole sizes.

A_{tot}(m^2) = Total area of the screen.

The air flow resistance R_{c} is:

$R_{\mathrm{c}} = (v_{\mathrm{w}} - v_{\mathrm{r}})/v_{\mathrm{w}}$ (%)

v_{w} (m/s) = Freeflow wind speed without screen

v_{r} (m/s) = Reduced wind speed with screen.

Fig. 8.30 Hedges as windbreaks in desert regions

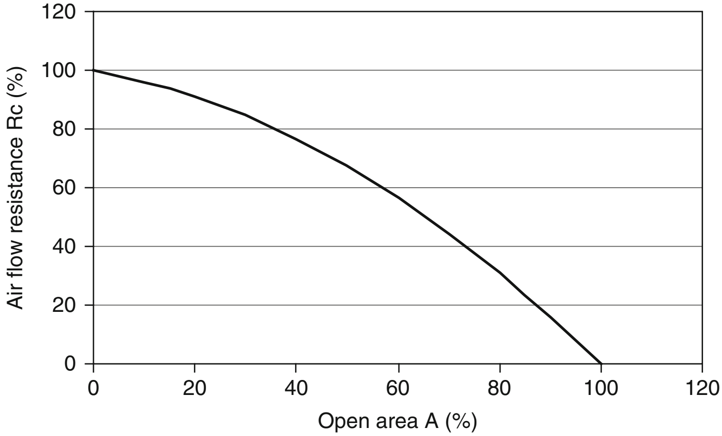

Fig. 8.31 Relationship between air flow resistance R_c and open area A (Dierickx 1998)

The relationship between R_c and A can be expressed by (Dierickx 1998), Fig. 8.31: $R_c = -0.0070 \times A^2 - 0.3 \times A + 100$.

Various geotextile materials were tested as windscreens with regard to their reduction of wind speed at different distances from the screen and at different heights above ground in wind-tunnel experiments (Dierickx et al. 2001a; Dierickx

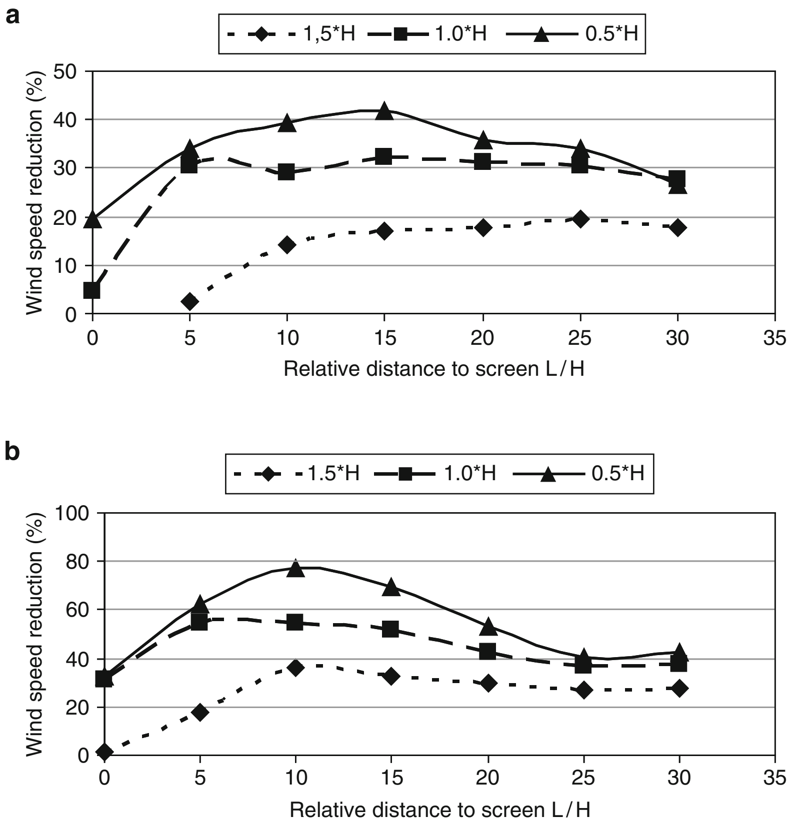

Fig. 8.32 Wind speed reduction (%) depending on relative distance to screen *L*/*H* for the heights 0.5*H*, 1.0*H*, and 1.5*H* above ground surface. (**a**) Open area $A = 57.5\%$ and air flow resistance $R_c = 59.6\%$. (**b**) $A = 49.1\%$, $R_c = 68.4\%$

et al. 2001b). Figure 8.32 shows the wind speed reduction (%) for two windscreen materials ($A = 57.5\%$ and $A = 49.1\%$) depending on the relative distance to the screen *L*/*H* and the height above ground, where *L* is the distance from the screen and *H* the height of the screen. Although the difference of the air resistance is very small, the windbreaking effect behind the screen B is much higher (Figs. 8.31–8.32).

