Chapter 6
Light Transmittance of Greenhouses

Light is one of the most important climatic factors for the photosynthetic activities of the plants. Crop growth is directly related to the available solar radiation. Optimizing the transmittance of solar radiation is a very important factor for crop growth in subtropical areas (Soriano et al. 2009); the light transmittance of greenhouses depends on:

- Type, thickness and spectral transmittance of cladding material by absorption and reflection (Chap. 7)
- Number of layers, single or double cladding
- Condensation on the cladding material (Chap. 7)
- Shading effect by greenhouse structural components
- Type of roof shape and roof inclination
- Orientation of the greenhouse
- Sun elevation, latitude, season of the year, time of day
- Share of direct and diffuse global radiation

It is relatively difficult to obtain accurate data about the greenhouse light transmittance.

Values of greenhouse transmittance for global radiation under practical conditions higher than 70% are the exception. The transmittance for single-covered greenhouses ranges between 55 and 70%, with the highest values in summer and the lowest in winter. The transmittance for double-covered greenhouses is 50–60% (Baille 1999b). A survey about the results on light transmittance measurements is given by von Elsner et al. (2000a, b) and von Zabeltitz (1999). Different roof shapes and roof inclinations have been investigated by Nisen (1969) (Figs. 6.1 and 6.2), and Kirsten (1973) (Fig. 6.3). Some new results of modelling the transmittance of plastic film greenhouses for different latitudes in Mediterranean areas have been published by Soriano et al. (2009).

The total transmittance T of a greenhouse is defined as the ratio of transmitted global radiation q_{rg} to the outside incoming radiation q_{ro}

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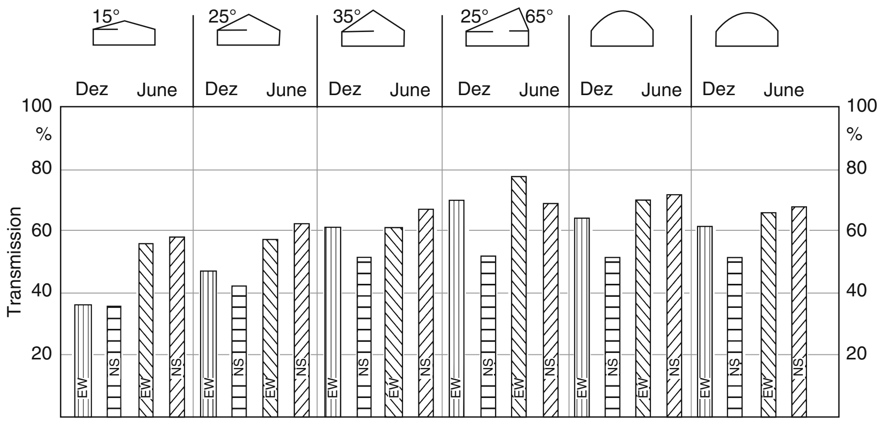

Fig 6.1 Mean transmittance of various greenhouse types with East–West (EW) and North–South (NS) orientation in December and June (Nisen 1969, von Zabeltitz 1999)

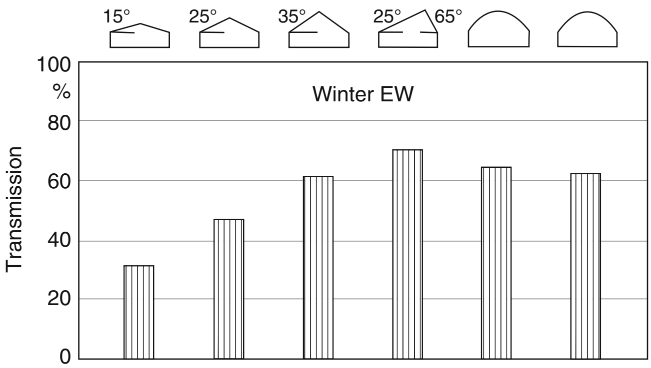

Fig. 6.2 Comprehensive description of the transmittance for EW orientation in winter (Nisen 1969)

$$T = q_{\rm rg}/q_{\rm ro}$$

The following conclusions can be drawn from Figs. 6.1 and 6.2:

- Light transmittance increases with roof inclination in saddle-roof structures.
- Light transmittance in EW-oriented greenhouses is higher in winter and lower in summer than in NS-oriented greenhouses.
- A saw-tooth or shed roof with the steeper and shorter roof side to the south in the Northern Hemisphere has a better transmittance than a saddle roof, but the roof surface area is larger.
- Greenhouses with curved roofs have better transmittance than greenhouses with saddle roof and 25° roof inclination.

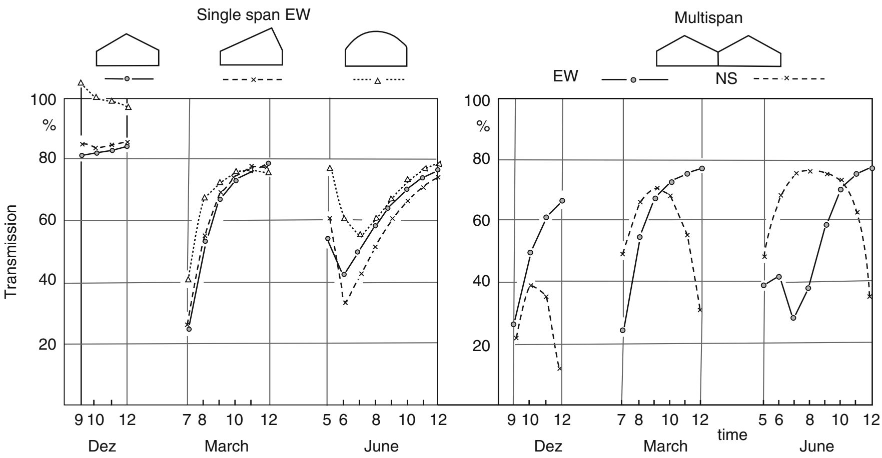

Fig. 6.3 Calculations for the transmittance for different greenhouse shapes at different times of the day (Kirsten 1973). A reduction of 10% by dirt and structural components is taken into consideration

Table 6.1 Light transmittance (%) of a Venlo-type greenhouse (Bot 1983)

Date	Orientation	
	East–West	North–South
21 December	45	35
21 February	58	53
22 March	59	62
21 April	60	67
21 June	65	70

The following conclusions can be drawn from Fig. 6.3:

- The best transmittance in winter is given by the curved roof of single-span greenhouses with an EW orientation, followed by the saw-tooth and saddle roof.
- The transmittance is a little bit better under a saddle roof in summer than under a saw-tooth roof.
- The transmittance through multi-span saddle-roof structures is higher in winter with EW orientation than NS.
- There is more light in the greenhouse with NS orientation in the morning in spring and summer.

Average daily figures for the transmittance of a Venlo-type greenhouse were calculated by Bot (1983) (Tables 6.1 and 6.2).

Weimann (1985, 1986) investigated EW-oriented plastic-film greenhouses covered with various single and double plastic films (Table 6.3).

Bredenbeck (1985) measured the light transmittance of three nearly identical greenhouses oriented in a NS direction. The greenhouses were covered with single glass, double glass and double acrylic sheets (Plexiglas Stegdoppelplatte, 16 mm).

