Summer School "Cover Materials for Greenhouses", 24 – 30 September 2018,
University of Thessaly, Volos, Greece

Climate Control

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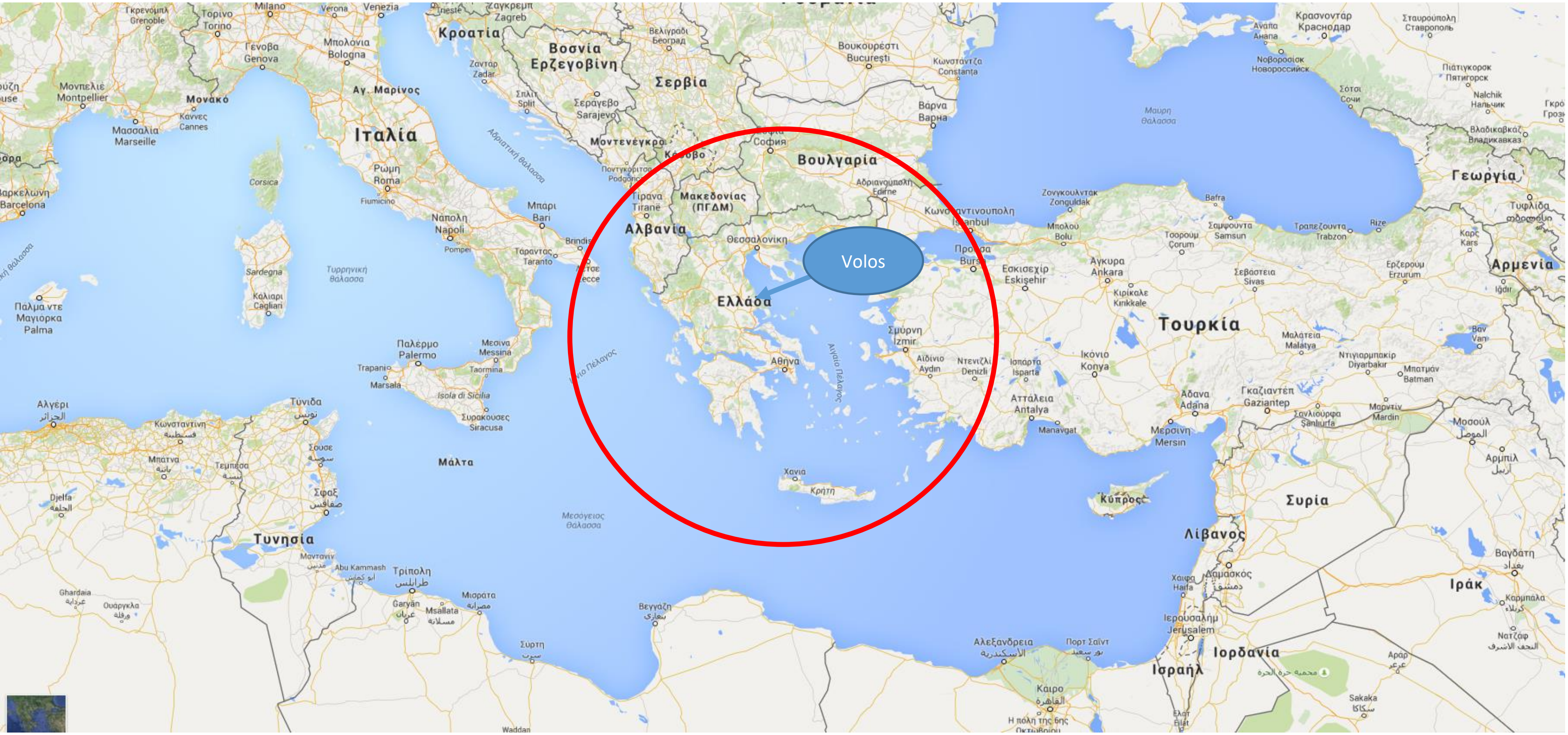
UNIVERSITY OF THESSALY
SCHOOL OF AGRICULTURAL SCIENCES
Department of Agriculture Crop Production and Rural Environment


Volos
Κροατία
Βοσνία Ερζεγοβίνη
Σερβία
Ιταλία
Βουλγαρία
Μακεδονίας (ΠΓΔΜ)
Αλβανία
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Γεωργία
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Μεσόγειος Θάλασσα
Μαύρη Θάλασσα
Αιγαίο Πέλαγος

The University of Thessaly is located in Volos

Latitude: 39.22

Longitude: 22.44

When tillage begins, other arts follow

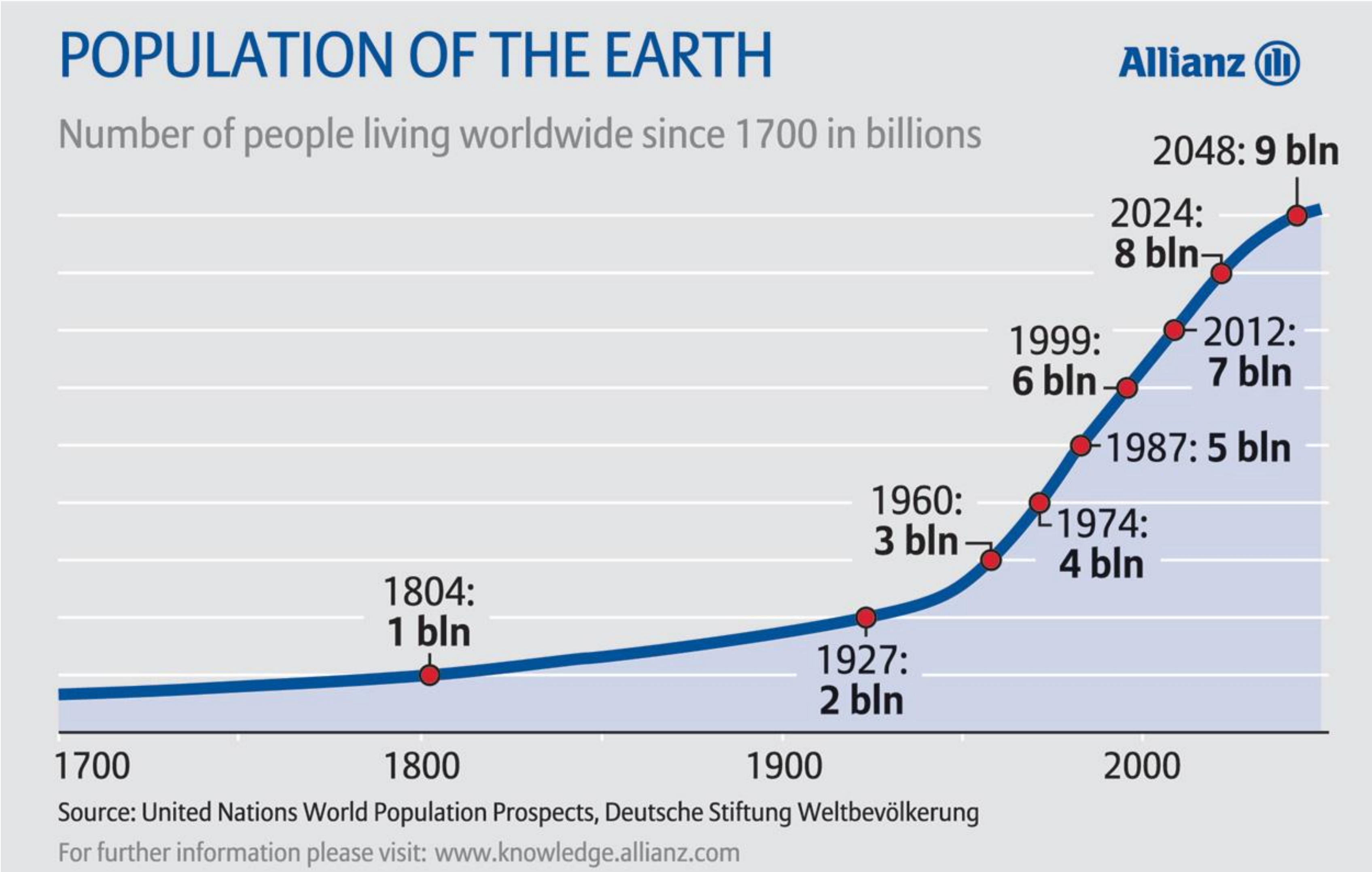
The farmers, therefore, are the founders of human civilization

Daniel Webster, 1840

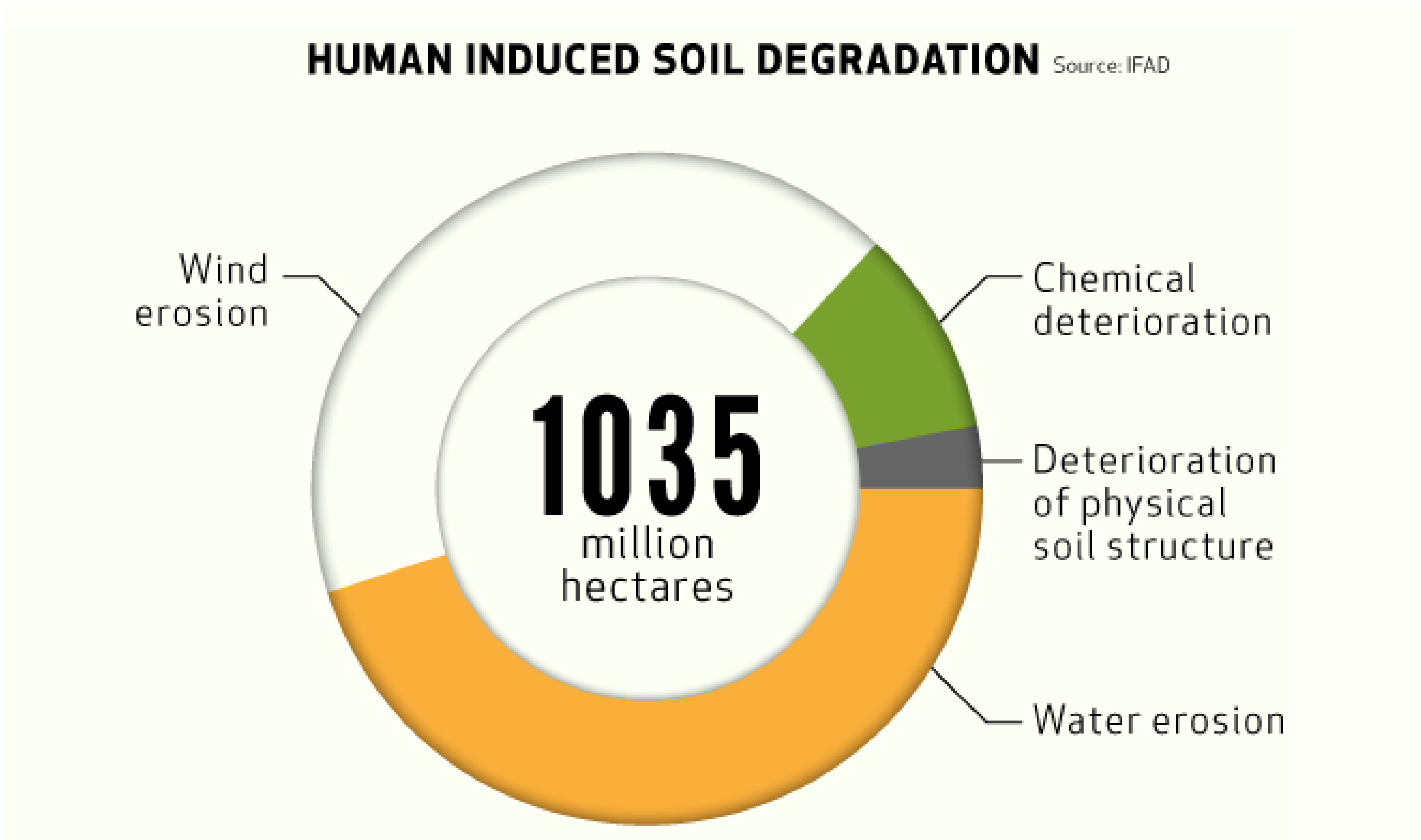
According to the Food and Agriculture Organization (FAO) Agriculture (croplands and pastures) occupies about 38% of Earth’s terrestrial surface—the largest use of land on the planet. This fact alone highlights the importance of farming for global economy, employment, energy use and environment.

Sustainability Challenges

Increase of population



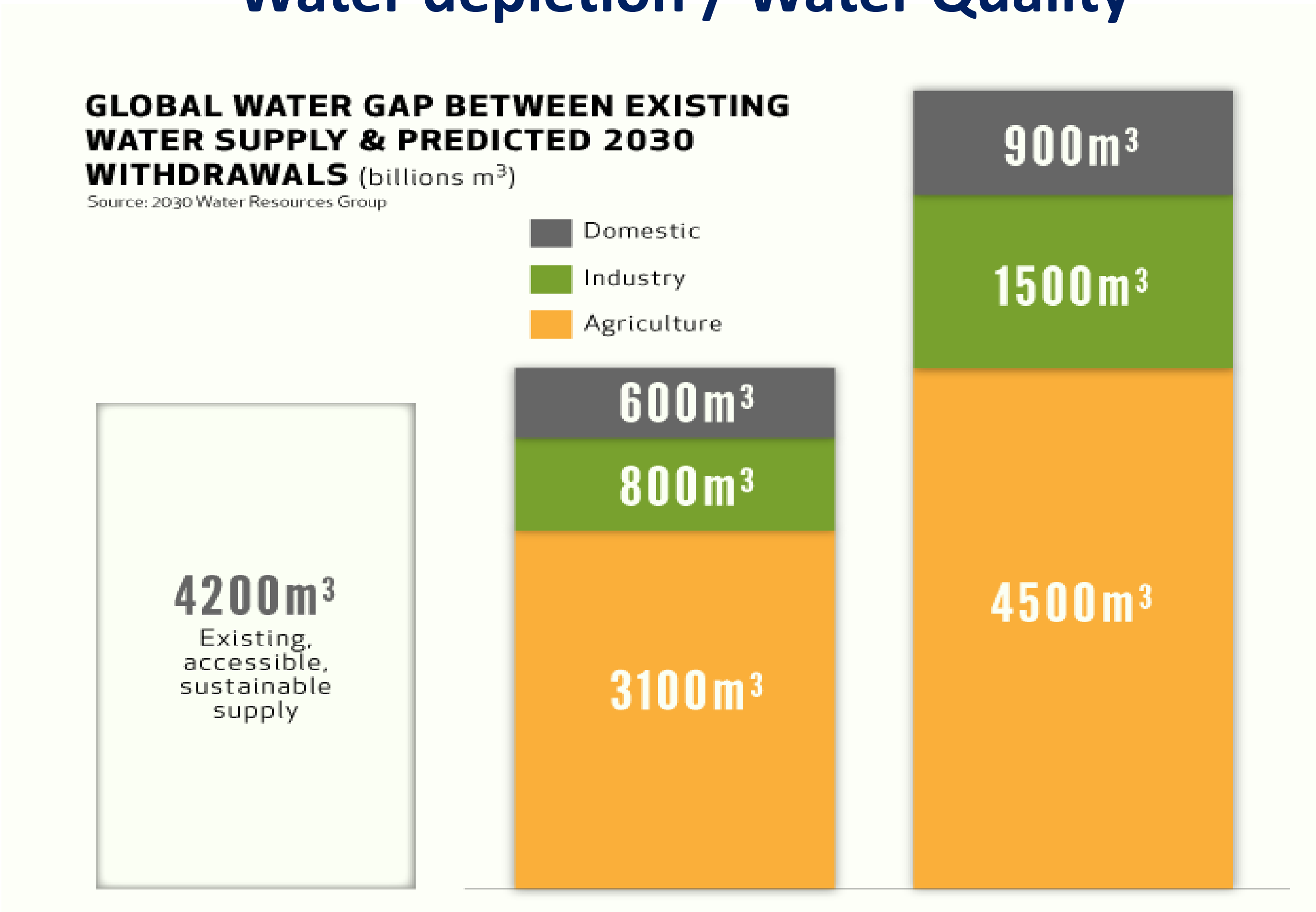
Available cropland is quickly degraded



By 2050, an estimated half of current arable land will become unusable due to desertification and land degradation