Figure 8.33 shows the wind speed reduction for various tested materials between the curves for materials with an open area of $A = 24$ and 49.1% respectively and $R_c = 88.8$ and 68.4% respectively for the heights of 1.0*H* and 1.5*H*. All materials with an open area higher than 50% and a flow reduction >68% create wind speed reductions of more than 30% in relative distance to screen of 10*H*–20*H*, even at a height of 1.5 times the screen height. The open area of the screen should not be lower than 20% (R_c about 90%), because turbulent flow stream will be produced and thereby insufficient local wind speed effects.

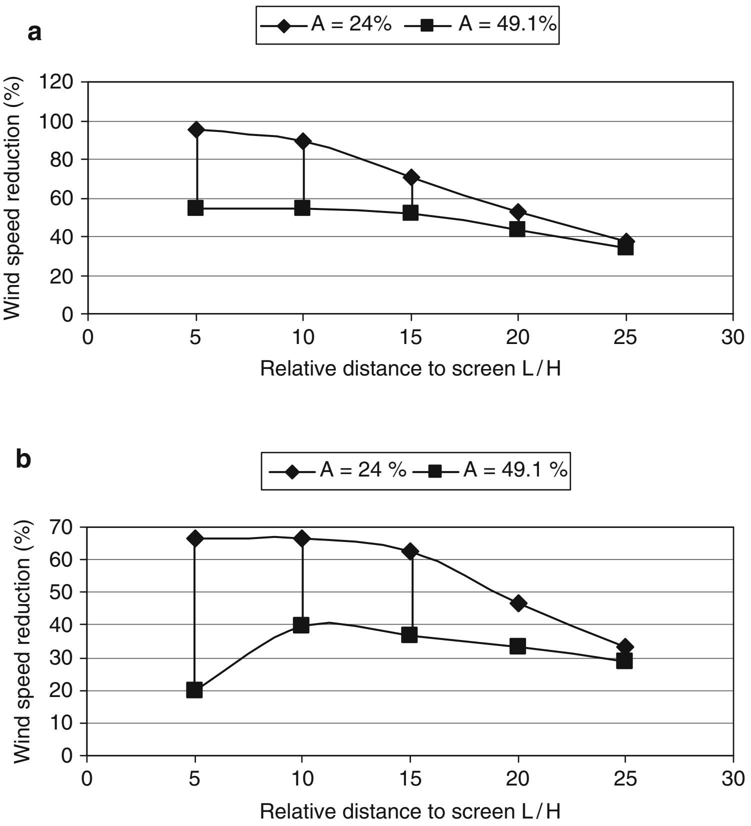

Fig. 8.33 Wind speed reduction for different material between the two curves with $A = 24\%$, $R_c = 88.8\%$ and $A = 49.1\%$, $R_c = 68.4\%$. (**a**) Height above ground 1.0*H*. (**b**) Height above ground 1.5*H*

A screen of 2.5 m height can theoretically protect a greenhouse of about 4 m height at a distance of 25–50 m from the screen.

The wind direction is not always perpendicular to the windscreen. Therefore, it may be important to know the effects on wind speed reduction, if the windscreen has an oblique position to the wind direction. Wind-tunnel experiments were carried out with screens of different positions to wind direction and different open areas (Dierickx et al. 2002).

Figure 8.34 shows the wind speed reduction at different heights and distances from the screen for a woven plastic material that has an open area $A = 62\%$ and an air flow resistance $R_c = 53.8\%$. The wind-flow angles oblique to the screen are 90° (perpendicular), 60° and 30°.