Table 6.2 Mean measured values for the light transmittance in plastic film and glass greenhouses are given by von Zabeltitz (1986a)

Cladding material	Orientation	Summer	Winter
Single glass	NS	55–60%	48–55%
	EW	60–70%	55–65%
Single PE film	EW	65–70%	50–65%
Double PE film	EW	50–60%	45–55%

Table 6.3 Light transmittance of different plastic-film greenhouses (Weimann 1985, 1986)

System	Mean transmittance (%)	
	Summer	Winter
Inflated double PE (0.2 mm) 1 Year old	53–55	52–53
Inflated double PE No-Drop (0.18 mm) 1 month old	55–62	58–60
Inflated double PE-EVA		55–58
Inflated single PE-EVA (0.18 mm) 1 year old		65
Single PE standard (0.2 mm) 1 year old		62

Table 6.4 Transmittance of different greenhouses (Bredenbeck 1985)

Greenhouse	Winter (%)	Summer (%)
Single glass greenhouse	55	60
Double glass greenhouse	42	49
Double acrylic, treated	60–64	60–64

Table 6.5 Influence of greenhouse orientation on daily light sum (Wh/m^2 day) in the Netherlands (Waaijenberg 2006)

Week number	East–West	North–South
2 January	379	293
4 January	426	322
6 February	578	530
10 March	1,243	1,226
14 April	1,955	2,104
20 June	2,720	2,969

The glass panes were 0.6 m wide, while the Acrylic sheets were 1.2 m wide, needing fewer construction components in the roof area. The acrylic sheets were treated inside and outside by a No-Drop wetting agent (5% Sun Clear solution). Measurements were taken continuously every 10 min by solarimeters. Mean values for the transmittance are given in Table 6.4. The transmittance of the treated double acrylic sheet was comparable to single glass, but had a energy saving of 40% in winter. After those results had been published, the manufacturer of the double acrylic sheets developed the well-known No-Drop double acrylic sheets for greenhouse cladding.

Waaijenberg (2006) reported the influence of greenhouse orientation on the daily sum of radiation (Wh/m^2 day) in the Netherlands (Table 6.5). The transmittance is higher in winter with east–west (+23%) than with north–south orientation. The north–south-oriented greenhouses get more light inside in summer.

One trend to improve greenhouse design in subtropical regions is the increasing of roof slopes for better light transmittance and runoff of condensed water

(Sect. 7.4), as well as higher structures for better inside climate conditions (Baille 2001; Castilla et al. 2004).

Castilla and Lopez-Galvez (1994) investigated so-called low-cost Parral-type greenhouses in Spain:

G1: Asymmetrical east–west oriented single-span greenhouse, 21 m wide, 18° roof slope to the north, 8° roof slope to the south, 2.43 m height to the eave and 4.5 m ridge height, ventilators at side wall and ridge.

G2: Conventional flat-roof Parral-type greenhouse, 2.33 m height, ventilators at side wall.

All ventilators were covered with insect screens, and the cladding material was 0.2 mm PE film.

The transmittances of the greenhouses are given in Table 6.6.

The solar radiation transmittance was higher in winter and spring during the main cropping season in the greenhouse with slight roof slopes than in the one with the flat roof. Only in midsummer is the transmittance under the flat roof higher.

The temperature difference inside to outside was always higher in the flat-roof greenhouse. The asymmetrical greenhouse with roof inclination was more profitable than the flat-roof greenhouse.

Castilla et al. (1999) got similar results with asymmetrical greenhouses. Steeper roof slopes improve the light transmittance in winter, resulting in better yields of vegetables (Montero and Anton 2003).

Increasing light transmittance has a positive effect, even in subtropical countries. Different plastic-film cladding materials on two identical round-arched greenhouses, three spans of 6 m each, 19.2 × 12 m total floor area, 2.5 m gutter height, 4 m ridge height, have been used to investigate the influence on flowers and tomatoes (Anton et al. 2005; Montero et al. 2005; Montero and Anton 2003). The plastic cladding materials were:

GH1: Coextruded three-layer plastic film. The light transmittance of the greenhouse was $T = 64\%$ from June to October.

GH2: Tetrafluor–ethylene copolymer, 60 μm thick. Light transmittance of the greenhouse $T = 81–83\%$ from June to October. The transmittance of GH2 remained high in spite of dust accumulation.

The measured temperatures and humidity were similar in both greenhouses.

