# Chapter 4
# Design Criteria for Greenhouses

Greenhouses have to provide optimal climate conditions for plants inside. They should be built less in accordance with national traditions but more with regard to general cropping needs and conditions of different climate zones (von Zabeltitz 1999, von Zabeltitz and Baudoin 1999). Greenhouses should withstand minimum action forces by wind, rain, snow, and crop loads. Minimum standards and technical specifications should be observed.

Most of the greenhouses in the world are plastic film greenhouses. Glass greenhouses can be found in particular in temperate climates of Northern Europe and relatively often in Turkey. Therefore, plastic-film greenhouses in particular are dealt with in this book.

The analysis of storm damage after a severe storm in the Netherlands 1990 gave the following results (Waaijenberg and Denkov 1992):

1. The profiles used in the bent trusses of plastic film greenhouses were too light, and the arches were deformed by wind.
2. The plastic film sometimes appeared to be stronger than the structure.
3. The plastic film tearing started at sharp edges of construction components which were in contact with the film.
4. The foundations were often not sufficiently secured against uplift forces.
5. Damage to plastic film greenhouses often started from the ventilation openings.
6. The connections of arch, purlin and ridge tubes were often not sufficient, especially clamp connections.
7. Too few bracings were fixed between structure components to give sufficient stability.

Experiences in other countries show that those weak points occur frequently.

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## 4.1 Greenhouse Types

Greenhouse types have been developed for the following climates:

- Tropical wet climates, lowlands with mean minimum temperature in the coldest month >12°C
- Subtropical climates and tropical highlands. Mean minimum temperature in the coldest month <12°C
- Dry and arid climates
- Temperate climates

In addition to the climate criteria, one has to design greenhouse types depending on the user (small-scale farmer or industrialised horticultural production), the material for construction, life cycle and the cost-effective availability of materials in the country. Greenhouses for a shorter life cycle, which can be cheaper, are wooden structures with untreated poles that can be corroded by rotting or by termites. The life cycle is 4–6 years. Greenhouses for a longer life cycle have galvanised steel tube or treated timber structures, with appropriate foundations. Special greenhouse designs are necessary for nurseries, and for larger plants and trees like bananas.

## 4.2 Site Selection

The following criteria should be considered with regard to site selection:

- The microclimate conditions
- The water and electricity supply
- Labour availability
- The distance to the markets and transportation costs
- The orientation of the greenhouses depends on the main wind and rain direction. Penetration of rain through ventilator openings has to be avoided. Fans for evaporation cooling should face the main wind direction.
- Natural circumstances such as high trees and buildings have to be considered with regard to shade effects and windbreaking.
- Windbreaks by natural planting or by artificial windbreak structure should be considered in the planning of the greenhouse if wind velocities are high.
- The soil at the greenhouse location should have adequate drainage provision.
- The soil topography should have a slight slope (about 0.5–1%) in the longitudinal direction to drain off rainwater.
- The Indian standard for greenhouse structures ISI 4462–1997 recommends a slightly southern-facing orientation for greenhouses in areas above 40° longitude, to present maximum winter sunlight to the crop.

## 4.3 General Design Criteria

The general design criteria for greenhouses are:

- The climate conditions in the regions
- The general design requirements for glass and plastic film greenhouses, including standards for different loads (European standard EN 13031-1, December 2001, ASAE EP 460 Dec 01, Indian standard for greenhouse structures ISI4462-1997).
- Measures for climate and pest control
- The most cost-effective locally available materials, and the expected duration of life.
- Technical measures for integrated production and protection (IPP).

## 4.4 Loads for Greenhouse Structures

Greenhouses should be low-cost but cost-effective structures. Nevertheless, they have to withstand outside weather stresses such as storm, rain, hail, and snow if snowfall occurs. Damage to greenhouses is very often caused by too weak structures (Fig. 4.1). To avoid severe damage, the greenhouse structure should be calculated and designed in accordance with available standards or technical specifications that give figures for different loads or actions to withstand influencing forces.