Sustainability Challenges

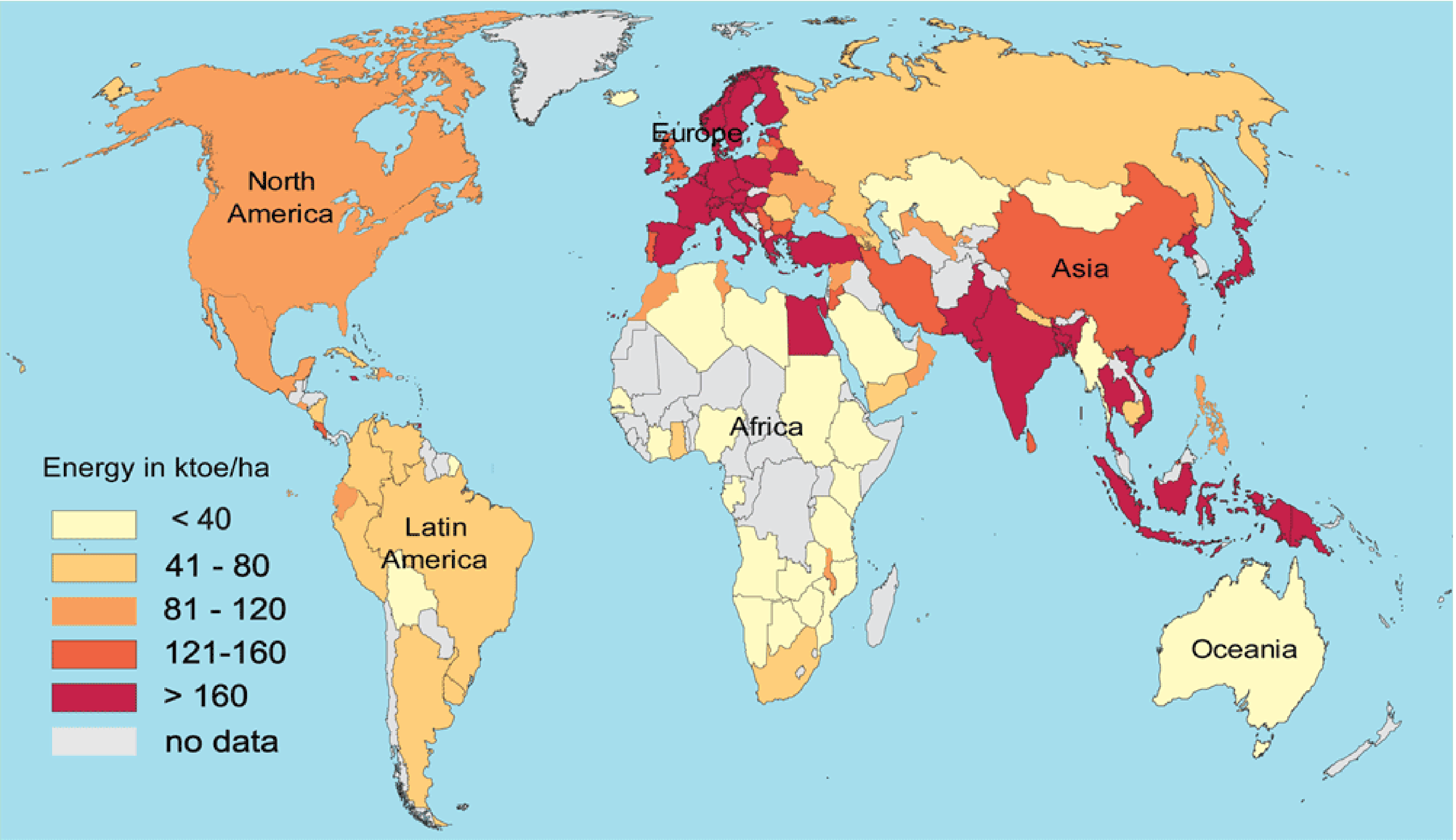
Water depletion / Water Quality



- 70% of earths' area is covered by water
- ~3% can be used for drinking-tap water
- ~70% of the water that can be used (drinking-tap water) is used for agricultural purposes
- Until 2025, 50% of world population will face water scarcity problems

Sustainability Challenges

Energy demand

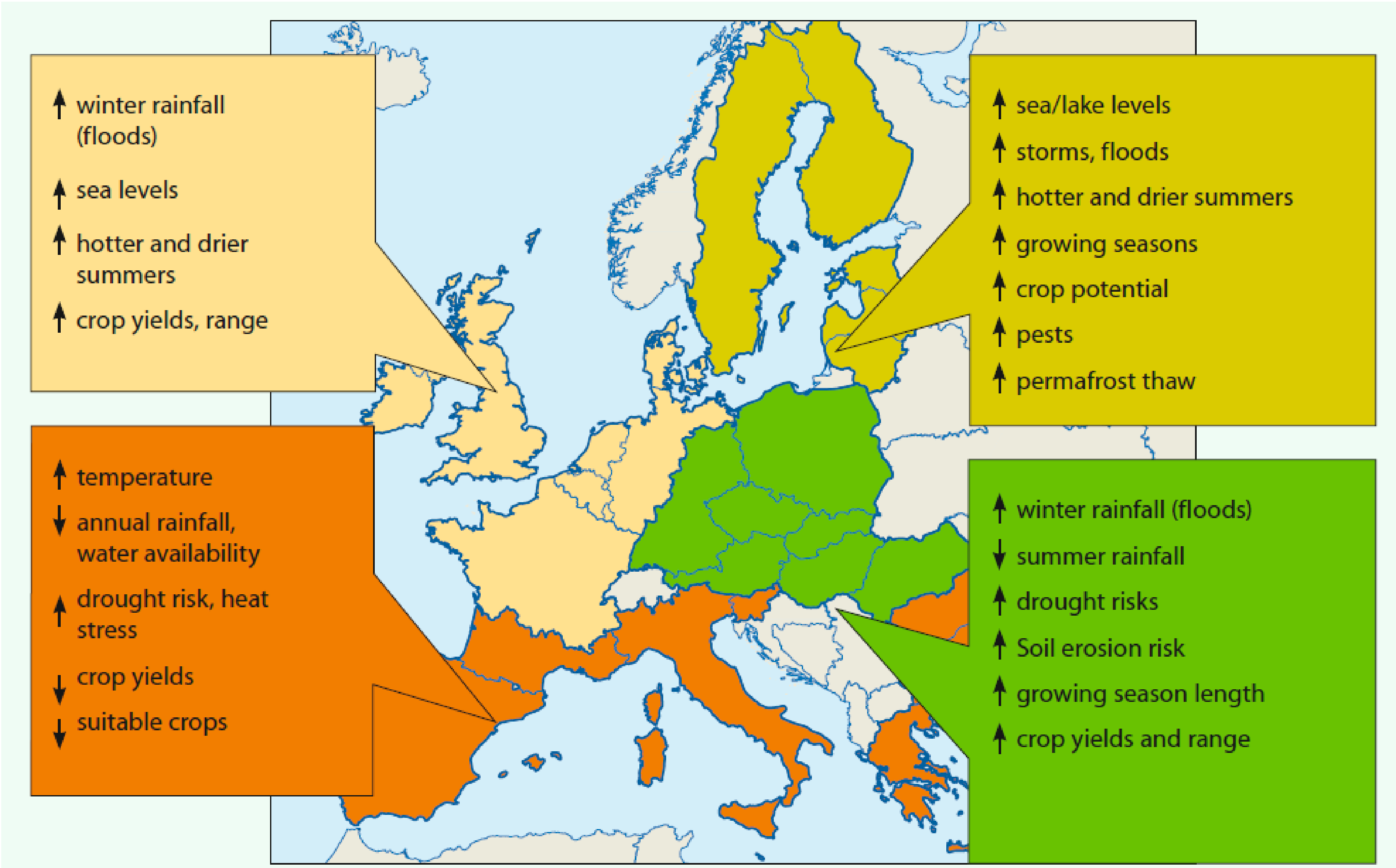


Worldwide energy demand is projected to grow by 44% between 2006 and 2030

In 2030 energy imports of EU will account of nearly 70% of energy needs

The Challenges

Agriculture is insufficiently prepared to cope with adaptation to climate change



Source: Commission DG Agriculture elaboration based on literature

What is expected for crops under cover in the near future?

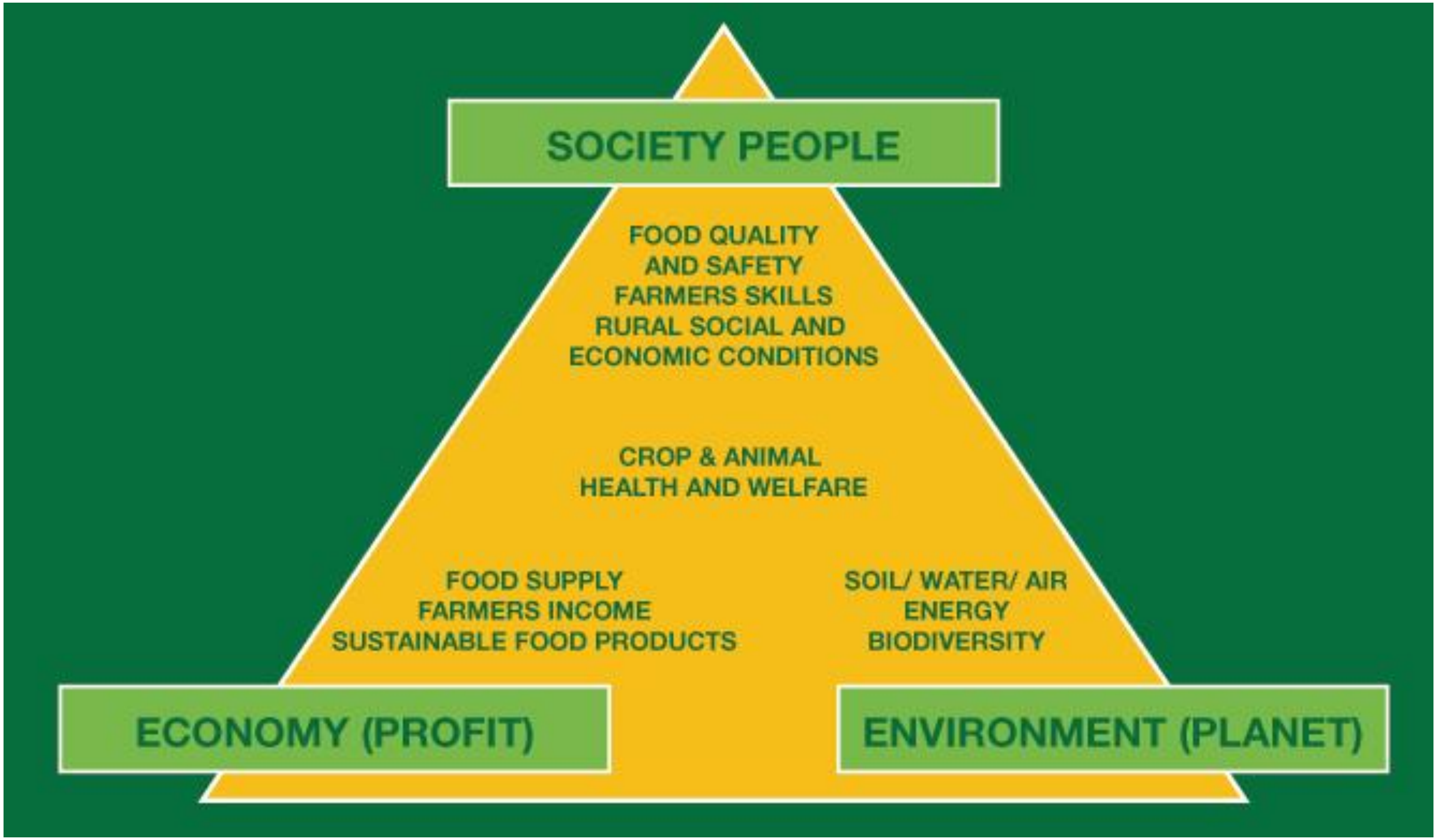
- Climate change
- Reduction of available water resources
- Consumer requirements for safe, high quality products

⇒ **Increase of crops under cover**

Crops under cover:

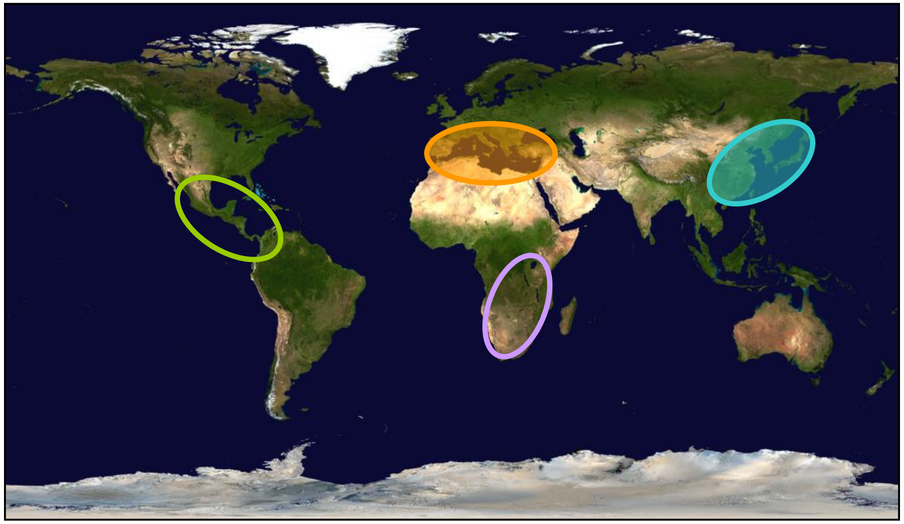
Greenhouses-Screenhouses

Crop production under cover enables the production of high quality products throughout the year with efficient use of inputs to water, fertilizers, pesticides and labor.



Sustainable greenhouse production is a productive, competitive and efficient way to produce safe agricultural products, while at the same time protecting and improving the natural environment and social/economic conditions of local communities

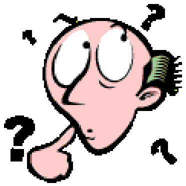
Greenhouses, especially those covered by PE films have been widely adopted and are used in many areas in the world, especially in areas with mild winter climate conditions



Three are the main factors taken into account when deciding the location for the installation of a greenhouse unit:

1. Production cost
2. Quality of the products
3. Logistics and transport cost to the market

Two main questions have to be replied prior to the installation of a new greenhouse unit:



1. What am I going to produce?
2. Where can I sell my products?

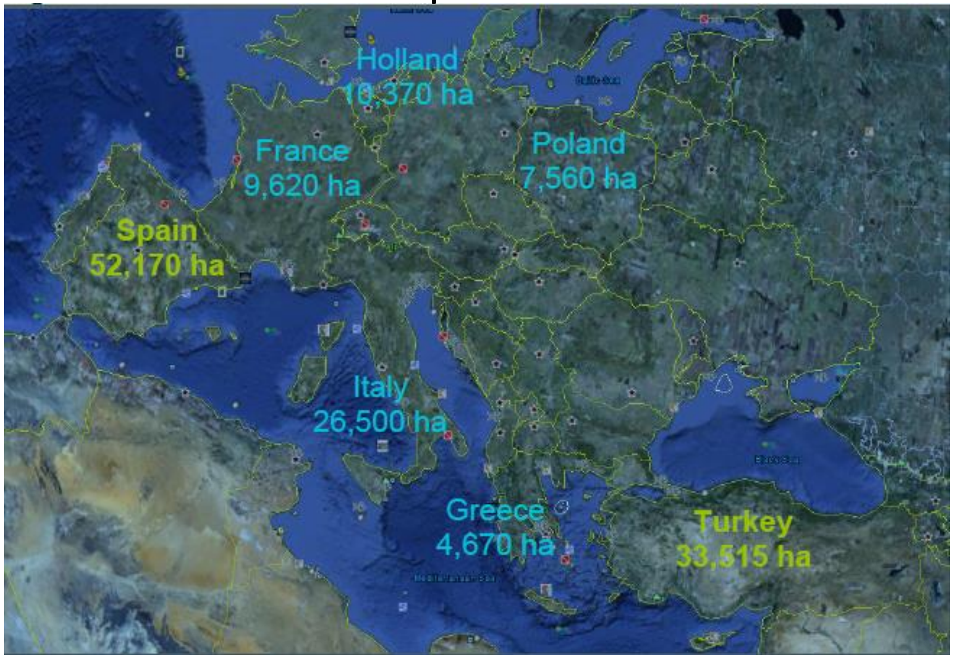
Food

Flowers

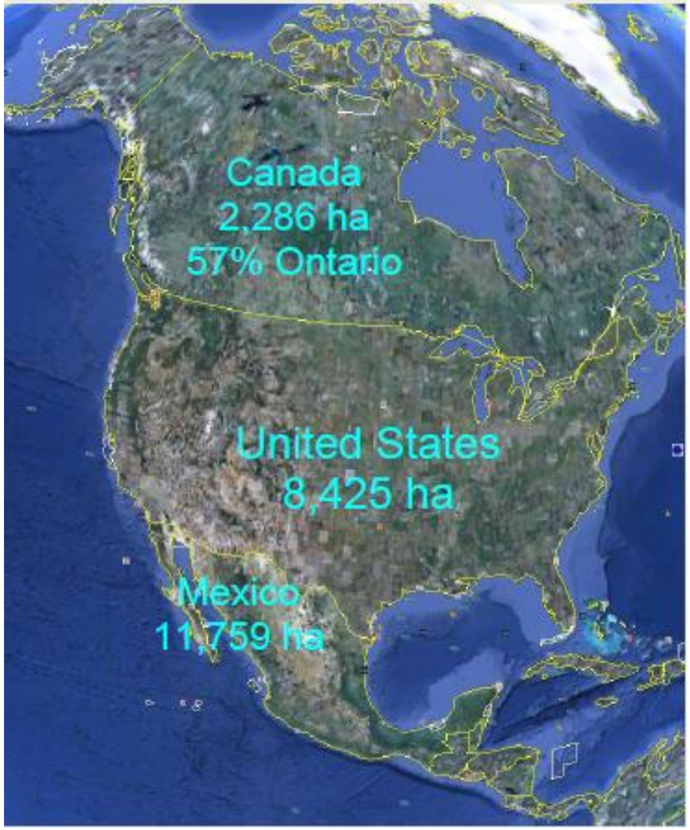
International or domestic market

Worldwide greenhouse production

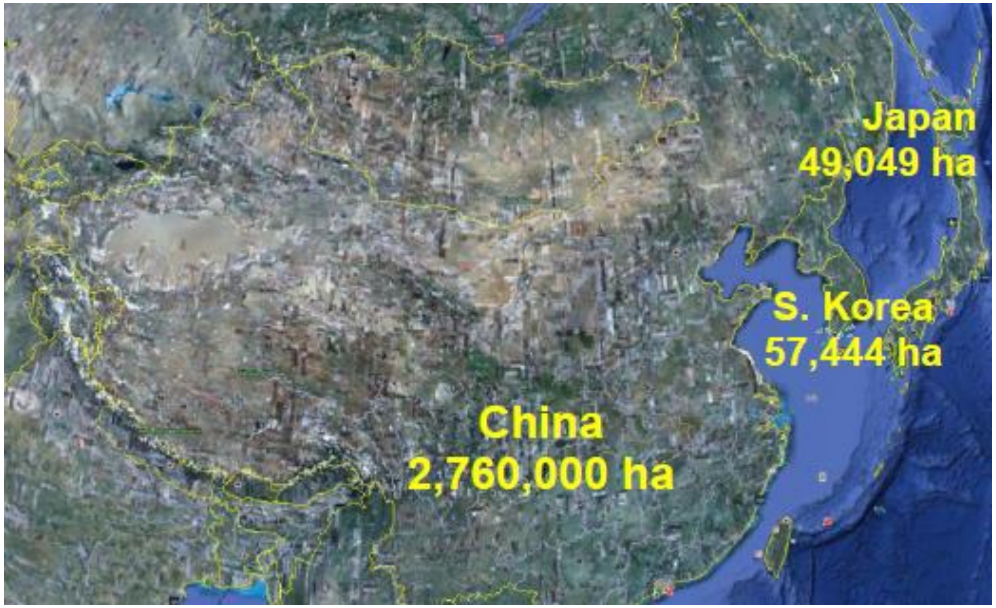
Europe



North America

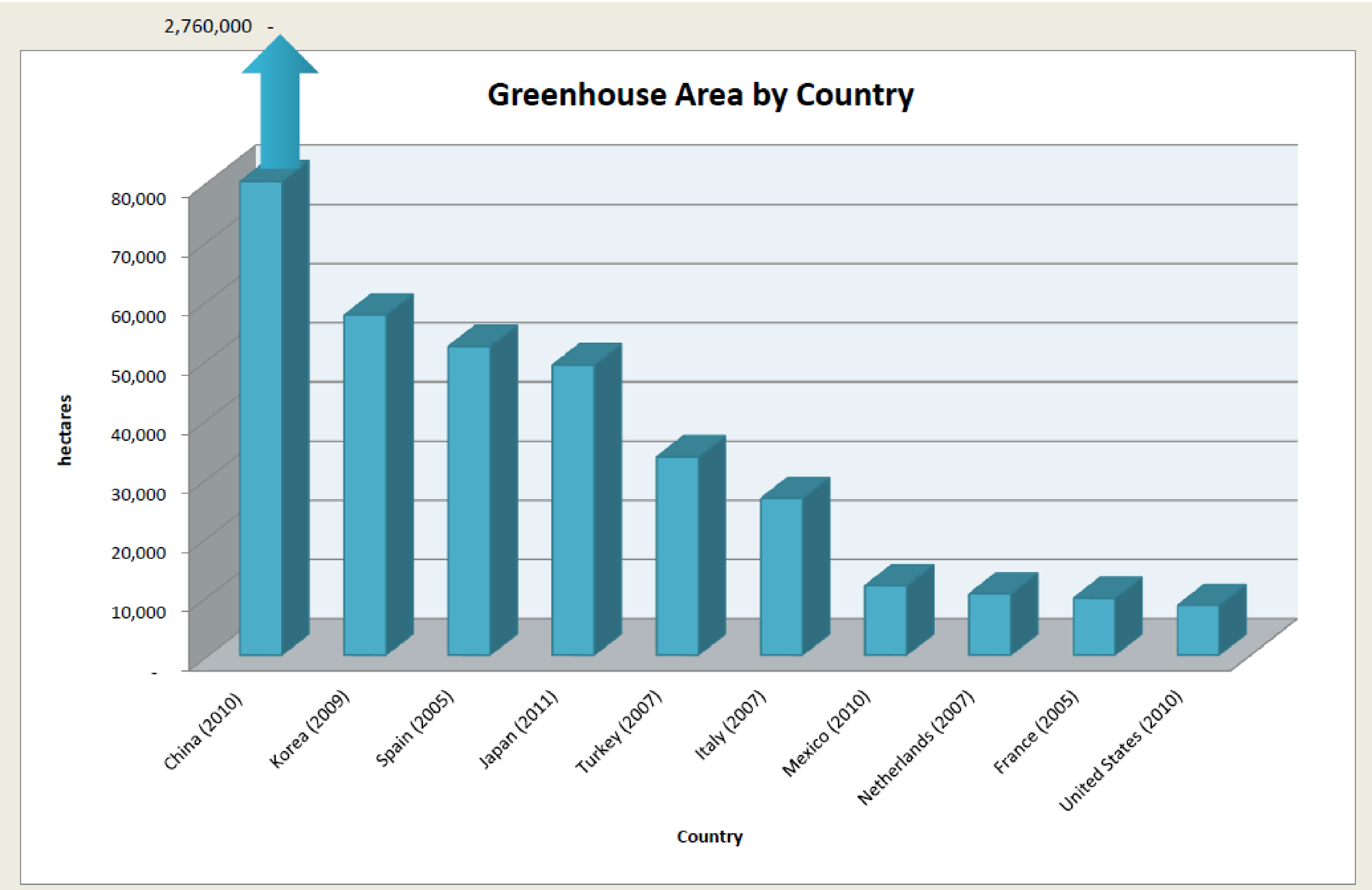


Asia

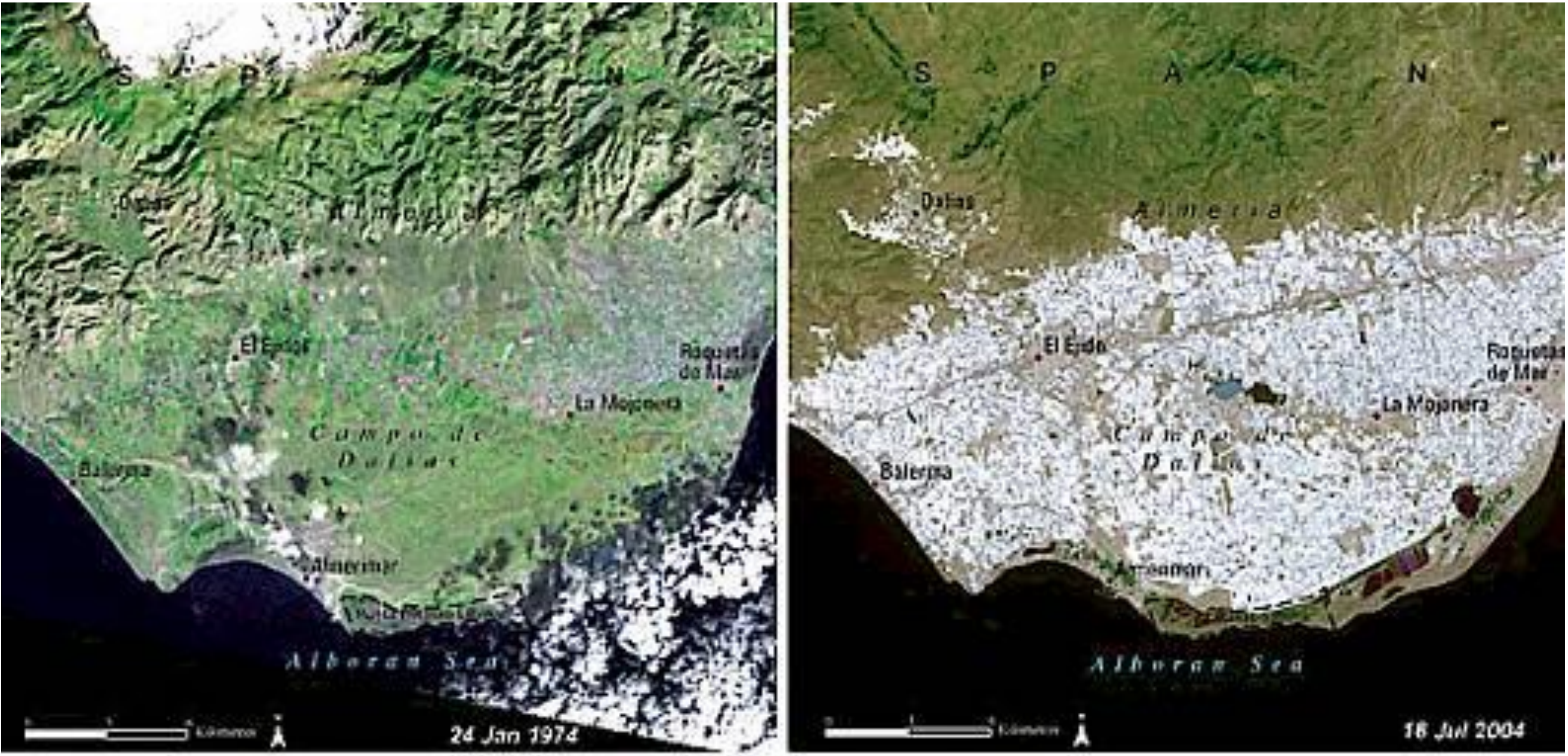


Top 5 Countries by Area (ha)

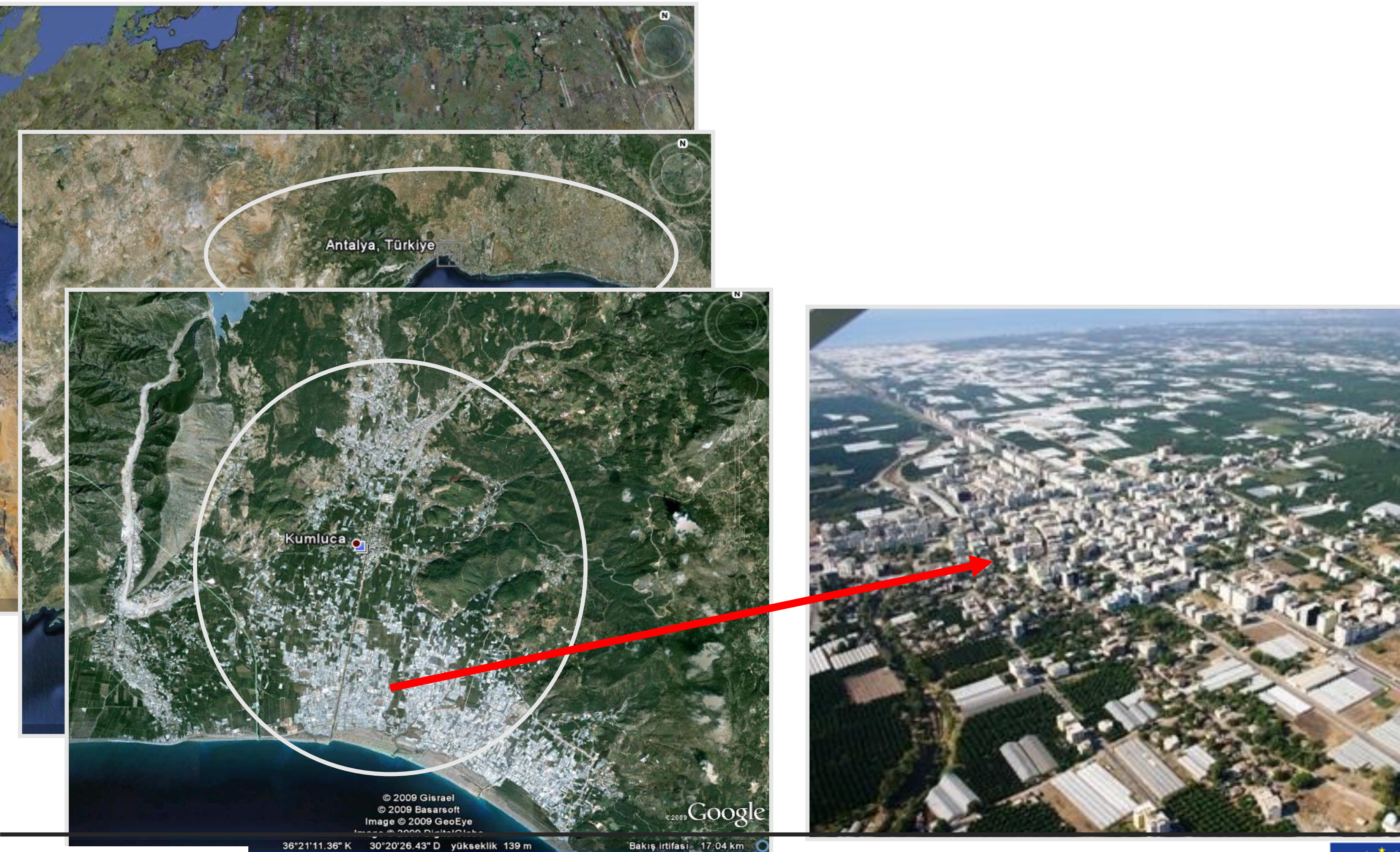
Total Area in Major Greenhouse Production Countries



Almeria, Spain


S P A I N
Dalias
El Ejido
Roquetas de Mar
La Mojonera
Campo de Dalias
Balerma
Almerimar
Alboran Sea
24 Jan 1974
S P A I N
Dalias
Almeria
El Ejido
Roquetas de Mar
La Mojonera
Balerma
Alboran Sea
16 Jul 2004

- Pictures from Antalya Province in Kumluca township which has the most intensive greenhouse area in Antalya.




Karşıyaka Mh.
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Food production

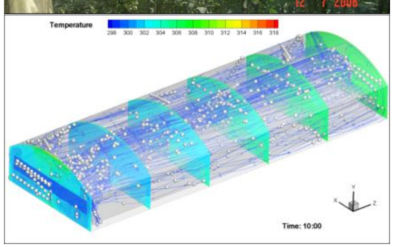
Flower production

Recent trends on greenhouse industry

New constraints on greenhouse industry :

- ✓A considerable rise of energy price;
- ✓A displacement of the production towards warmer regions;
- ✓Increasing constraints for a sustainable crop production with a severe limitation of energy and chemical inputs and more and more concerns on quality.

Scientific approaches for sustainable greenhouse



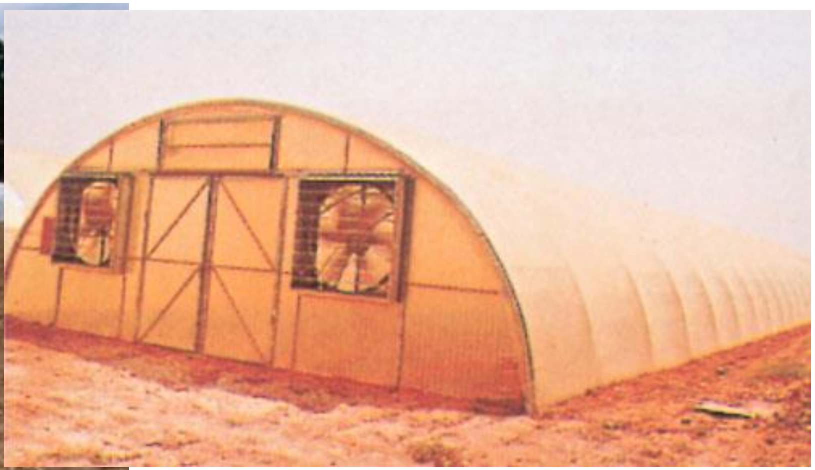
- ❑ Proper choice of the location
- ❑ Optimum design of their climatization (ventilation, heating, cooling, shading) systems
- ❑ Energy saving and use of renewable energy sources
- ❑ Use of physical means for the reduction of use of pesticides (insect screens, UV blocking materials).
- ❑ Rational management of water resources - use of hydroponics.
- ❑ Smart climate control

Greenhouse Types

Glasshouses

Glasshouses,

Tunnel


Tunnel

Multispan with Round Arched Roof

Multispan with Assymetric Roof

Multispan with Pointed Arched Roof (Gothic)