Wind screens are most effective when their position is perpendicular to the wind direction (90°). The wind speed reduction decreases with increasing angle oblique to the wind direction. Even an acceleration of wind speed may occur in some

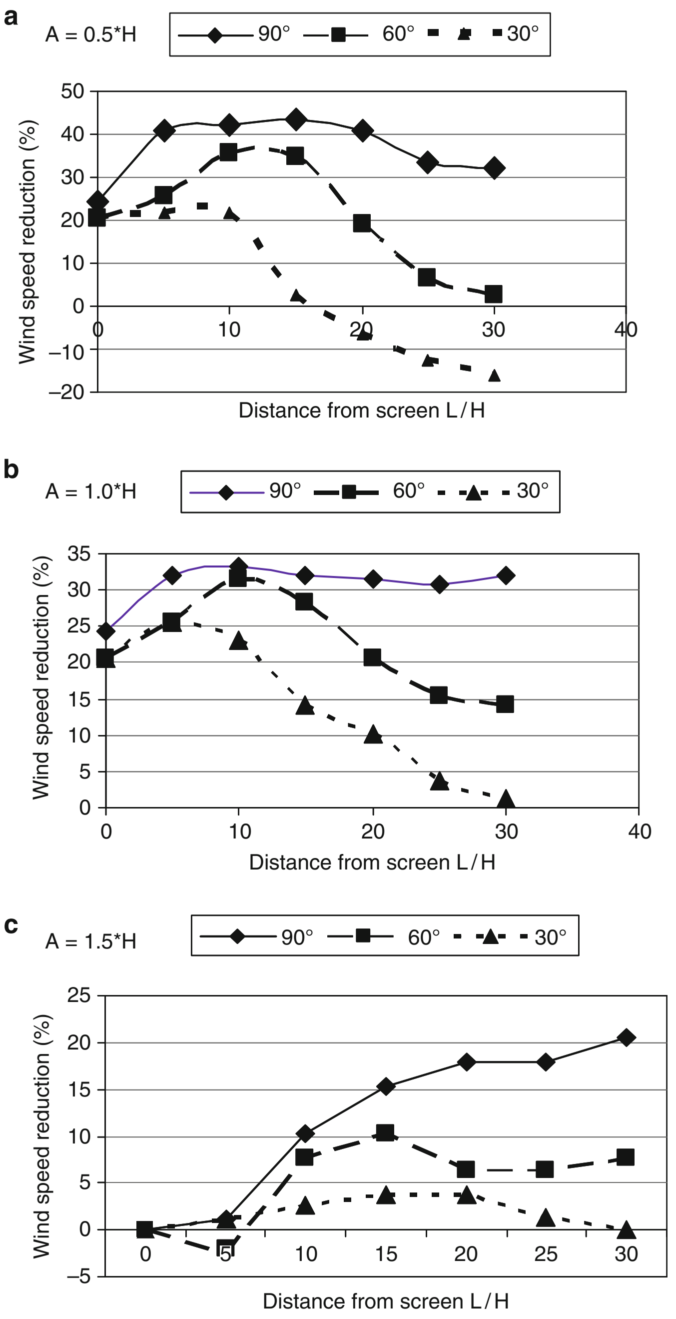

Fig. 8.34 Wind speed reduction for a plastic material, $A = 6.2\%$, $R_c = 53.8\%$, with different inclinations of wind direction, 90°, 60°, 30°, to the screen. (**a**) Height above ground 0.5*H*. (**b**) Height above ground 1.0*H*. (**c**) Height above ground 1.5*H*

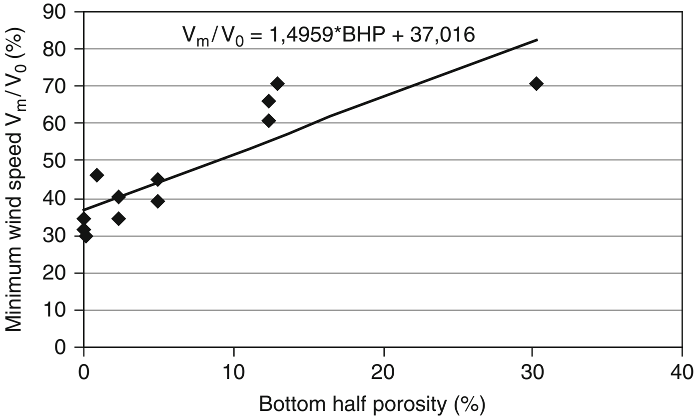

Fig. 8.35 Relationship between mean minimum wind speed v_m/v_0 and bottom-half porosity BHP (Loeffler et al. 1992)

positions of wind screen to wind direction (30°, $L/H > 15$). Wind screens with an open area >60% are more effective in oblique wind.