**Fig. 4.1** Too weak tunnel structure damaged by wind

The European standard EN 13031-1 (December 2001) "*gives rules for structural design and construction of greenhouse structures for the professional production of plants and crops*".

According to the standard, "*greenhouses shall be designed by verifying that no relevant limit state is exceeded. The relevant limit states to be considered depend on the class of the greenhouse*".

*"Greenhouses shall be classified in accordance with a minimum design working life for the structure and the tolerance to frame displacements of the cladding systems"*.

Ggreenhouse structures are divided into two classes, A and B, depending on tolerance to possible frame displacements, and into three groups, depending on the minimum design working life of 5, 10, and 15 years respectively. Glass-covered greenhouses have to be designed according to A15 (Class A, 15 years minimum design working life), sophisticated plastic film covered multi-span greenhouses according to B15, and simple plastic film tunnels and shade houses according to B10 and B5 ( Waaijenberg 2006; EN 13031-1, 2001).

The main loads or actions to be considered are:

- *Dead load* or permanent load "self-weight of structural and non-structural elements, excluding the installations even if they are permanently present".
- *Wind loads* are "actions imposed on the structure by wind".
- *Snow loads* have to be considered in regions with snowfall.
- *Crop loads* have to be considered where structures support crops. Where crops are suspended on separate horizontal wires the horizontal tensile forces transmitted to the structure have to be taken into assessment.

The different actions shall be considered in combinations which are given in the standard. The European standard is valid for the EU. It can be taken as an example also for other regions outside the EU.

## 4.5 General Requirements

The climatic conditions are the essential basis for the protected cultivation of plants and for the construction of protective structures. Chapter 2 describes the most important climatic zones (Figs. 2.14–2.16). That results in the following additional requirements for greenhouses and shade houses for the climatic zones (von Zabeltitz and Baudoin 1999).

### *4.5.1 Ar: Tropical Wet Climates*

#### 4.5.1.1 Regions

Amazon basin of South America, equatorial West Africa, insular and peninsular area of Southeast Asia.

#### 4.5.1.2 Climatic Conditions

- High monthly precipitation quantities and high mean humidity throughout the year.
- Only small variations of temperature and solar radiation in the course of the year.
- Day and night temperatures above the biological minimum for plant production throughout the year.
- Irradiation which can be too high.

#### 4.5.1.3 Greenhouse Structures

A protection from precipitation and too high solar radiation is necessary throughout the year. Only covering of the roof area is needed for protection from rain, solar radiation, and wind. The cladding material has to reduce solar radiation and shade the cultures. As outdoor temperatures are constantly high, sidewalls and gables can remain open. This results in good ventilation. Temperatures and humidity do not rise much higher than in the open air. If necessary, ventilation openings have to be equipped with insect screens in order to keep out insects, but the reduction of ventilation efficiency has to be considered. Rainwater should not penetrate the greenhouse, but should be led off by gutters or ditches.

### *4.5.2 Aw: Tropical Wet and Dry Climates*

#### 4.5.2.1 Regions

North and south of the equator on all continents between latitudes 5° and 20°.

#### 4.5.2.2 Climatic Conditions

- Separation of rainy and dry seasons
- High monthly precipitation and high mean humidity during the rainy season
- Slightly higher temperatures and higher average irradiation sums during the dry period
- Relatively even course of temperatures with small variations throughout the year
- Day and night temperatures above the biological minimum throughout the year

#### 4.5.2.3 Greenhouse Structures

The crop has to be protected from high solar radiation throughout the year. Protection from rain is only necessary during the rainy season. In case of serious droughts during the dry period, rainwater should be collected for irrigation purposes during the dry period. The greenhouses must have gutters, and rainwater reservoirs

have to be built. In the dry season, humidity can drop considerably during the day. Temperature conditions do not demand closable ventilators. They might, however, become necessary in the case of extremely low humidity. In the case of closed ventilators, humidity in the greenhouse actually rises due to evapotranspiration, but temperature also rises. If humidity is too low, evaporation cooling or fog systems are possibilities to create a favourable climate.