Greenhouse / Sustainability issues

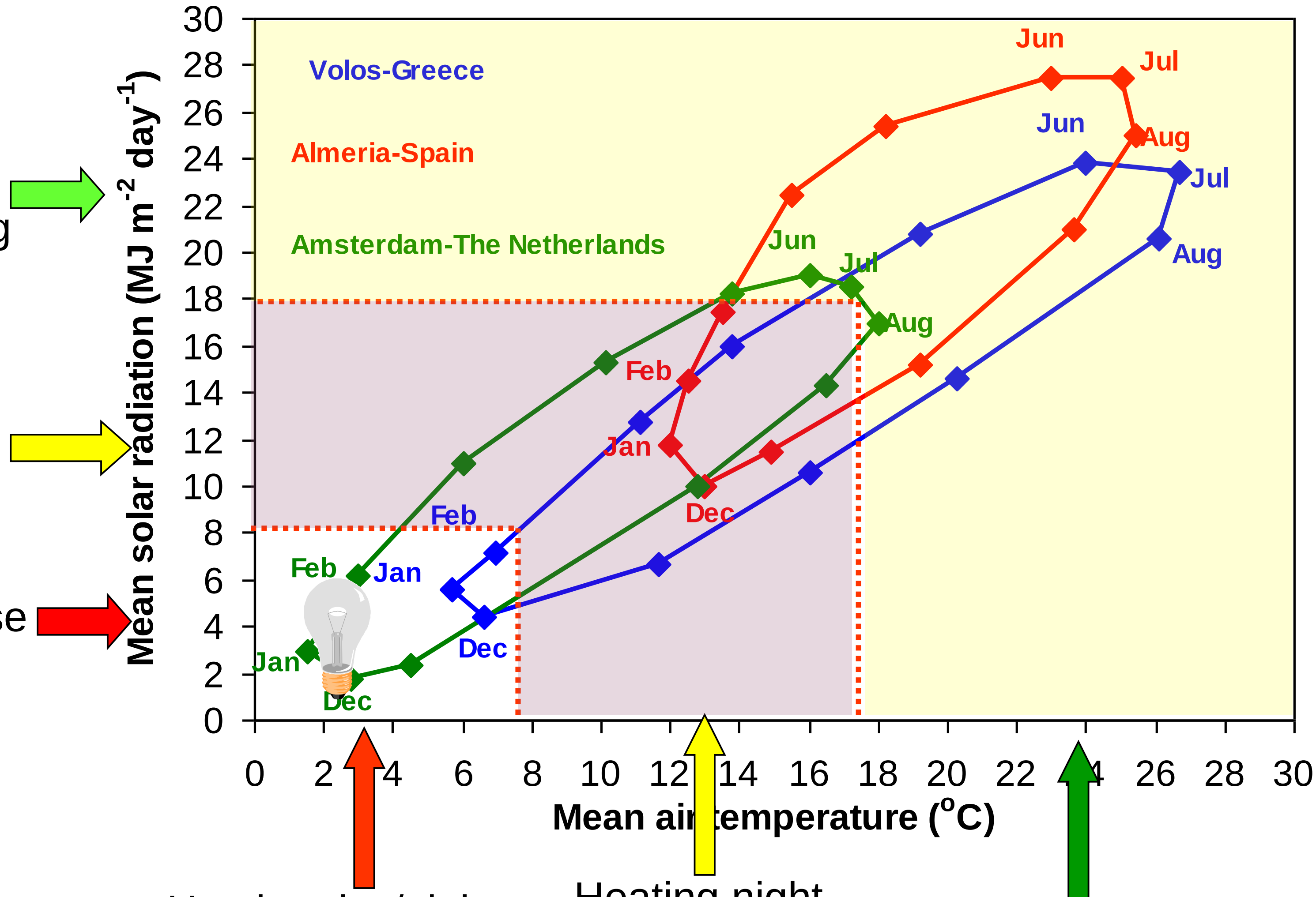
Location

Regional suitability-needs

Continuous ventilation- cooling

Discontinuous ventilation

Closed greenhouse



Heating day/night

Heating night

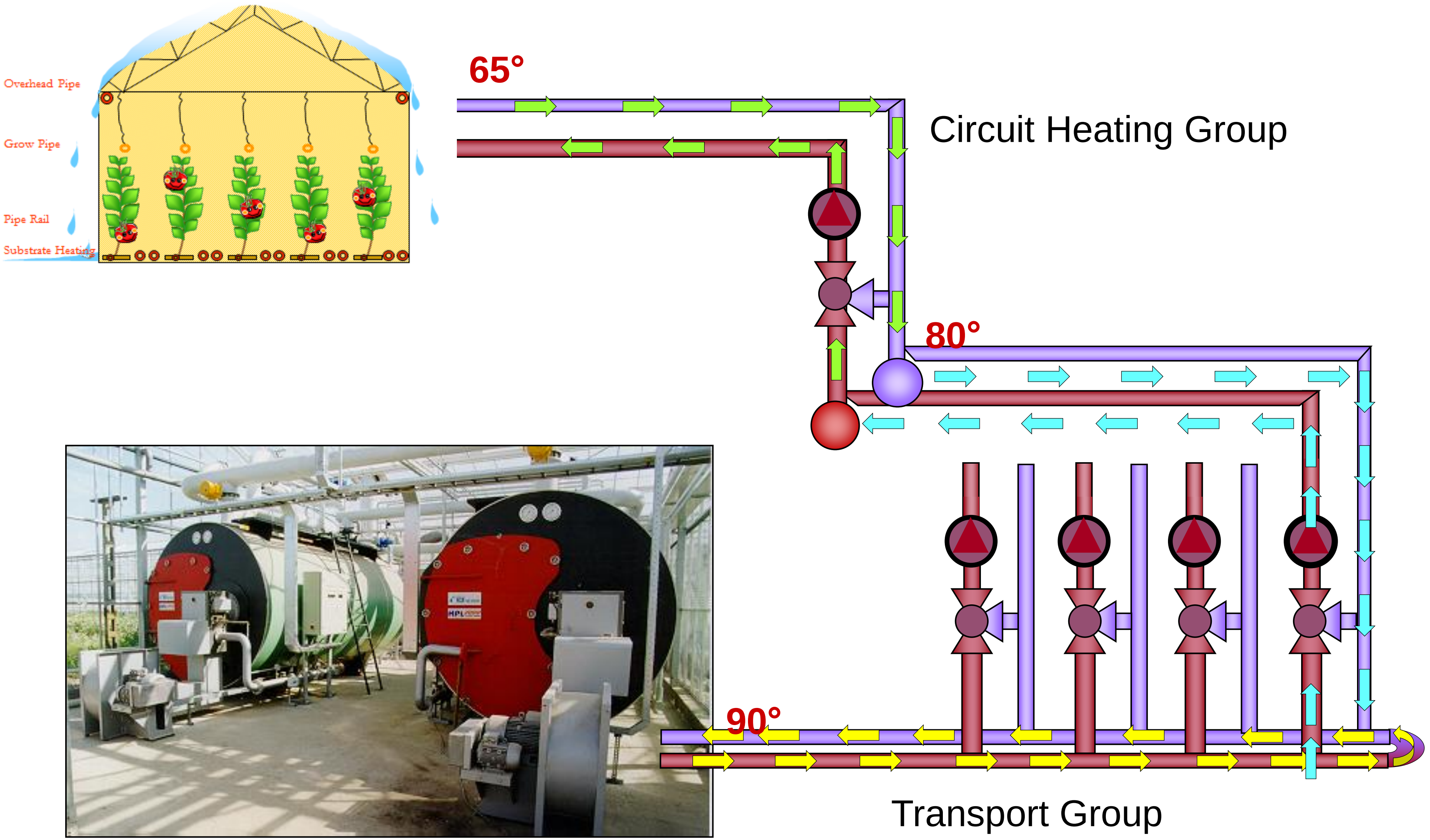
No heating

Greenhouse / Sustainability issues

Climatisation systems

Heating

Hot water from boiler to plant

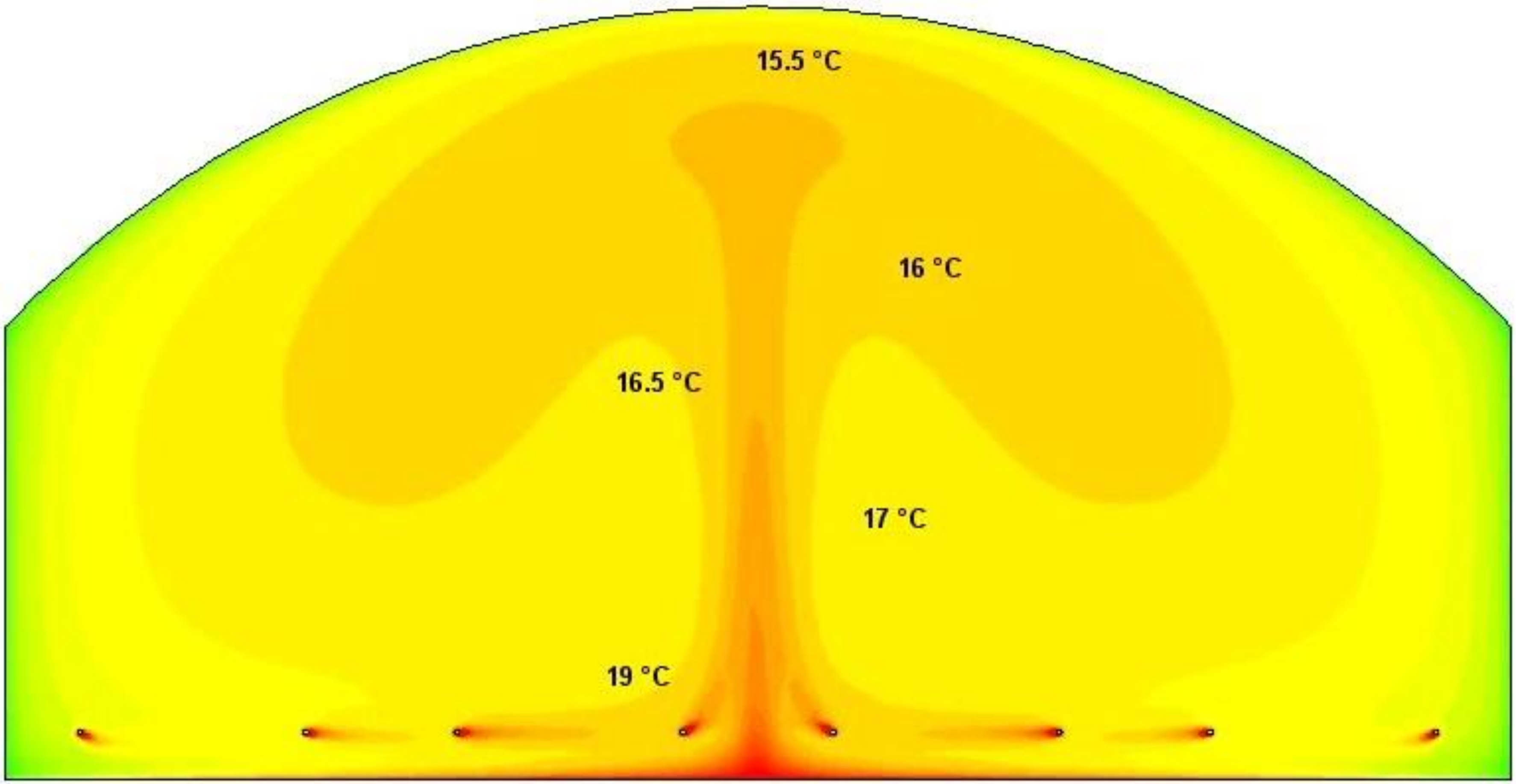



Heating


THERMOKEY


223
Syngenta
Geent
Growdena

System’s design with CFD – Heating



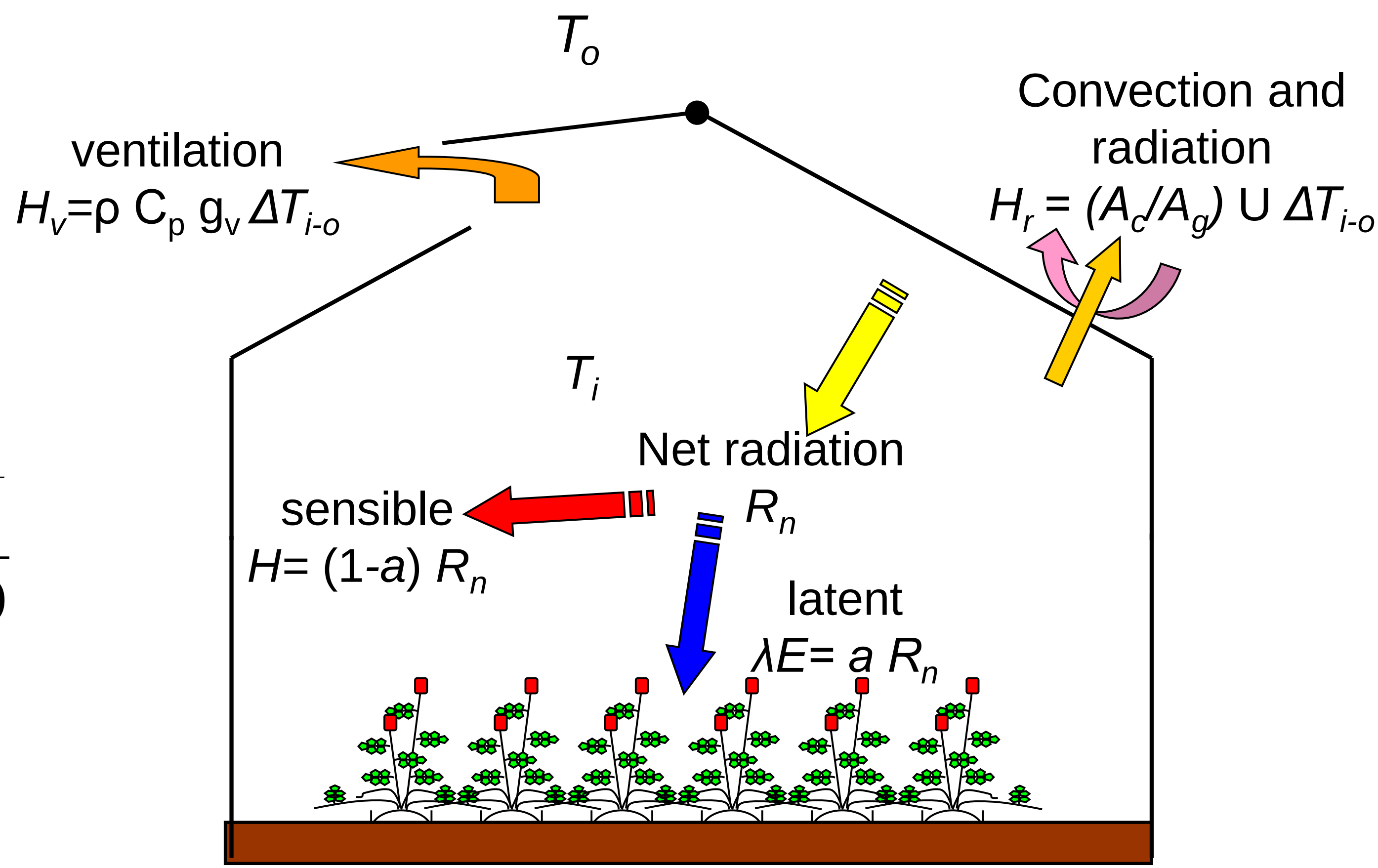
Using CFD models we can examine (numerically) different locations of the heating pipes and conclude about the heating efficiency and the uniformity of air temperature distribution inside the greenhouse.


Natural Ventilation
Dynamic Ventilation
Cooling
Fan and Pad and FogEvaporative Cooling
Shading

Calculation of ventilation needs

Greenhouse energy balance

$$g_v = \frac{N \frac{V}{A_g}}{3600}$$



Calculation of ventilation needs

$$Rn\ (1-a) =$$

$$=[(A_c/A_g)\ U\ (Ti-To)] + [\rho C_p N\ (V/A_g)\ (Ti-To\ )/3600]$$

Means of air temperature reduction

$$T_i = T_o + \frac{(1-\alpha)R_n}{\mathrm{U}\,(\mathrm{A_c}/\mathrm{A_g}) + \rho \mathrm{C_p}\left({}^{NV/A_g}\!\big/_{3600} \right)}$$

Vent opening area

$$S = N * L * h$$

S: vent opening area (m^2)

N: number of vents

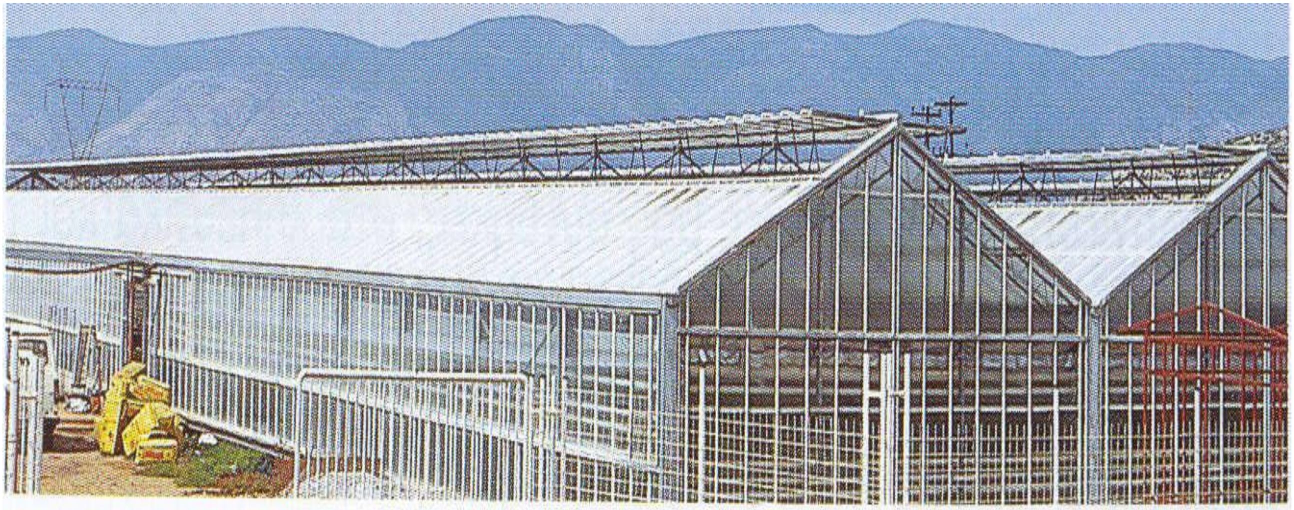
L: vent length (m)

h: vent opening height (m)

