Requirements of greenhouse covering materials in different climatic locations - overview available materials and (dis)advantages

Workshop, 14th of September 2011, Wageningen

Silke Hemming, Wageningen UR Greenhouse Horticulture

Requirements

- Covering materials for horticultural applications:
  - High light transmission
  - Optimum light spectrum
  - Optimum heat input - low heat losses
  - Optimum condensation behaviour
  - High mechanical resistance
  - Low sensitivity to ageing (UV, temperatures, chemicals)
  - Fabrication sizes
  - Costs

Greenhouse coverings

- Glass
  - Floatglass – Greenhouse glass
  - White glass – Low-iron, Crystal Clear, Optiwhite, Clear glass, Ultrawhite, Diamantglas...
  - AR glass – Coating or surface treatment, Sunarc AR glass, Centrosol HiT, GroGlass AR...
  - Diffuse glass – surface treatment with different structures, Vetrasol, V&V diffuus, Centrolsol Struktur, Prismatic, Velglass, Brisa...

Greenhouse coverings

- Plastic films
  - PE-UV polyethylene with UV-stabilisation
  - PE-IR polyethylene with IR-absorption
  - EVA ethylenvinylactetate
  - ETFE ethenetetrafluourethene
- Plastic sheets
  - PMMA polymethylmethacrylate (double)
  - PC polycarbonate (double)
  - PVC polyvinylacetate
  - GRP glass-reinforced polyester (fibre glass)

General

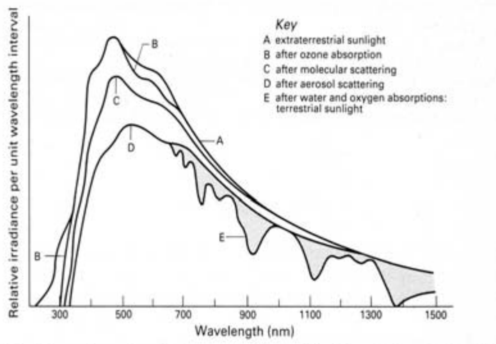


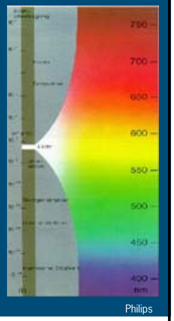
Figure 3.1 The spectrum of sunlight, progressively modified by various processes as it penetrates the atmosphere.