A rough surface on the windward side of the windbreak is less effective for wind reduction than a smooth surface, because of the formation of turbulent flows (Dierickx et al. 2003).

Inclined wind screens, particularly those with an inclination of 30° to the vertical position, are comparable to wedge-shaped natural windbreaks. If the width of the inclined screen is the same as for the vertical screen, the vertical screen is more effective, because of the smaller vertical height of the inclined screen. Inclined screens with the same vertical height as their vertical position will be more efficient than the vertical ones, but the screen width is larger, and as a result more costly. For natural windbreaks this phenomenon may be important (Dierickx et al. 2003).

If the open area of the wind screen is not evenly spread over the screen height, the wind speed reduction may vary. Wilson (1987) reported that the difference in wind speed reduction is nearly the same beyond a distance of $L = 7H$ for a windscreen of 50% open area and a windscreen which is more dense or more open near the ground surface.

Natural shelterbelts or hedges can be sufficient windbreaks, but the shading effect for greenhouses has to be considered. The effectiveness of various shelterbelts has been measured by Torita and Satov (2007) (Table 8.1).

Other natural shelterbelts have been evaluated by Loeffler et al. (1992) (Table 8.2). They measured optical porosity by evaluating black and white photographic silhouettes and using a digitizing technique (Kenney 1987). The full-height porosity from ground surface to the top of the trees, as well as the bottom-half porosity of the lower half of the tree height, were quantified. The measured values of v_m/v_0 and L_m are given in Table 8.2.

The wind speed reduction behind the pines was much less than behind the cedar and spruce windbreaks, due to large gaps in the pine wind break.

Table 8.1 Dimensions of some shelterbelts in the field site and wind speed reduction values

Shelterbelt	Height H (m)	Width (m)	Height to crown base (m)	Tree density (trees/ha)	v_m/v_0 (%)	L_m (m)	L_{70} (m)
Spruces	11	37	2	1,500	35.4	4.1H	9.2H
Broad-leaved wood with leaves	13	37	7	1,900	30.4	2.7H	8.3H
Broad-leaved wood without leaves	13	37	7	1,900	66.2	5.2H	2.6H
Spruces, pines, birches	10.7	30	3.7	1,500	26.7	4.2H	13.6H
Spruces, birches, pines	11	50	2	1,800	20.8	2.7H	10H
Spruces, birches	12	40	2	2,000	24.2	0.42H	7.8H
Birches	6	5	2	2,200	64.4	3.7H	10.9H

v_m (m/s) = mean minimum leeward wind speed
v_0 (m/s) = mean undisturbed windward wind speed
L_m (m) = Distance of mean minimum wind speed from the edge of shelterbelt
L_{70} (m) = Distance from shelterbelt where the wind speed does not exceed 70% of v_0

Table 8.2 Mean minimum wind speed v_m/v_0 and distance L_m of mean minimum wind speed behind the windbreaks at different sites. Increasing v_m/v_0 means decreasing wind speed reduction

Trees	Full-height porosity (%)	Bottom-half porosity (%)	v_m/v_0 (%)	L_m (m)
Norway spruce (five sites)	16.5–21.4	0.8–5	39.3–45	4H
Cedar (three sites)	10.6–20.4	0–0.1	31.5–34.6	3H–4H
Scots pine (four sites)	18.1–36.9	12.4–13	60.6–70.8	3H–4H

The mean minimum wind speed v_m/v_0 could be significantly related to the optical bottom-half porosity BHP of the windbreaks, (Fig. 8.35).

The relationship between windbreak structures and their function has been summarised as follows (Heisler and Dewalle 1988):

- The horizontal extent of wind protection is generally proportional to windbreak height.
- The wind speed reduction is related to the open area of the windbreak.
- Very dense barriers are less effective than medium porous barriers for wind speed reduction of 10–30 % at larger distances.
- Height growth of a natural windbreak may be more important than density when areas as large as possible have to be protected. But shading should be considered for the wind protection of greenhouses.
- Natural barriers with width less than height and a steep side produce a larger wind reduction over a greater distance than very wide windbreaks or streamlined windbreaks in cross-section.
- Tree windbreaks lose less effectiveness in oblique winds than thin artificial wind screens
- Turbulent wind flow decreases with increasing open area of the windbreak.