Natural Ventilation

Lateral Openings

Roof Openings

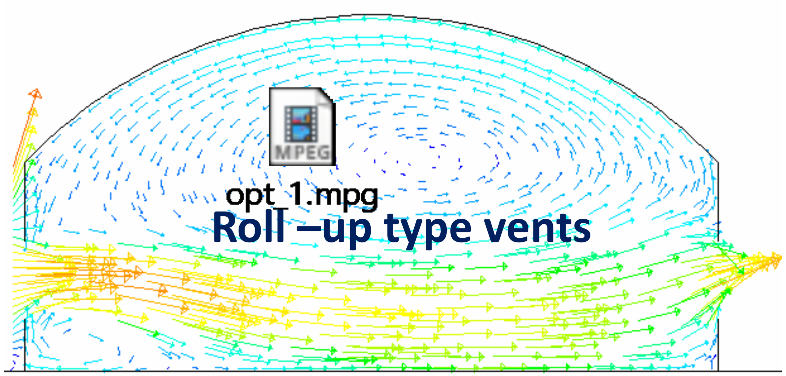


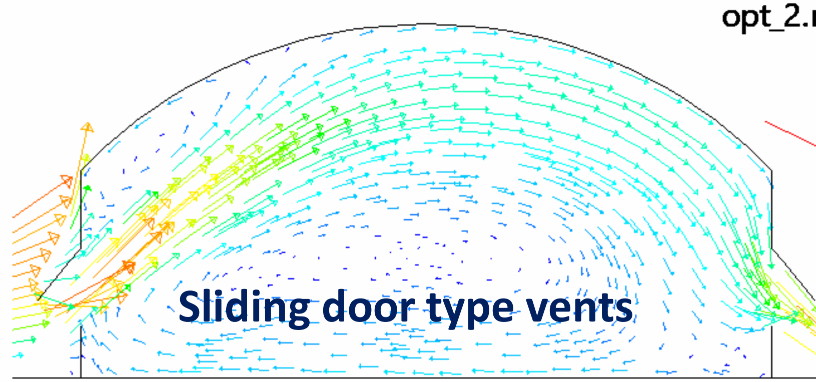
Air velocity distribution with two different vent openings

A strong air current near greenhouse floor and lower air velocities in the roof

Airflow is driven near roof and exits the greenhouse through the leeward vent. Air velocity is strongly reduced near greenhouse floor.

opt_2.mpg



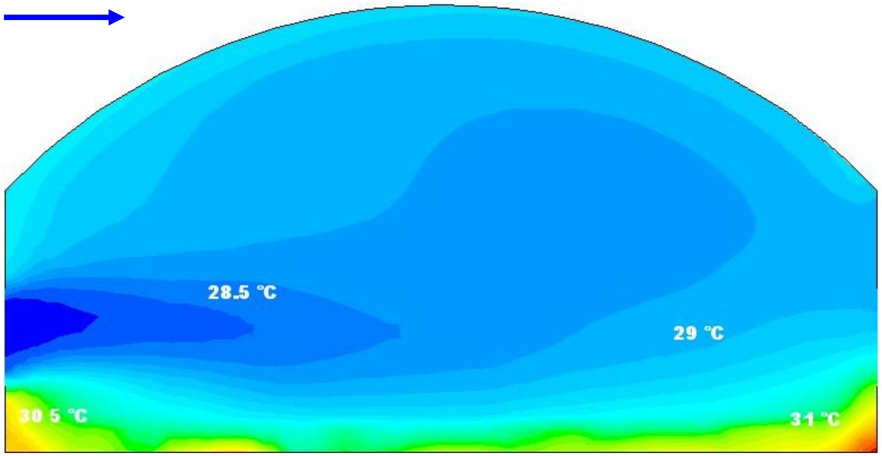


CFD models – improving natural ventilation systems

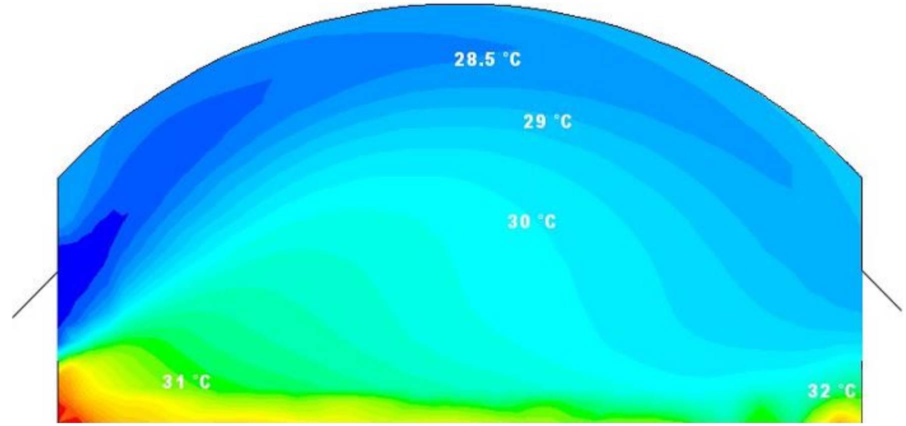
Air temperature distribution for different vent openings

WD

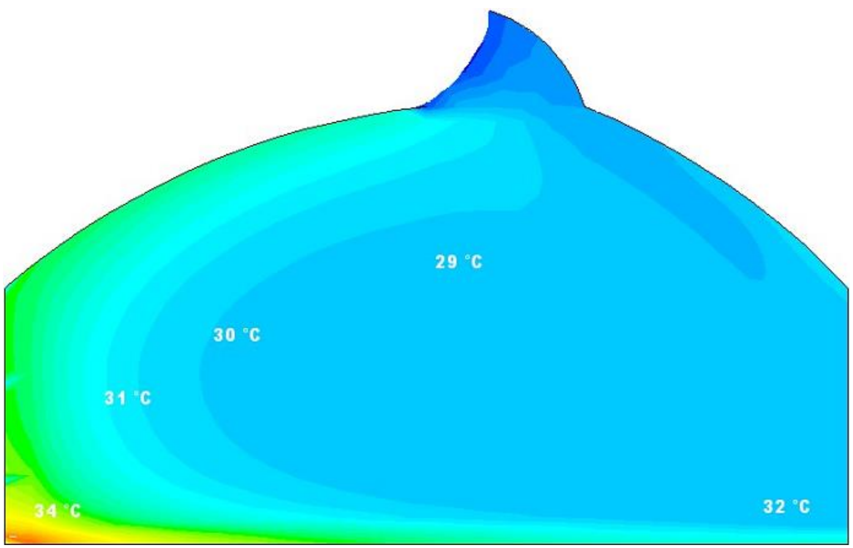
Roll –up type vents



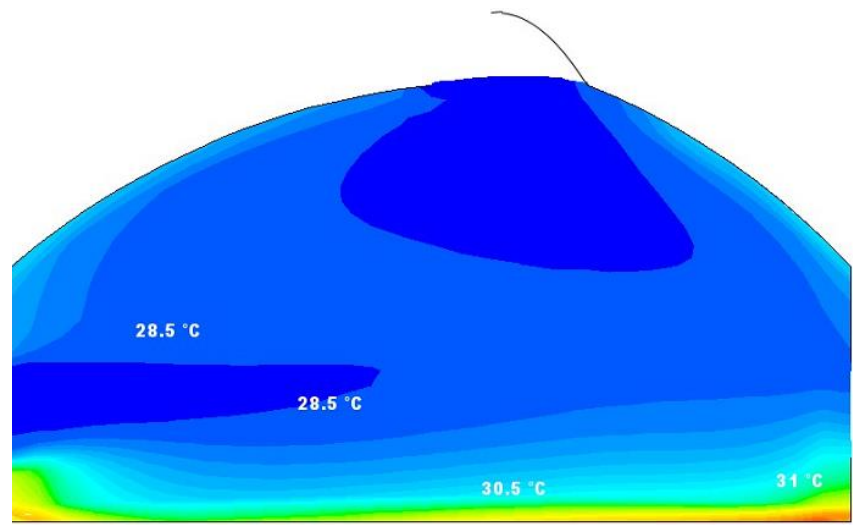
Sliding door type vents



Roof only

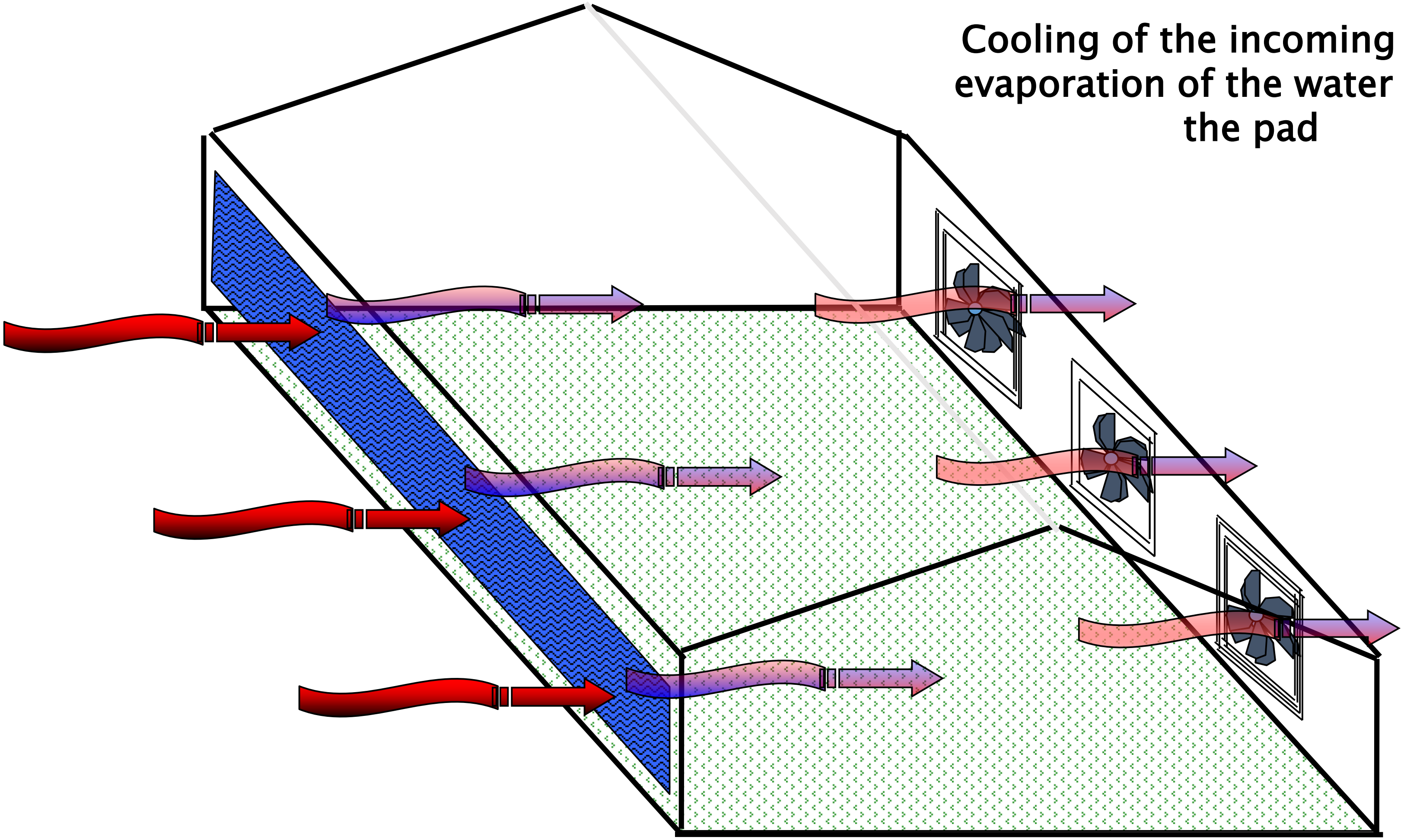


Side & Roof



Evaporative Cooling- Fan and Pad Cooling system

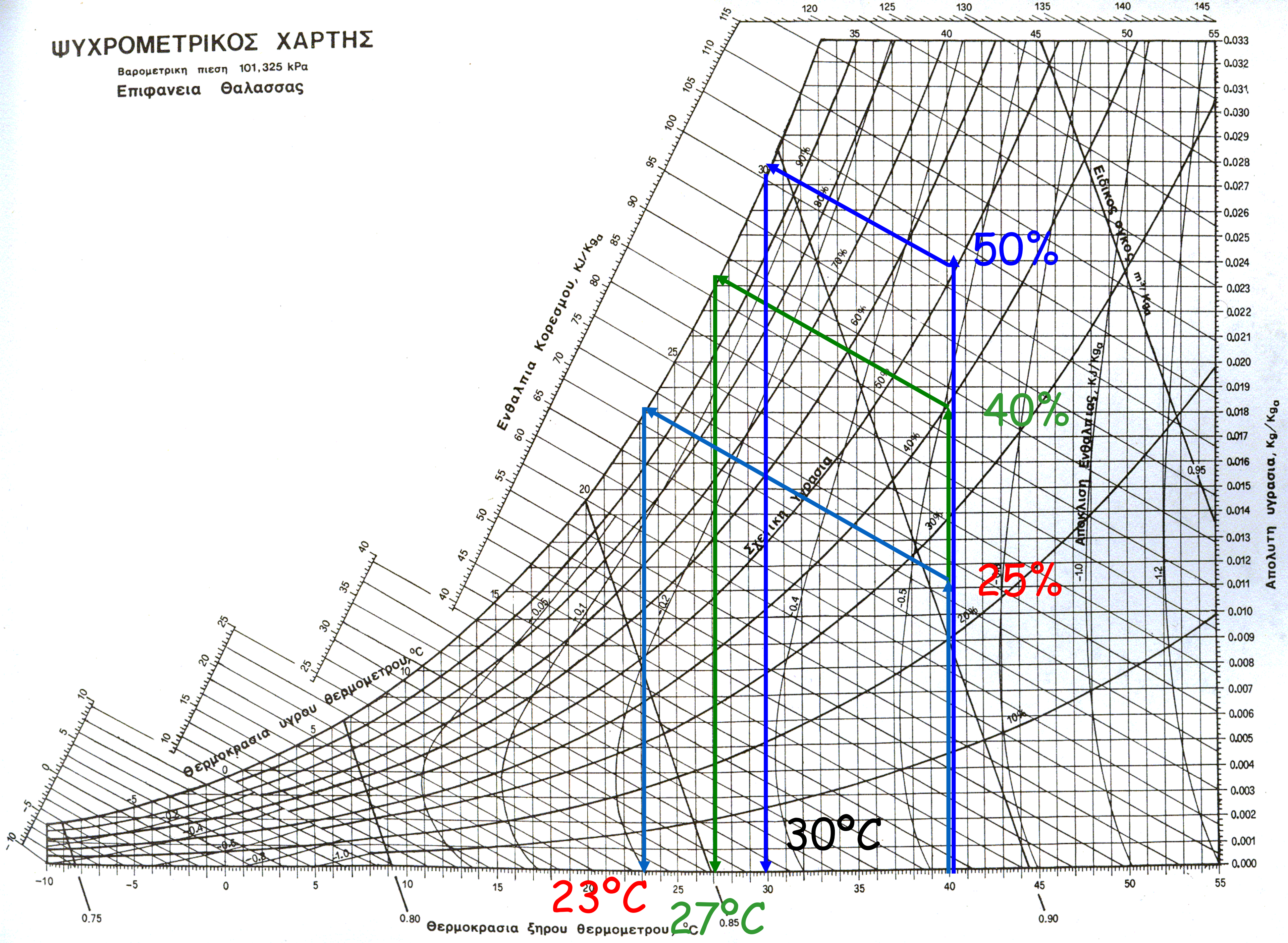
Cooling of the incoming air with evaporation of the water through the pad



Fan and Pad Cooling System

Fan and Pad Cooling System

Fan and Pad Cooling System


ΨΥΧΡΟΜΕΤΡΙΚΟΣ ΧΑΡΤΗΣ
Βαρομετρικη πιεση 101,325 kPa
Επιφανεια Θαλασσας
Ενθαλπια Κορεσμου, KJ/Kga
Θερμοκρασια υγρου θερμομετρου, °C
Θερμοκρασια ξηρου θερμομετρου, °C
Σχετικη υγρασια
Ειδικος ογκος m³/Kga
Αποκλιση Ενθαλπιας, KJ/Kga
Απολυτη υγρασια, Kg/Kga
50%
40%
25%
30°C
23°C
27°C

Fogging - Misting

- **Low pressure systems**

(working pressure 5 bars)

Water droplets diameter >200μm.