General

Solar radiation (300-2500nm), energy input greenhouse

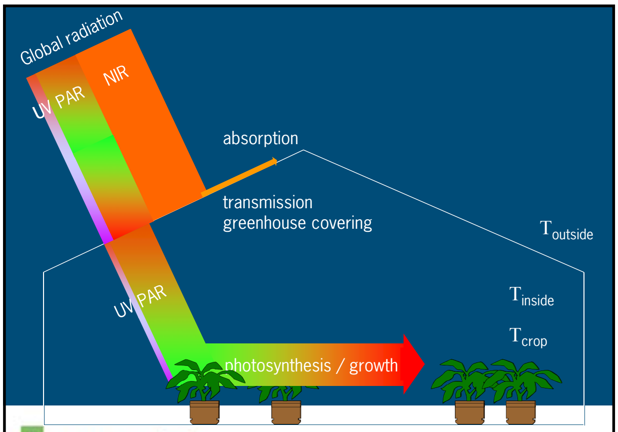
Relevant for horitcultural applications

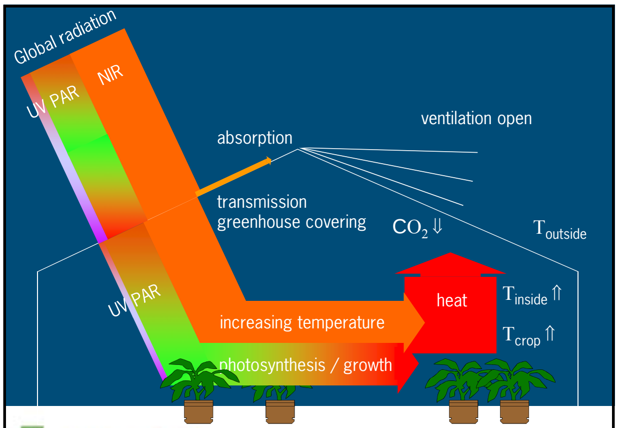
UV	300-400 nm	morphogenesis
PAR	400-700 nm	photosynthesis, morphogenesis
FR	700-800 nm	morphogenesis
NIR	800-2500 nm	*increasing greenhouse temperature*
FIR	2.5-100 µm	*heat radiation*



Philips

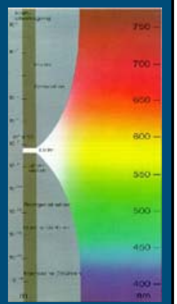
Heat radiation, energy loss greenhouse



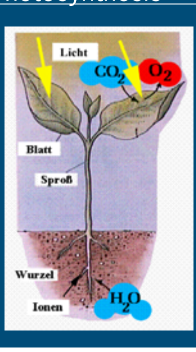


PAR light

- 400 – 700 nm = **PAR light**
- **PAR** = **P**hotosynthetic **A**ctive **R**adiation



Photosynthesis



- CO_2 + water + light → sugar + O_2
- Lightreaction: absorption of lightenergy, transfromation into usable energy
- Darkreaction: energy is transformed into sugar
- Sugars are used for growth

Light quantity

Light quantity

Light transmission <<50%

Tropics

Spain

Light quantity

Light transmission >75%

The Netherlands

Spain

Light quantity

More light by…

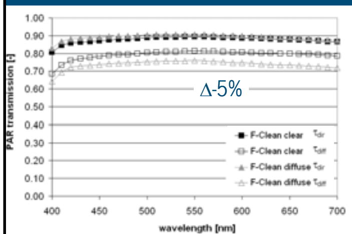
- Advanced covering material
  - White glass (+1-2%)
  - Modern coatings on glass (+5-8%)
  - New plastic films ETFE (+3%)
- Lighter greenhoues construction (<5%)
- Less installations (+1-5%)
- Roof angle (<1%)
- Greenhouse orientation
- Cleaning (up to 10%)

Light transmission

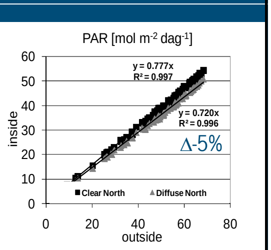
Clear sky → perpendicular; Clouded sky → hemispherical

Material	thickness	light transmission perpendicular	light transmission hemispherical
Floatglass	4 mm	89-90%	82%
White glass	4 mm	90-91%	83%
AR glass	4 mm	95-97%	89-90%
Diffuse glass	4 mm	90-91%	76-82%
PE / EVA films	200 µm	85-90%	78-82%
ETFE (F-Clean)	100 µm	93%	86%
PC sheet	8-16 mm	76-80%	60-70%
PMMA sheet	16 mm	89-92%	ca. 76%

Measurement method

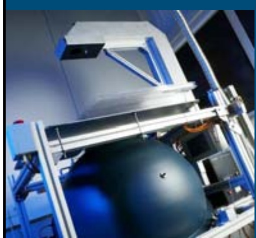


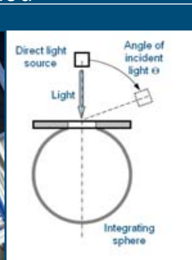
Perpendicular and hemipherical light transmission of diffuse and clear covering

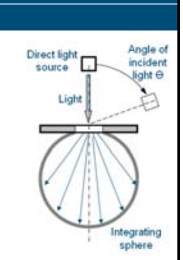


Measurements of daily PAR integral in- and outside experimental greenhouses with diffuse and clear covering Apr.-Sep. 2006 in NL