### *4.5.3 Cf: Subtropical Humid*

#### 4.5.3.1 Regions

Uruguay, coastal regions in the east of China, South Japan, southeast coast of Australia, South-East regions of the USA

#### 4.5.3.2 Climatic Conditions

- High monthly precipitation quantities and high average humidity throughout the year
- Strong seasonal differences in temperature and solar radiation values between summer and winter
- Night frosts which can occur during winter

#### 4.5.3.3 Greenhouse Structures

Precipitation is also a problem in subtropical humid climates throughout the year. Greenhouses serve to protect the cultures from too heavy rain. Gutters are necessary to discharge the rainwater. Solar radiation is a problem only during summer months. In winter, the daily solar radiation sum drops to values 50–70% lower than those in summer. It ranges from approximately 2–3.5 kWh/m$^2$ day. Greenhouses should therefore let through as much light as possible. Daily temperatures are relatively high; greenhouses must have good ventilation efficiency. During the night, temperatures can sink considerably; therefore, greenhouses must have ventilators that can be closed overnight. In addition, the covering material should have a transmittance as low as possible for long-wave radiation, in order to reduce thermal radiation of the plants.

In summer, temperatures and daily sum of solar radiation are higher than in the tropical zones. Therefore, shading and very good ventilation are required. Shading facilities should be movable, in order to let through as much light as possible into the greenhouse in winter.

### *4.5.4 Cs: Subtropical Dry Summer. Mediterranean*

#### 4.5.4.1 Regions

Borderlands of Mediterranean Sea, lowland California, central Chile, southern part of South Africa, parts of southern Australia.

#### 4.5.4.2 Climatic Conditions

- Distinct seasons with very hot dry summers and mild winters
- Sometimes, temperatures below 5°C at night ,and possible occurrence of frost
- Rainfall concentrated on wintertime

#### 4.5.4.3 Greenhouse Structures

Greenhouses with lockable ventilators have to be tight, in order to protect crops from too low temperatures in winter. Often, it is necessary to heat the greenhouse. The covering material should be impervious to long-wave radiation to minimize thermal radiation out of the greenhouses. Gutters are advantageous for the collection of rainwater for irrigation purposes. During the hot summer months with high temperatures, vegetables are often not cultivated in greenhouses.

### *4.5.5 H: Tropical Highlands*

#### 4.5.5.1 Regions

Colombia, Kenya, Malawi.

#### 4.5.5.2 Climatic Conditions

- Mean temperatures depend on altitude. They are very even throughout the year, but with considerable temperature variations between night and day.
- Precipitation distributed over the year, with stronger variations from year to year
- High even solar radiation throughout the year.

#### 4.5.5.3 Greenhouse Structures

According to altitude and crop, greenhouses with or without lockable ventilators are necessary. Additional requirements are large ventilation openings, covering material impervious to rainwater, and gutters for the collection of rainwater.

### *4.5.6 B: Dry Climates*

#### 4.5.6.1 Regions

Arid and semiarid regions.

#### 4.5.6.2 Climatic Conditions

- Evapotranspiration is higher than precipitation
- Not enough water
- Brackish water sometimes available in the underground
- Strong temperature variations between day and night. Frost can occur at night
- Low humidity and high solar radiation during the day
- Sand storms

#### 4.5.6.3 Greenhouse Structures

Greenhouses have to protect crops from excessively high irradiation, wind, sand storms and too low humidity. They must have efficient ventilators that can be closed at night. In the case of low humidity and high temperatures, evaporation cooling can be installed that operates with brackish water if available. Brackish water can, if there is a lack of irrigation water, be desalinated by solar energy.