- **High pressure systems**

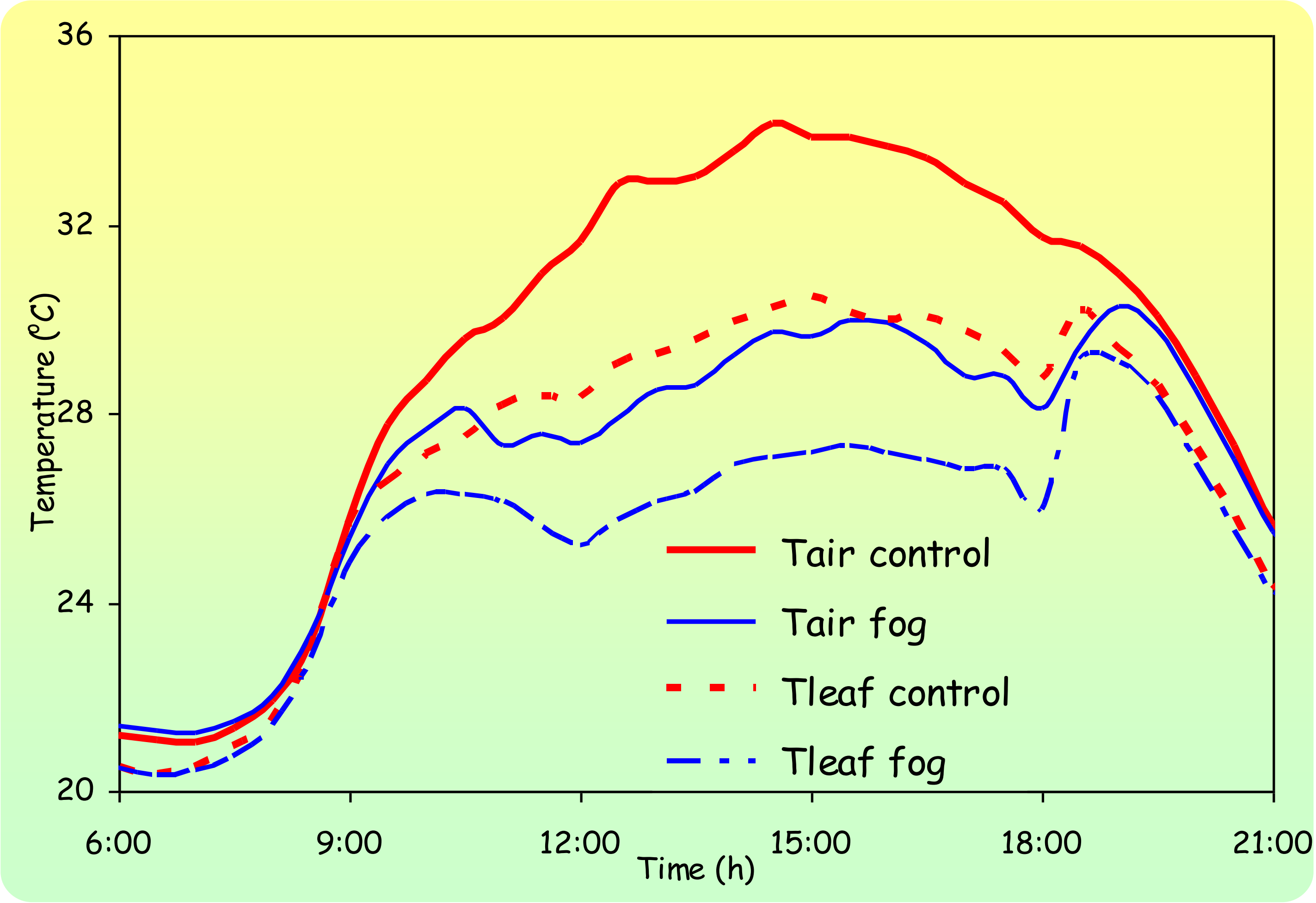
(working pressure 60 bars)

Water droplets diameter 10-30 μm.

(A hair has diameter of 40 to 200 μm)

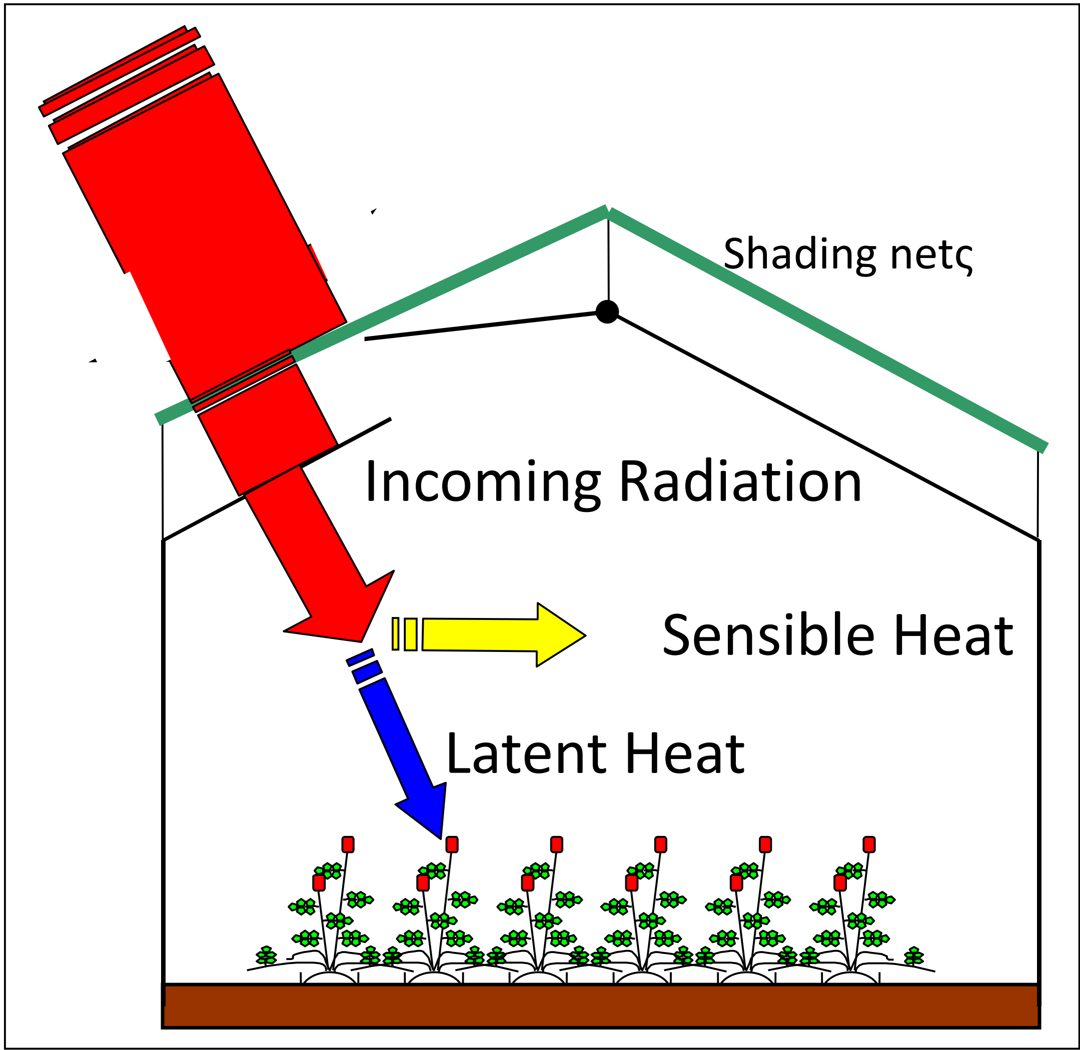
Intelligent climate control / Ventilation-Shading-Cooling