Measurement method



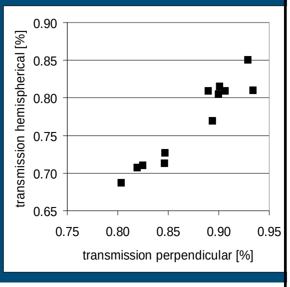




Light intensity: plastic films

- PAR transmission different materials

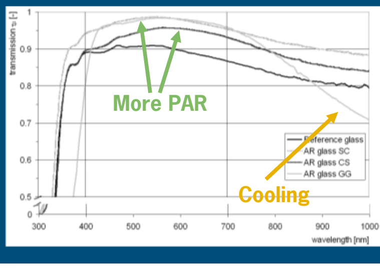
Material	*perpendicular*	*hemispherical*
Producer 1-1 PE-EVA-film	89.0%	80.9%
Producer 1-2 PE-EVA film	89.4%	76.9%
Producer 1-3 PE-film +	82.0%	70.7%
Producer 2-1 PE-EVA-film	90.1%	81.5%
Producer 2-2 PE-EVA-film	84.7%	72.6%
Producer 2-3 PE-EVA-film	84.7%	71.3%
Producer 2-4 PE-EVA-film	80.3%	68.7%
Producer 2-5 PE-film	90.0%	80.5%
Producer 3-1 PE-EVA-film	82.5%	71.0%
Producer 3-2 PE-EVA-film	90.6%	80.9%
Producer 4-1 ETFE Film	92.9%	85.0%
Producer 4-2 ETFE Film	93.4%	81.0%



WAGENINGEN UR

Light intensity: modern coatings

- *Spectral transmission of glass with different* ***anti-reflection coatings*** *from three different producers (SA, CS, GG)*



- Increase of PAR by AR coating → Higher crop production
- Changed spectrum
- Possibilities for cooling
- Possibilities for energy saving with double materials

WAGENINGEN UR

Light transmission: modern coatings

	Standaard tuinbouwglas, Basisglas 1	CentroSolar, Basisglas 3	CentroSolar, Basisglas 3+ AR	CentroSolar, , Basisglas 3 dubbel	CentroSolar Basisglas 3+ AR dubbel	CentroSolar, Basisglas 4	CentroSolar, Basisglas 4 + AR	CentroSolar, Basisglas 4 dubbel	CentroSolar, Basisglas 4 + AR dubbel
hemispherical	82.2%	82.4%	89.3%	71.6%	82.2%	84.4%	91.1%	75.1%	86.0%
perpendicular	89.0%	89.3%	94.2%	80.8%	89.7%	91.0%	95.9%	84.0%	92.9%

WAGENINGEN UR

Light diffusion

WAGENINGEN UR

Light diffusion

Greenhouse covering materials are able to scatter light rays, transforming direct light into diffuse light

50%

0%

Haze

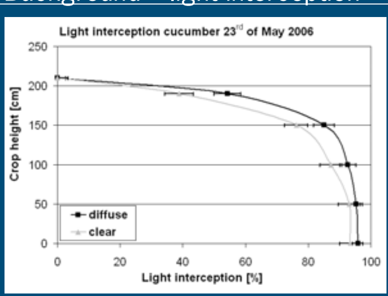
WAGENINGEN UR

Light diffusion

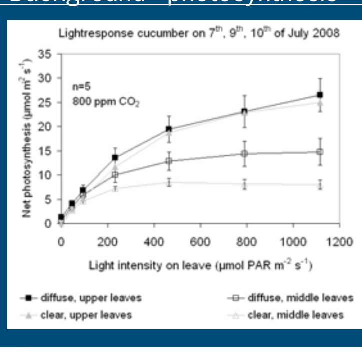
- Horizontal light distribution
  - Cast shadow from greenhouse construction elements
  - Non-uniform growth and development in greenhouse
- Vertical light distribution
  - Most light intercepted by upper leaves
  - Lower leaves contribute less to photosynthesis