The high radiation transmittance in GH2 resulted very positively in early blooming time, quality and quantity of the geranium crop.

The increase of light led to higher yields of the tomato crop in summer and winter. The final yields of tomatoes were 15 and 27% higher in GH2 for winter and summer crop respectively.

Table 6.6 Solar radiation transmittance (%) of two greenhouses G1 and G2 in the south of Spain

Month	Greenhouse G1	G2
December	70.6	62.5
March	70.7	66.3
June	71.7	74.2
September	64.3	65.5

These results are in contradiction to the often expressed opinion that light in subtropics is above crop requirements even in winter.

Therefore greenhouse manufacturers, plastic film manufacturers and growers should pay more attention to the light transmittance of greenhouses to improve economic results.

Soriano et al. (2004) measured and calculated the light transmittance of greenhouse scale models with different saddle roof slopes for the Mediterranean region all year round (37° North altitude). The scale of the models was 1:15. Each model had three spans, 110 cm long, 40 cm wide, and was covered with glass panes. East–west orientation is better than north–south orientation for maximum light transmittance in autumn and winter. Table 6.7 shows the seasonal light transmittance for different roof slopes.

The symmetrical saddle roof with 27° roof slope had the highest transmittance in winter, and the most uniform transmittance throughout the year. The seasonal variation in transmittance was highest in the asymmetrical saddle roof 18°/8°.

Soriano et al. (2009) calculated the direct solar radiation transmittance of multi-span plastic-film greenhouses (Parral-type) with different roof slopes and orientations in Mediterranean areas for latitudes of 30°N, 37°N, and 45°N. Most of the global radiation in Mediterranean regions is direct radiation. The cladding material was a multilayer plastic film (PE, EVA, PE No-Drop) of 200 μm thickness.

The following regions can be found around the investigated latitudes

30°N	37°N	45°N
South Morocco	North Tunisia	North Italy
North Egypt	South Spain	North Japan
South Israel	South Sicily	North USA
Kuwait	South Turkey	
South Iran	North India	
North Mexico	North Japan	
South USA		
South Japan		

The maximum transmittance at latitude of 30°N in winter has been calculated as 76.4% for roof angles of 35°S/25°N and 76.3% for roof angles 35°S/30°N. The maximum transmittance at latitude 37° in winter has been calculated as 74.2% for roof angles 35°S/30°N. Taking into consideration the problem of drop condensation (Sect. 7.4), symmetrical roof angles of about 30° may be optimal for greenhouses in subtropical regions (Table 6.8).

Table 6.7 Mean seasonal transmittance throughout the year for four roof slopes (Soriano et al. 2004)

Roof slopes (°)		Seasonal transmittance (%)		
South-facing	North-facing	Summer solstice	Equinox	Winter solstice
18	8	74.9	69.8	59
36	55	69.7	66.3	56.7
45	27	71.3	67.7	66.6
27	27	71	68.5	70.1

Table 6.8 Calculated solar radiation transmittance (%) on December 21 at different latitudes and different roof slopes (Soriano et al. 2009)

Roof slope South/North (°)	Latitude and orientation 30° EW	30° NS	37° EW	37° NS	45° EW	45° NS
	Transmittance (%)					
10/10	65–70	60–65	60–65	55–60	60–65	50–55
20/20	70–75	60–65	70–75	55–60	65–70	50–55
30/30	75–80	60–65	70–75	55–60	65–70	50–55
35/35	75–80	60–65	70–75	55–60	65–70	50–55
25/30	70–75	60–65	70–75	55–60	65–70	50–55
35/30	75–80	60–65	70–75	55–60	65–70	50–55
30/35	70–75	60–65	70–75	55–60	65–70	50–55

Ageing and dust deposition on cladding materials and screens have a remarkable influence on the light transmittance. The reduction of light transmittance by dirt accumulation, depending on the material, can be as high as 30% (see Sect. 7.2).