## 4.6 General Design Requirements

The general design requirements for plastic-film greenhouses are:

### *4.6.1 A. Structure*

1. Sufficient stability against wind and crop loads. That means sufficient dimensions of the construction components, and installation of wind braces (Fig. 4.2: also see Chap. 8).
2. Mounting and installation according to technical specifications (Chap. 8).
3. The connections and connectors between the different construction components must not move or slide by load forces (Fig. 4.3) (Sect. 8.2).
4. The foundations under the stanchions have to endure pressure and suction forces by wind (Sect. 8.1).

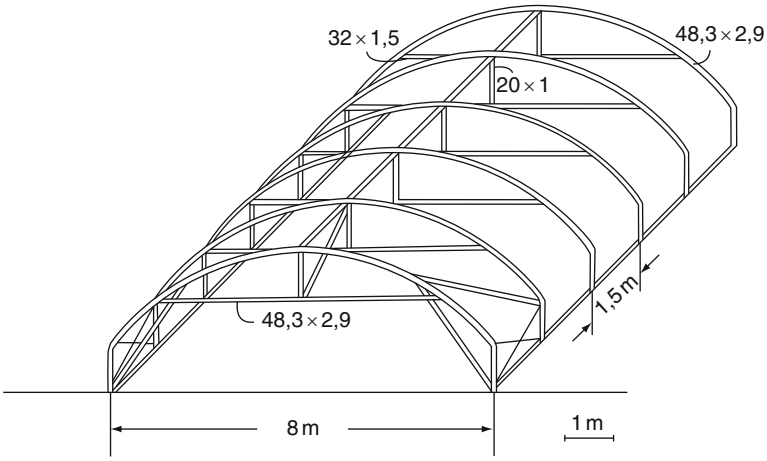


**Fig. 4.2** Round arched tunnel calculated according to Dutch Greenhouse standard NEN 3859 (Waaijenberg 1990; Waaijenberg and Denkov 1992)

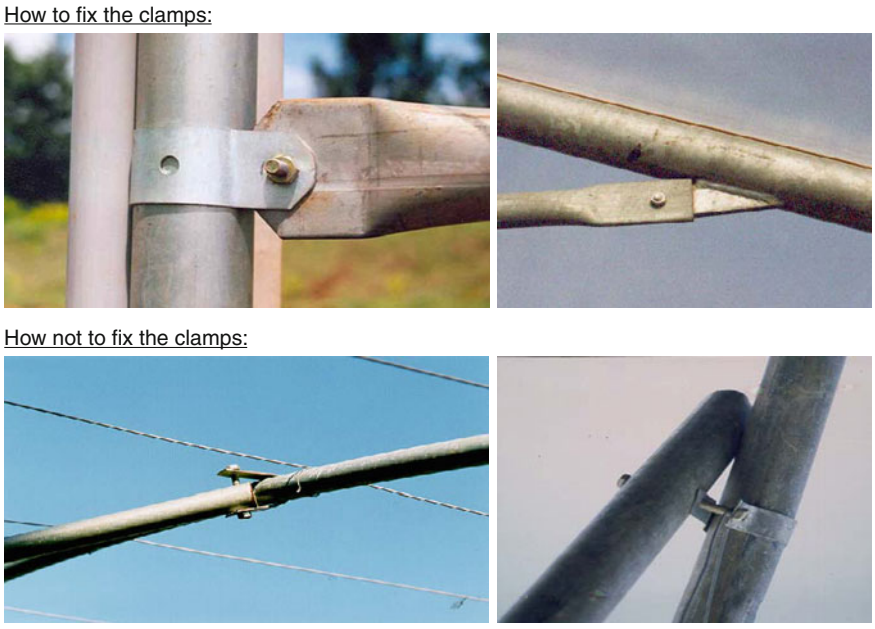


**Fig. 4.3** Connectors and clamps: how to do and how not to do

5. The plastic film must not flutter by wind forces. It has to be stretched and fixed tightly on the structure (Sect. 8.3).
6. The use of simple and detachable fastening devices for changing the film. The nailing of the film on the structure is not to be recommended (Sect. 8.3).