WAGENINGEN UR

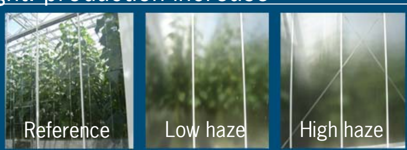
Background – light interception



Background - photosynthesis

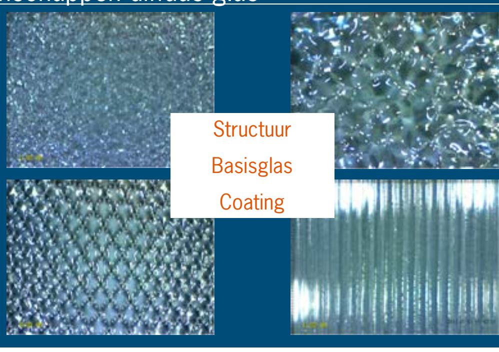


Diffuse light: production increase



		Reference	Low haze	High haze
Spring crop 2008	Kg/m^2		+6.5%	+9.2%
	Nr/m^2		+3.5%	+5.2%
Autumn crop 2008	Kg/m^2		+8.8%	+9.7%
	Nr/m^2		+5.3%	+6.1%

Eigenschappen diffuus glas



Structuur

Basisglas

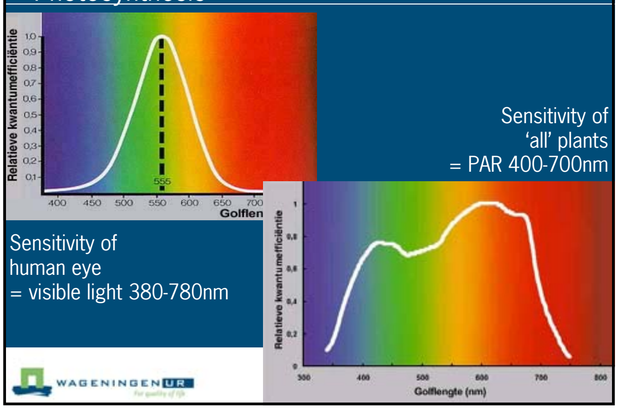
Coating

Light quality

Photosynthesis

- 400-700nm photosynthetic active radiation
- Lightreceptors: chlorophyl, carotinoids
  - Plants use theoretically all colours for photosynthesis
  - Most plants use red light (≈650nm) and blue light (≈ 450nm) more efficiently
  - Plants adapt to colours during growth

Photosynthesis



Sensitivity of 'all' plants = PAR 400-700nm

Sensitivity of human eye = visible light 380-780nm

Morphogenesis

- 300-800nm
- Specific lightreceptors for UVB, UVA, Blue and Red:Far-red
  - Elongation
  - Side shoots
  - Leaf area and leaf thickness
  - Flowering
  - Colour of flowers and leaves
  - Germination

Light quality

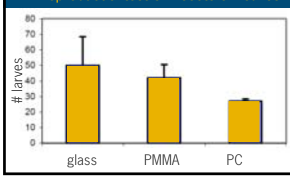
- UV-transparent films influence:
  - Hardening of crops;
  - Leaf and flower colour (lettuce "lollo rosso", aubergines, some flowers or flowering potplants);
  - Compact growth (bedding plants, some potplants)
  - Behaviour of insects (white fly, trips, louse, (bumble-) bee)

Light quality – UV influence on insects

- Population growth of insects on *chrysanthemum* under different UV-transparant covers

after 6 weeks		louse			white fly			trips		
		#	mean	s.d	#	mean	s.d	#	mean	s.d.
Glas	A	19320	24420.5	7213.2	341	376.5	50.2	303	219.5	118.1
	D	29521			412			136		
PMMA	B	17528	21163.5	5141.4	481	429.0	73.5	164	201.0	52.3
	E	24799			377			238		
PC	C	11421	13007.0	2242.9	173	242.0	97.6	128	163.0	49.5
	F	14593			311			198		