Fog: Effects on air and leaf temperature



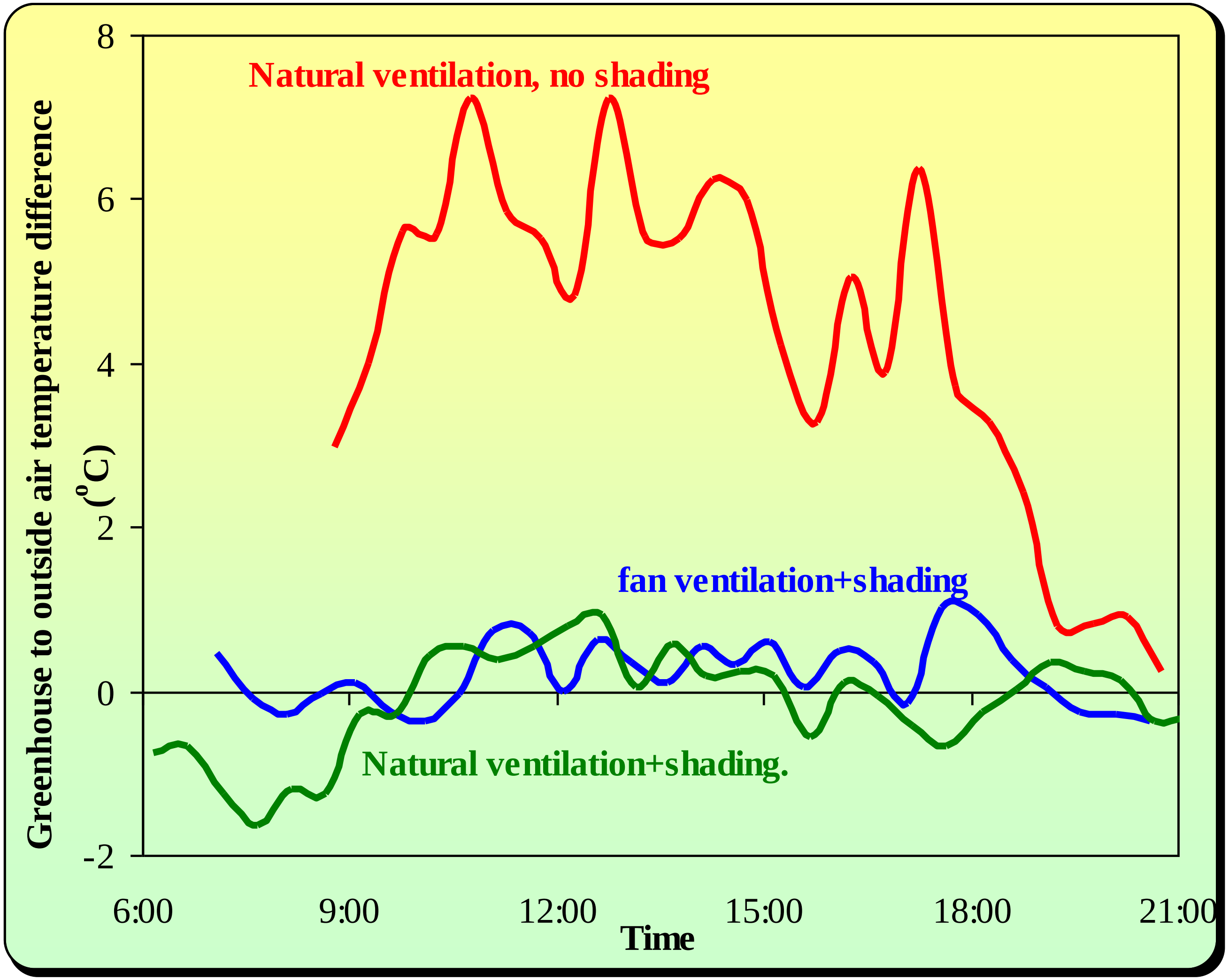
Shading

- Shading with withening
- Shading with internal or external nets- sxreens



Efficiency of Ventilation-Shading-Cooling

Ventilation and shading- effects on air temperature

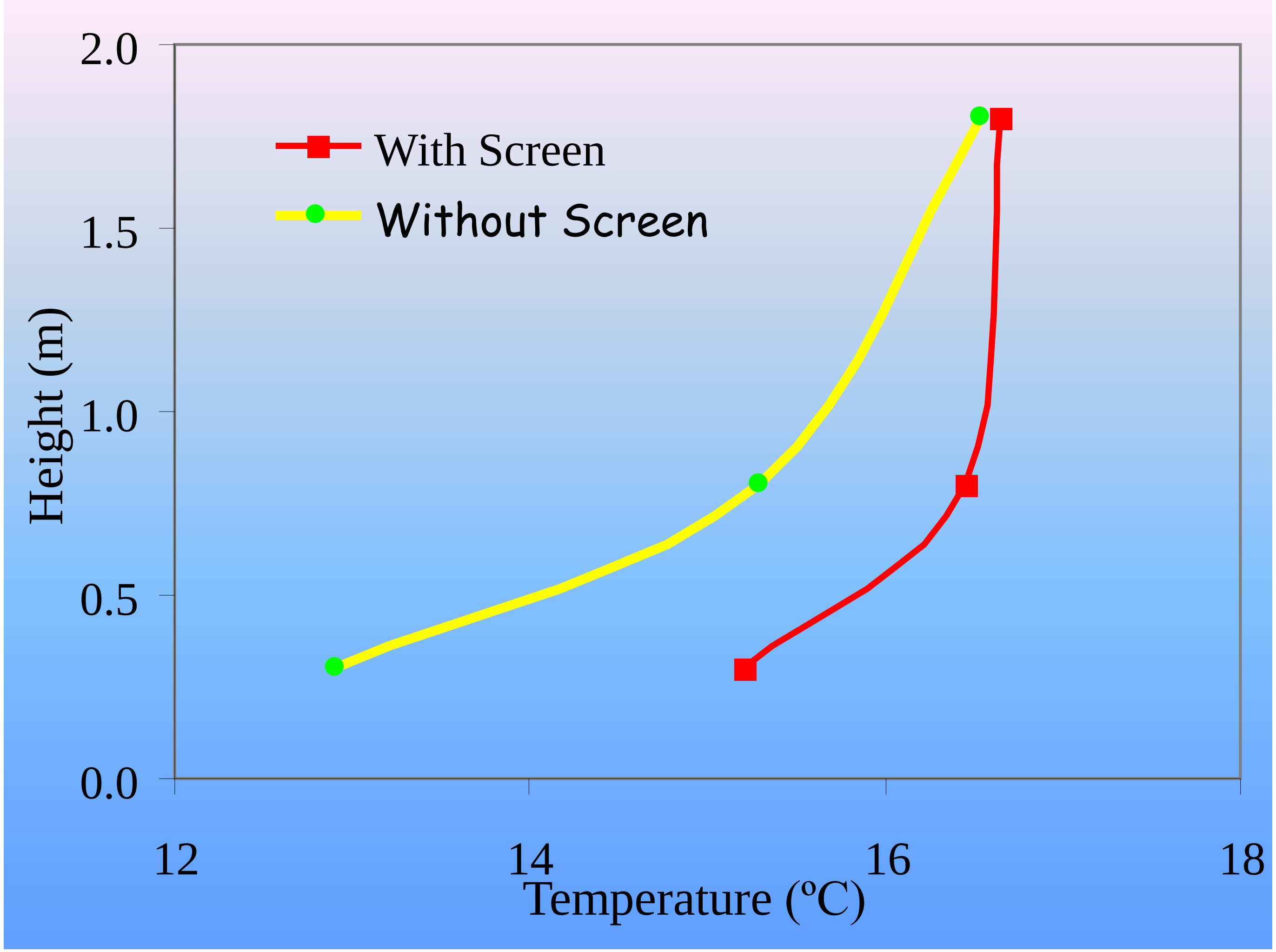


Greenhouse / Sustainability issues

Energy saving - RES


Thermal screen for energy saving

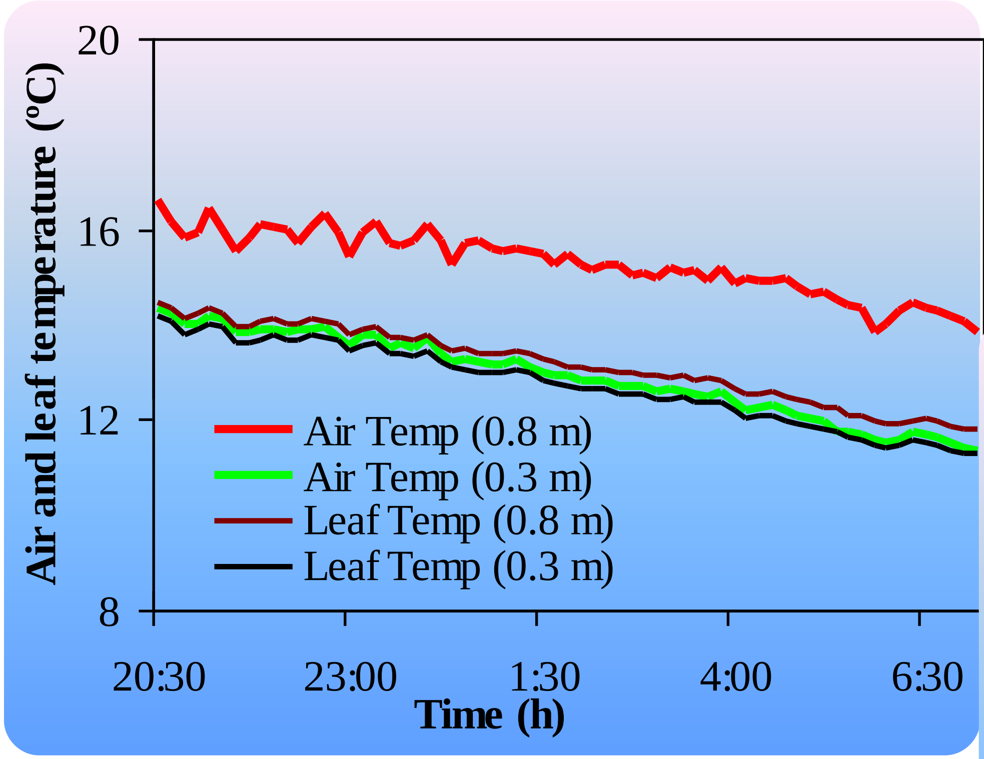
Vertical Temperature Profile



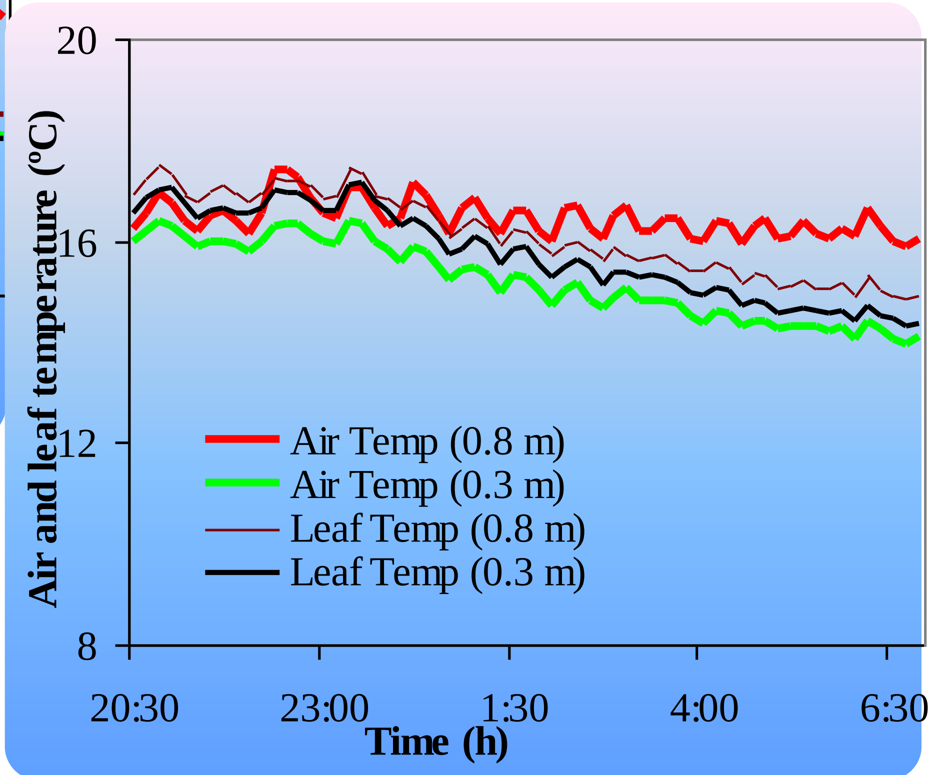
Kittas et al., 2003

Influence of thermal screen on crop temperature

Without thermal screens



With thermal screen



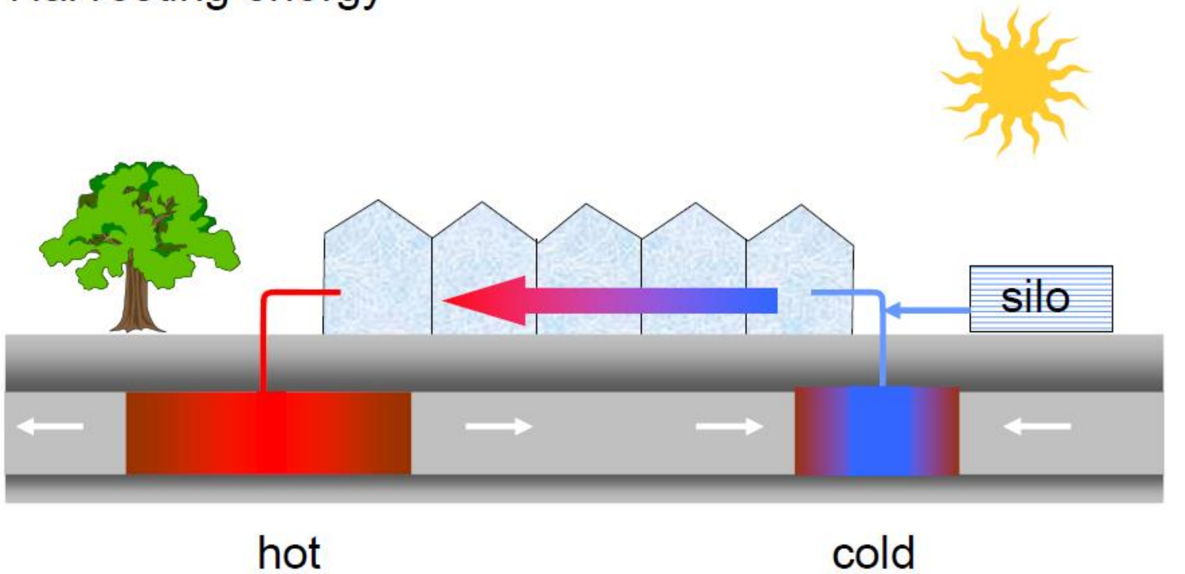
Passive solar system

Use of renewable energy sources

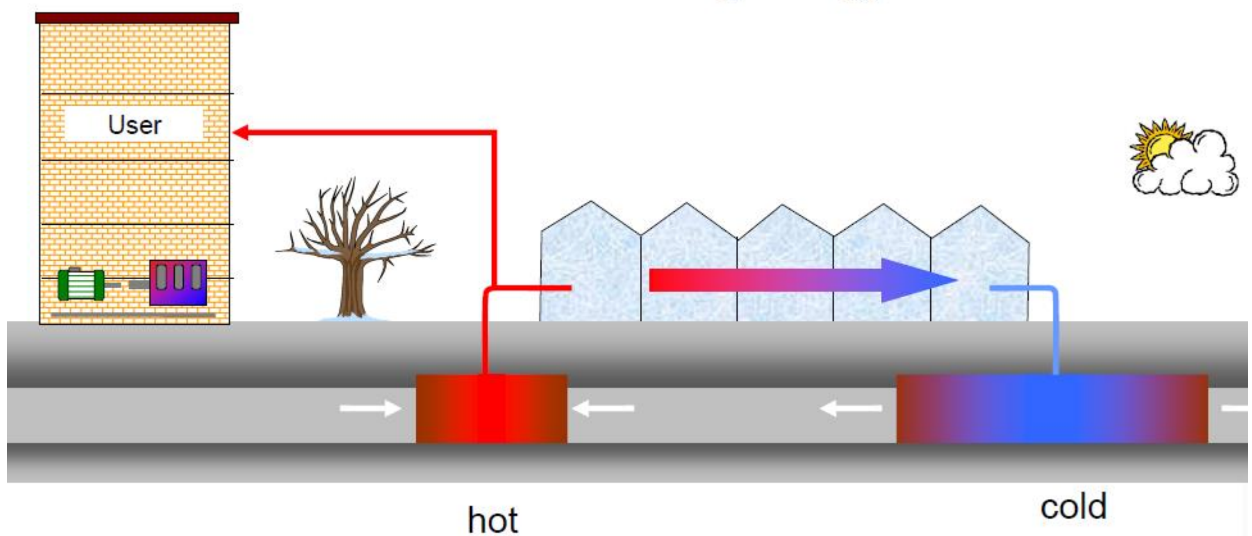
Intelligent Technologies

The Closed greenhouse

Harvesting energy



Re-using energy



Project Budget 2.576.548€ - 50% EC Contribution
Project Duration 01/09/2010 – 31/08/2016

LIFE 09 ENV/GR/000296

Adapt2change

“Adapt agricultural production to climate change and limited water supply”

adapt2change

Τ.Ε.Ι. ΘΕΣΣΑΛΙΑΣ

ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

Τ.Ε.Ι. ΠΕΙΡΑΙΑ
ΤΕΧΝΟΛΟΓΙΚΟ ΕΚΠΑΙΔΕΥΤΙΚΟ ΙΔΡΥΜΑ ΠΕΙΡΑΙΑ

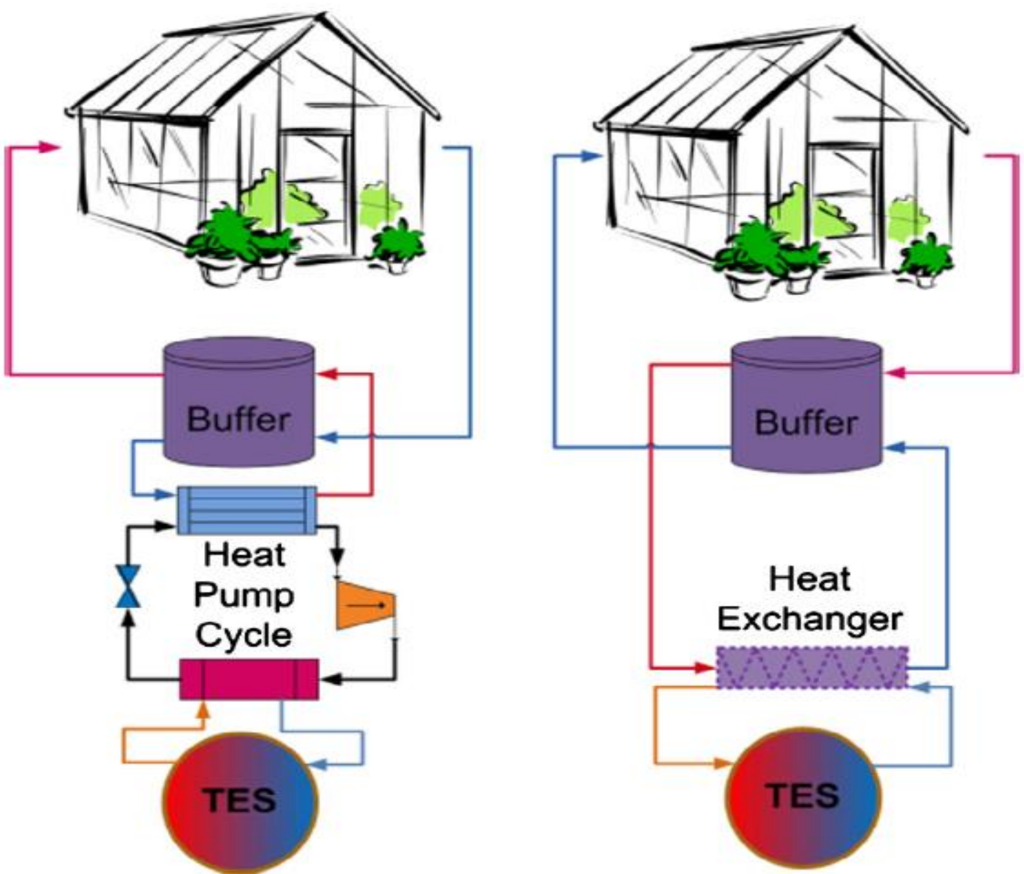
icon GROUP
ΟΜΙΛΟΣ ΤΕΧΝΙΚΩΝ ΕΤΑΙΡΙΩΝ

ΕΥΡΩΠΛΗΡΟΦΟΡΗΣΗ Α.Ε.
Κέντρο Επαγγελματικής Κατάρτισης

Heating - Cooling

During winter the heat pump harvests energy from a thermal energy storage tank (e.g. soil or water) and upgrades this energy to fill the buffer needed for greenhouse heati

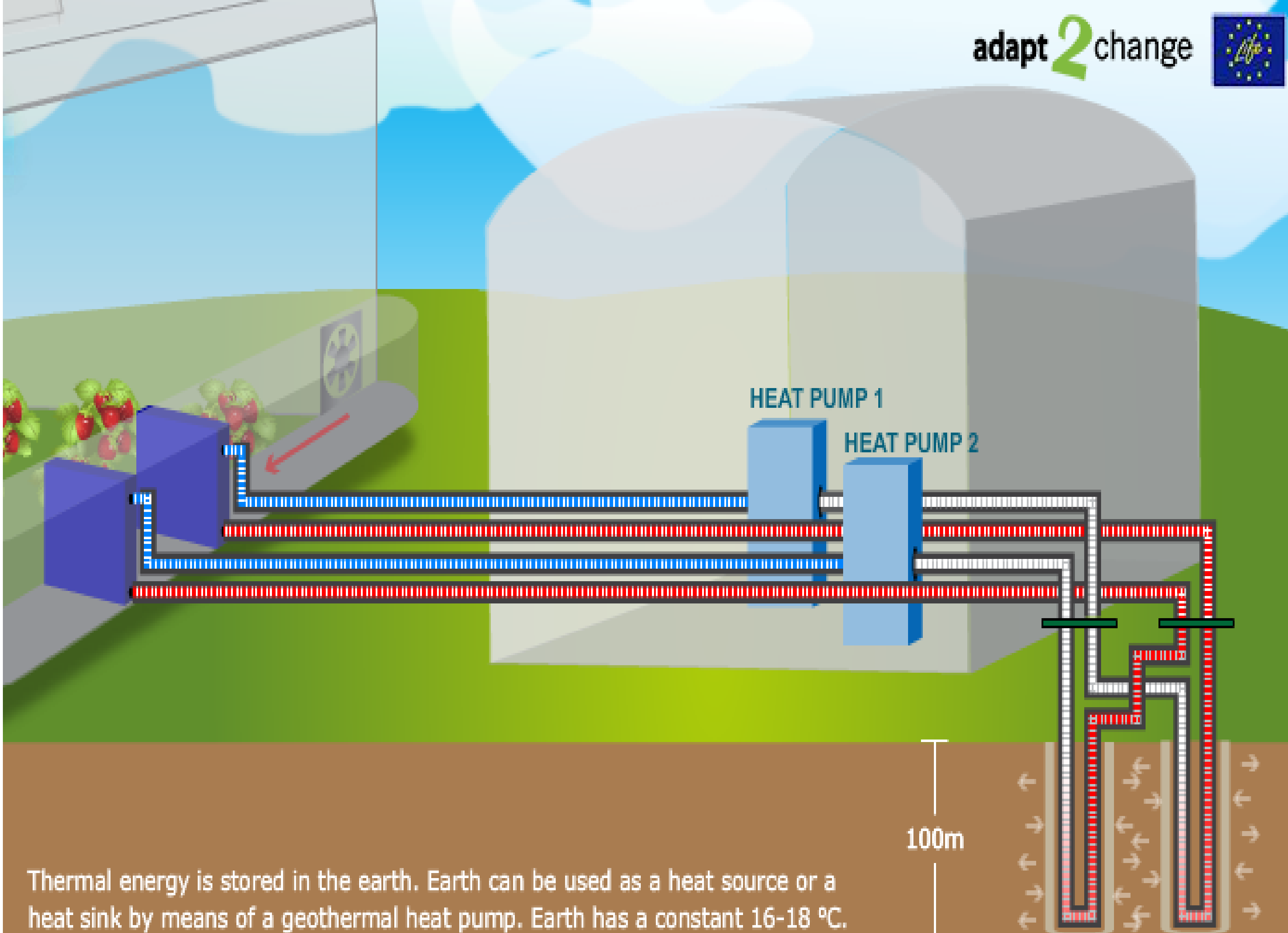
During hot period the heat exchanger is used to harvest the energy from the greenhouse air for cooling and store this energy to the thermal energy storage to be used latter on for heating.



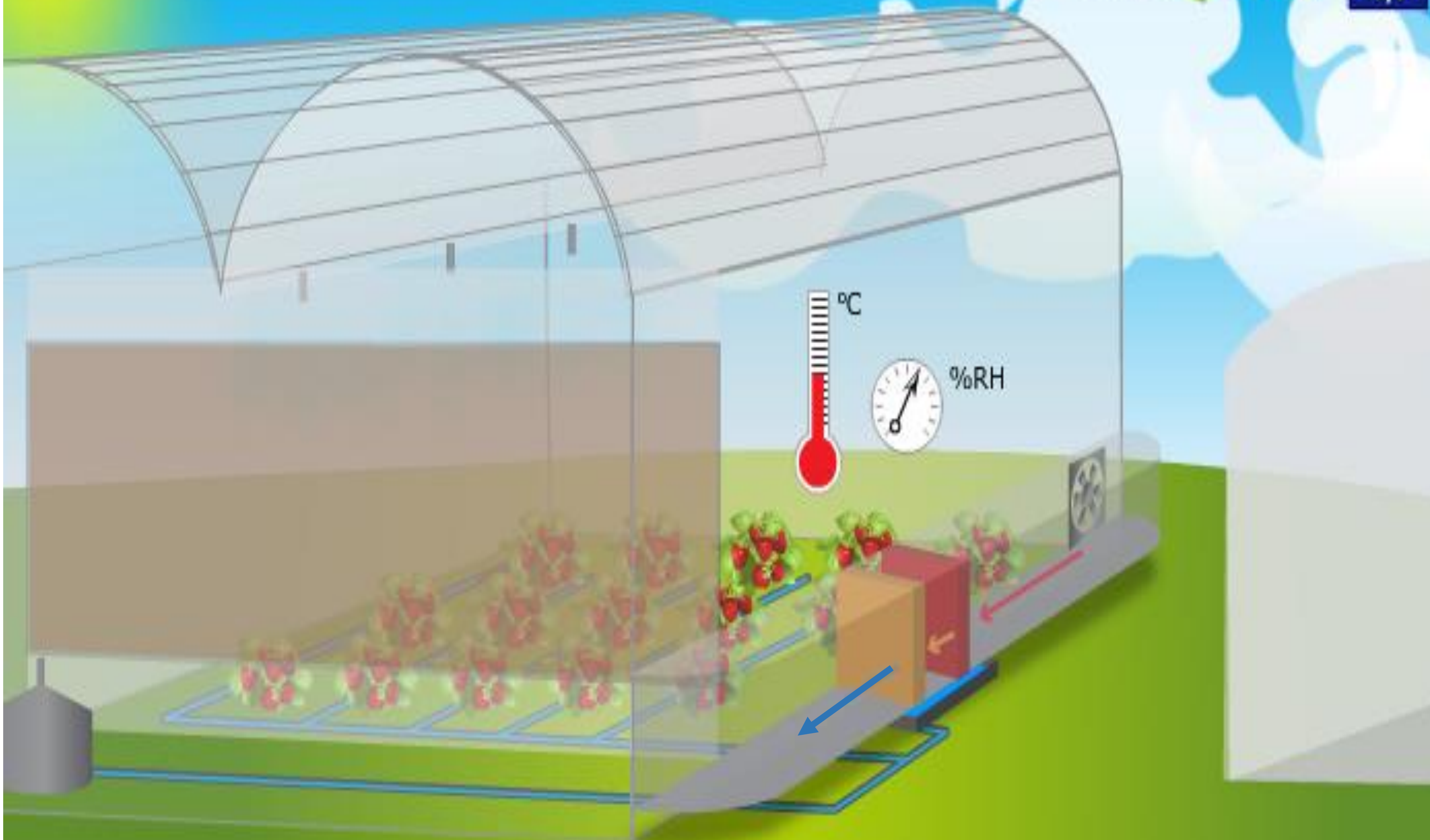
Closed Greenhouse Concept
Shallow Geothermal Energy

Humid air allows storing more thermal energy at a given temperature, because of the use of latent heat in addition to the sensible heat. In conventional GH humid air is released to the environment.