7. Insulation of Steel Components
   The plastic film must not touch directly steel components that are heated up by solar radiation. The steel components should be insulated by plastic strips, or the plastic film should be painted white where it touches the steel components (Fig. 4.4). Unprotected steel components can be heated up to 70°C by solar radiation and the film will be destroyed quickly.
8. Drops of condensed water should not fall down from the inner surface of the film onto the plants, but they have to run off at the film.

**Fig. 4.4** Insulation of steel components or protection by white painting of the plastic film

**Fig. 4.5** Drops at the inner surface of the roof fall down and reduce light transmittance

Droplets on the inner film surface reduce the light transmittance of the greenhouse by 10–15% (Fig. 4.5). No horizontal roof areas but sufficient roof slope of more than 10° and the use of plastic film with No-Drop additives can avoid those disadvantages. Wires below the plastic film hinder the run-off of droplets. They fall down at the wires. The installation of wires should be avoided. Condensation itself is desirable to avoid too high humidity. Condensation should appear as film condensation (Sect. 7.4).

9. Gutters or deep ditches are necessary to drain off and collect the rainwater.
   No water penetration from side wall, gable and roof into the greenhouse (Fig. 4.6).
10. Durable materials which are available and cost-effective in the country should be used for the greenhouse design and construction.
    The maximum width of the greenhouse unit depends on the maximum available width of plastic film, if the film is stretched in longitudinal direction of the greenhouse.
11. Windbreaks should be installed if the wind velocity is too high.

The most important factors for the stability of the greenhouses are:

- The dimensions of the construction components
- The connection of the components by clamps
- The foundation
- The fastening and stretching of the plastic film