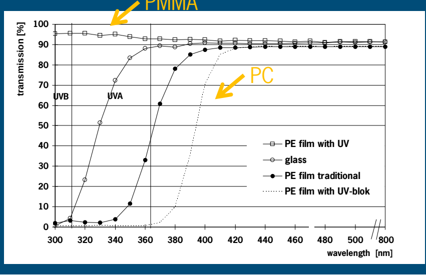
- Reproductiontest of insects on leaves → indirect influence of UV (plant as food source)



Many other influence factors:
- temperature / humidity / light
- sanitation
- plant vitality

Light quality

- UV transmission of different materials



Heat losses

Heat losses

- Thermicity:
  - Unheated greenhouses:
  - in cold, clear nights greenhouse inside temperature can fall below outside temperature
  - Heated greenhouses:
  - Insulation effect, energy saving
  - Especially night temperatures are higher

Heat losses

- Transmission for infrared radiation (heat) is depending on:
- Material/Polymer
- Thickness of material
- Number of layers
- Film surface dry – wet
- IR absorbing pigments/coatings

Comparison other materials

- FIR transmission different materials

Material	thickness	FIR-transmission
Glass	4 mm	0%
PE film	200 µm	40-60%
PE film thermic	200 µm	20-40%
EVA film	180 µm	20-40%
ETFE film	100 µm	15-20%
PC double sheet	12 mm	0%
PMMA double sheet	16 mm	0%

Heat losses

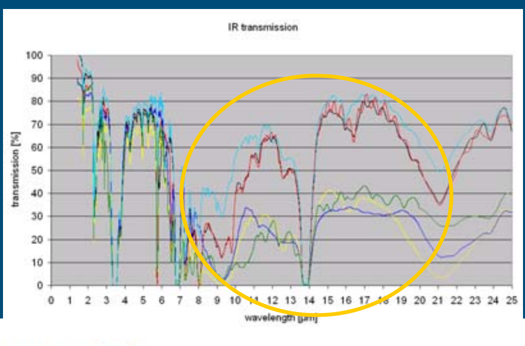
- Thermicity:
  - PE-film are not thermic
  - Mineral fillers
  - EVA-Co-Polymer-film are thermic („co-ex“)
  - Extrusion of several polymer layers

Low EVA-content
→ Good mechanical properties

Foto: Hyplast

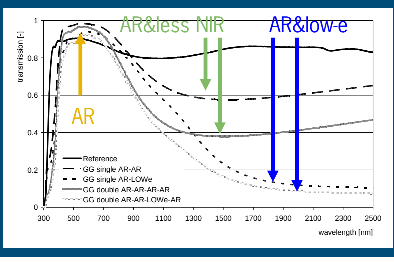
High EVA-content
→ Good thermal properties

Comparison other materials



Results - covering

- *Spectral transmission of glass with coatings (anti-reflection and low-emission) for perpendicular global radiation (300-2500nm)*



Energy saving: coverings

- *Optical properties of different greenhouse glasses (GG) with anti-reflection and/or low-emission coatings for perpendicular PAR (400-700nm)*

Type greenhouse glass	Type coating	Transmission perpendicular $\tau_{PAR,p}$ [-]	Transmission hemispherical $\tau_{PAR,h}$ [-]	Emission coefficients ε_{up} / $\varepsilon_{inside\ up}$ / $\varepsilon_{inside\ down}$ / ε_{down} [-],	NIR reflection factor [-]	k-value material [$Wm^{-2}K^{-1}$]
single (ref)	no	0.897	0.822	0.89/-/-/0.89	0	7.60
single	AR-AR	0.965	0.905	0.85/-/-/0.85	0.24	7.14
single	AR-lowε	0.901	0.838	0.85/-/-/0.11	0.32	5.73
double	AR-AR-AR-AR	0.934	0.850	0.85/0.85/0.85/0.85	0.36	3.61
double	AR-AR-lowε-AR	0.872	0.785	0.85/0.17/0.85/0.85	0.42	2.37

Results

- *Year-round energy consumption, dry weight production and CO_2 concentration under different greenhouse glasses calculated by KASPRO, CO_2 use from boiler only and additional CO_2 use from an external source.*

CO_2 source		Ref	GG single AR-AR	GG single AR-lowε	GG double AR-AR-AR-AR	GG double AR-AR-lowε-AR
boiler	CO_2 concentration 11:00-16:00 h [ppm]	747	750	7[illegible]1	[illegible]15	[illegible]04
	gas use from boiler [$m^3.m^{-2}$]	34.5	35.5	2[illegible].4	[illegible].7	[illegible].1
	Dry weight production [$kg.m^{-2}$]	8.3	9.0	8[illegible]0	[illegible].3	[illegible].6
	dosage CO_2 [$kg.m^{-2}$]	26.1	27.1	2[illegible].4	[illegible].2	[illegible]4.8
boiler & external	CO_2 concentration 11:00-16:00 h [ppm]	798	800	7[illegible]4	[illegible]90	[illegible]87
	gas use from boiler [$m^3.m^{-2}$]	33.7	34.7	2[illegible].7	[illegible]5.0	[illegible].4
	Dry weight production [$kg.m^{-2}$]	9.0	9.8	9[illegible]0	[illegible].3	[illegible].5
	dosage CO_2 [$kg.m^{-2}$]	43.5	43.8	4[illegible].1	[illegible]7.3	[illegible]3.3

max. 18% 25% 33%

decreasing k-value

Condensation behaviour

Condensation

- Condensation in the greenhouse:
  - High humidity
  - Difference between outside and inside air
  - On inside of film, water drops or water film

Foto: CIBA, Italien

Condensation

- Water drops or film:
  - Reduction of light transmission up to 15%
  - Damage of crops due to dripping off
  - Anti-drop-additives reduce surface tension
  - Durability of anti-drop-effect often max. 2 years

Foto: IMAG

Condensation behaviour AR glass

Condensation behaviour AR glass

Ageing

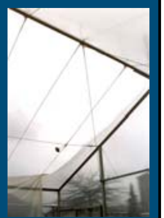
Ageing

- Plastic materials are ageing due to several factors:
  - UV-radiation
  - Chemical influences
  - Thermal influences
  - Mechanical influences

Foto: Waaijenberg, IMAG

Ageing

- Ageing due to UV-radiation:
  - UV(B) destroys polymer
  - UV-absorbers: used in PE-UV and EVA films
  - UV-stabilisizers: NI-Quencher or HALS
  - UV-reflektionn: PVDF and ETFE films



Ageing

Reduction of transmission due to material ageing

Material	Reduction in light transmission	Per year
PMMA	max. 6% in 10 years	3%
PC	max. 6% in 10 years	3%
PE and EVA	ca. 6% in 4-5 years	3%
ETFE	2-3% in 10 years	1.5%
Glass	almost 0%	0%

Ageing

- Ageing due to UV-radiation:
  - Lifetime of a film
  - Depending on region, UV-intensity
  - The Netherlands yearly 80 kLy -> 5 years film
  - Spaini yearly 160 kLy -> 2,5 years film

thickness film	max. yearly radiation
150 µm	250-300 kLy
180 µm	300-350 kLy
200 µm	350-400 kLy
220 µm	400-450 kLy
250 µm	450-500 kLy

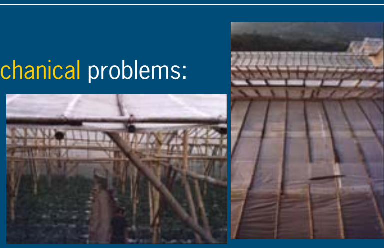
1 kLy = 11,62 kW*h*m^{-2}

Ageing

- Ageing due to chemicals:
  - Use of pesticides
  - Sulphus and chlorine destroy stabilizers (HALS)
  - Better stabilizers are needed

Ageing

- Ageing due to mechanical problems:



- Solution:
- Make a good greenhouse design
- Fix and stretch films with special profiles

Summary

Wageningen UR Glastuinbouw

Innovations in Horticulture