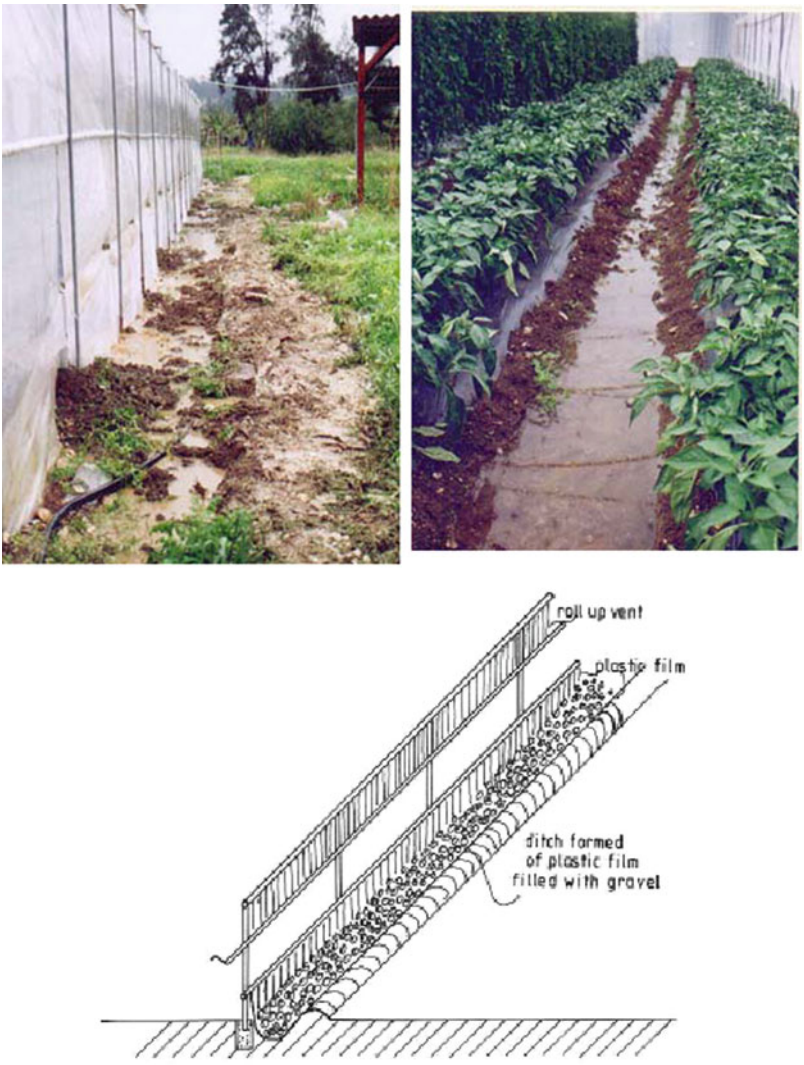


**Fig. 4.6** If there is no gutter or ditch, the consequence is heavy rainwater penetration inside the greenhouse. Ditches of dug plastic film filled with gravel are to be recommended

### *4.6.2 B. Climate Control*

Appropriate climate conditions are prerequisite for plant growth and quality. That means in particular appropriate temperature on hot days and in cold nights, appropriate humidity level, no $CO_2$ deficit, and enough light. The main requirements are:

1. Sufficient ventilation efficiency (Chap. 9).
   The ratio of ventilation opening to greenhouse floor area should be more than 20–25%, if no insect screens are installed. Multi-span greenhouses have to have ridge or roof ventilation, if the mean maximum temperature is above 27°C and if the greenhouses have more than three spans.
2. Lockable ventilators should be installed in regions where mean minimum temperatures are lower than 12°C.
3. Larger greenhouse volume is favourable for climate control on hot days.
   Side walls should be 3 m high or more. This also provides a buffer for $CO_2$ supply if the vents are closed on colder days and the light conditions are sufficient.
4. The plastic film should have a low transmittance for long-wave radiation, to reduce heat transfer by radiation from plants and soil to the outside atmosphere. Materials with high transmittance for long-wave radiation increase the heat transfer by radiation from the crop through the cover, with the consequences of lower air temperature, lower plant temperature and temperature inversion (inside temperature lower than outside). If the plant and air temperature sink below the dew-point temperature, condensation and fog may occur, and the danger of diseases increases. Thermic film with IR absorber or co-extruded PE and EVA film should be used for greenhouses, to keep the temperature as high as possible in unheated greenhouses during cold nights (Chap. 7).
5. The structure has to be tight.
   It is very important to avoid leaks, even in unheated greenhouses, to keep the warm air inside as long as possible during night. Main sources of leaks are the ventilators and the doors. If a temperature inversion occurs, or if the inside humidity is too high, it is more efficient to ventilate the greenhouse, in particular in the morning (Sect. 8.4).
6. Heating becomes necessary for heat-requiring crops in some winter months.
   Cheap fossil fuel heating systems, simple solar heating equipment or geothermal energy should be used if available (Chap. 12).
7. Energy-saving measures in heated as well as in non-heated greenhouses.
8. Irrigation systems with high water use efficiency and low evaporation should be used. These systems are drip irrigation with fertilizer distribution.

### *4.6.3 C. Integrated Plant Production and Protection (IPP)*

Integrated production and protection (IPP) aims in finding alternative solutions to reduce pesticide application.

*Insect screens* are used in front of the ventilation openings and doors to keep useful insects inside, and to prevent pest insects from penetrating the greenhouse (Chap. 10).

Insect screens with different mesh openings are used because the insects are of various sizes.

Criteria for the choice of insect screens are:

- The species of insects to be screened out
- The influence on the greenhouse climate
- UV stability and mechanical durability (thickness of threads)
- The cost in comparison to the economic value of the crop

Insect screens reduce the ventilation efficiency remarkably. Sufficient ventilation efficiency has to be guaranteed, even in screened greenhouses. To guarantee climate conditions similar to those in unscreened houses, enlarged ventilation openings should be designed. If the ratio of vent opening to greenhouse floor area is 20–25% in unscreened houses, the vent opening should be enlarged in screened houses by a factor of about 2 for a insect screen against white fly.

Different principles of greenhouse structure, cladding materials and climate control measures are available to meet all these requirements (Chap. 10).