BACK NEXT



Thermal energy is stored in the earth. Earth can be used as a heat source or a heat sink by means of a geothermal heat pump. Earth has a constant 16-18 °C. Heat pumps transfer heat from the greenhouse through dehydration, to the earth as a "heat sink".



Cooling of humid air creates condensation, releasing thermal energy and distilled water.
Distilled water is stored and reused in GH operations.

adapt 2 change

adapt2change

Heat Exchangers

adapt2change

adapt2change

Heat Pumps

adapt2change

Effect of closed greenhouse

The use of the closed greenhouse may result to:

- Increase of production up to 25% due to the positive effect of CO_2 enrichment
- Reduce energy consumption up to 35%
- Reduce consumption (50%) and increase water use efficiency up to 75%
- Reduce pesticides use up to 80%

Greenhouse / Sustainability issues

IPM technologies / systems

Insect Screens

Screens reduce insect migration and crop damage, thus

reduce the need for pesticide application and so they protect the environment

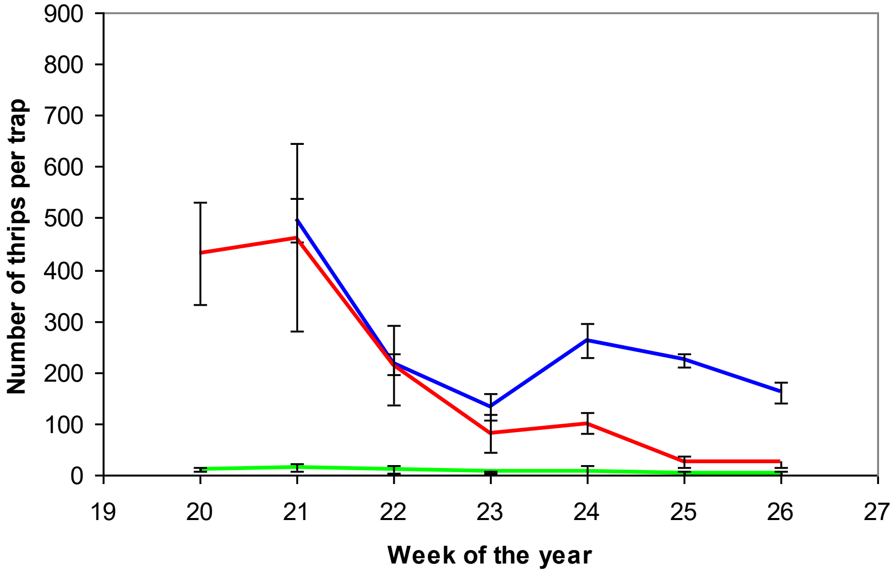
⇕

Screens acting as an extra barrier to airflow they impede ventilation and thus they influence internal greenhouse microclimate

Insect proof Screens

Screen for the protection against insects. However we need larger openings

Distribution of species of thrips (May to July)

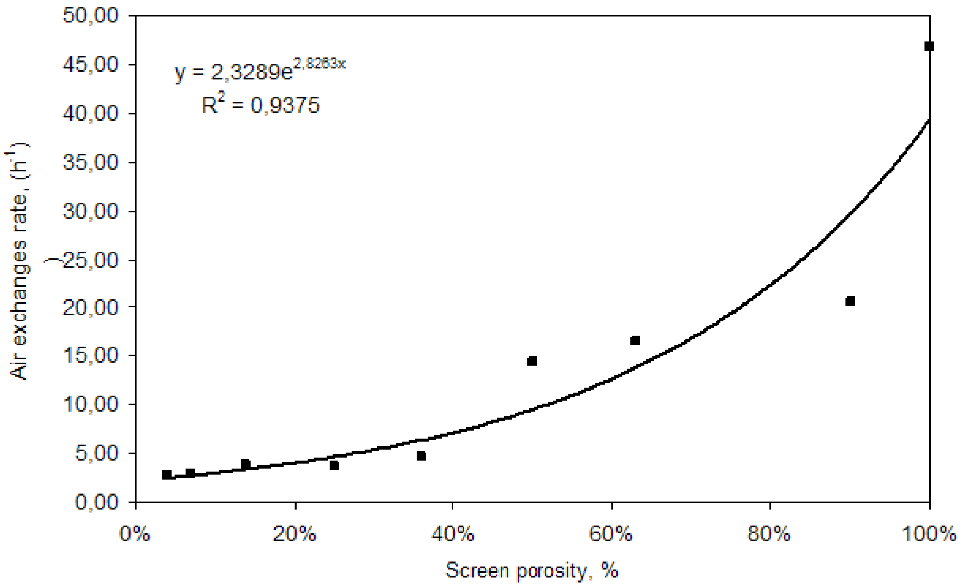


Outside environment

Greenhouse without screen

Greenhouse with screen

Correlation between screen porosity and ventilation rate

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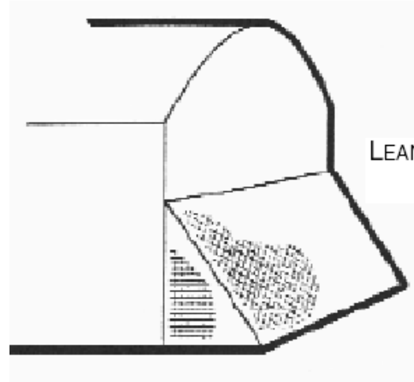
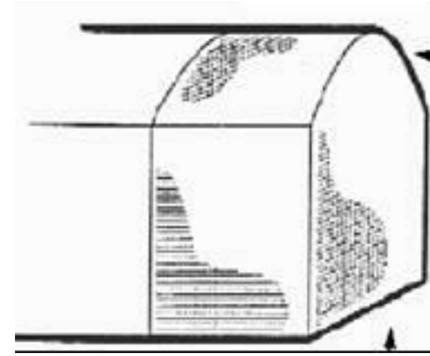
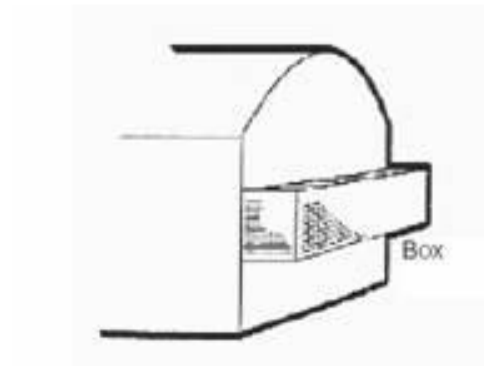

LEAN

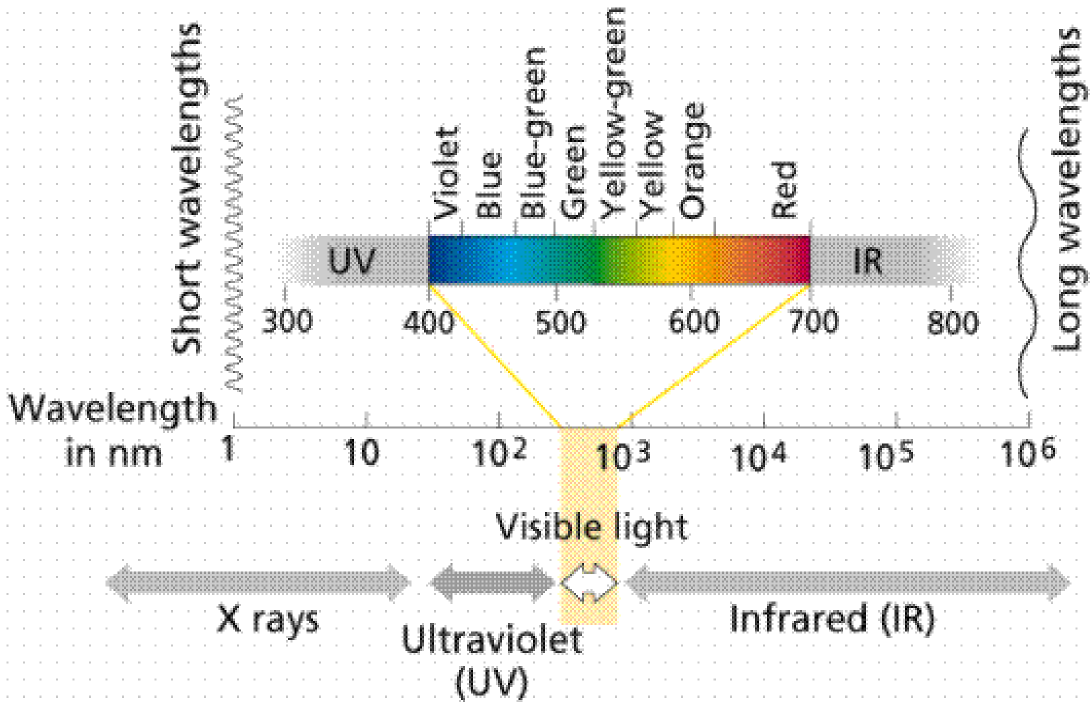


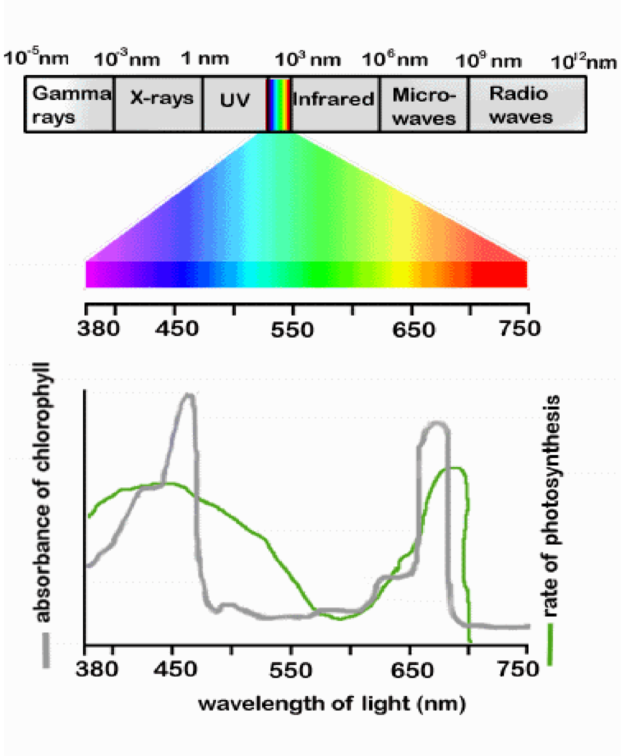

BOX

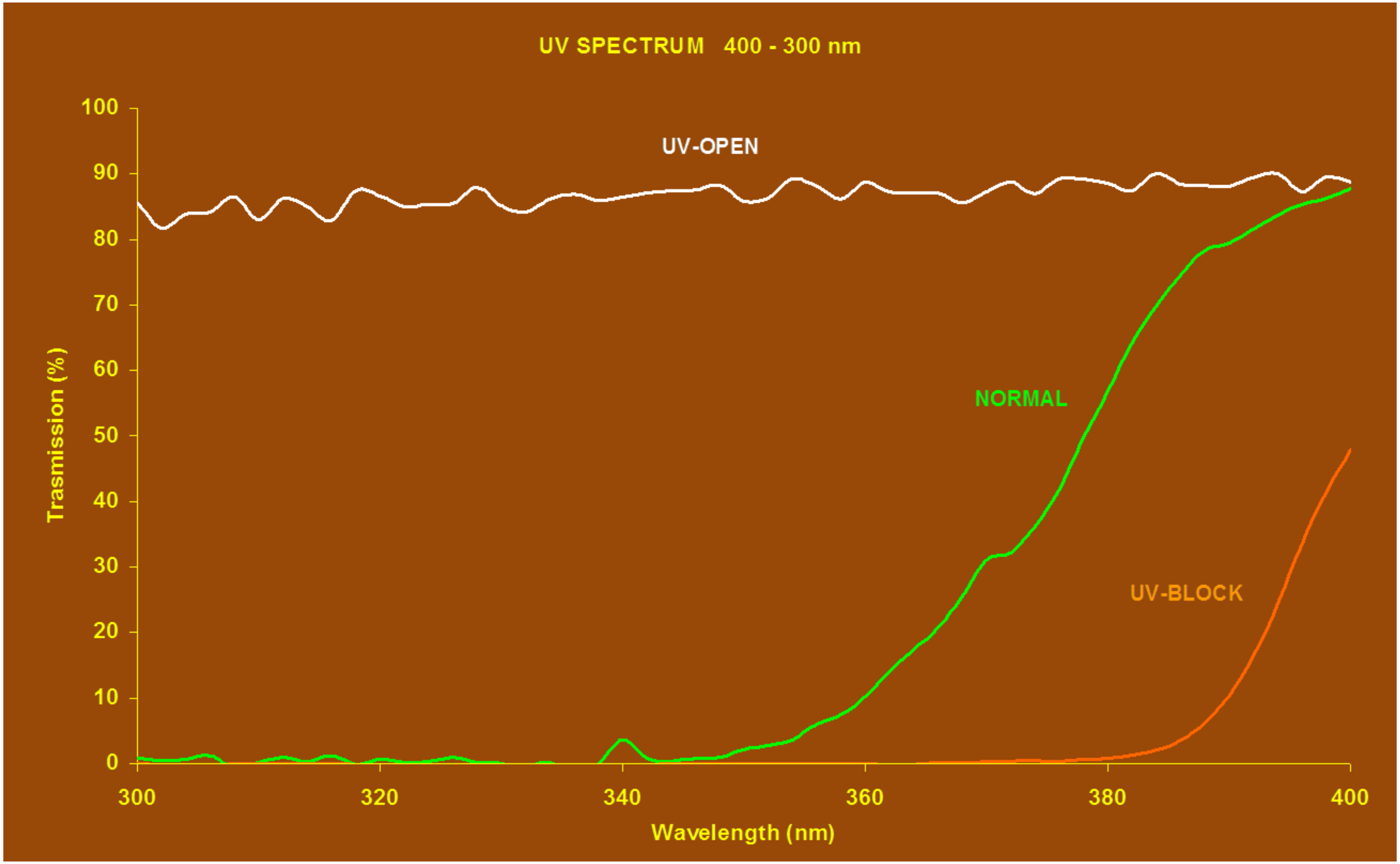
Integrated crop production / no pesticides

Use of photo selective covering materials

UV-absorbing cover materials started to spread recently after the observation that in greenhouses covered with those films, a reduction of insect populations and fungi diseases was obtained.



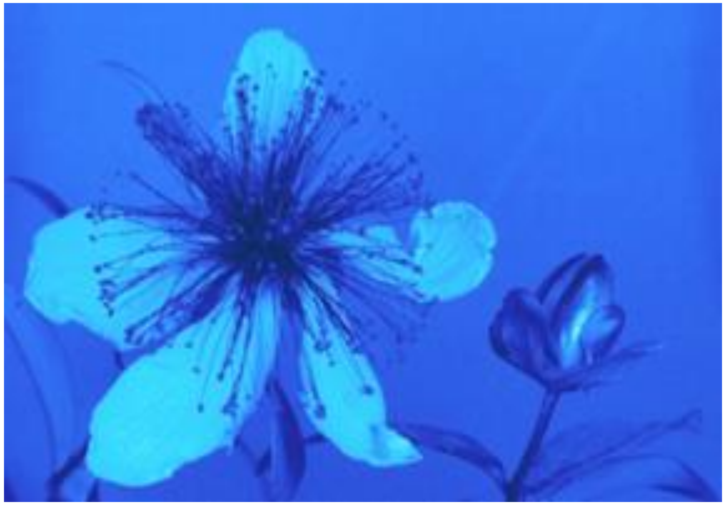




UV SPECTRUM 400 - 300 nm
UV-OPEN
NORMAL
UV-BLOCK
Trasmission (%)
Wavelength (nm)
100
90
80
70
60
50
40
30
20
10
0
300
320
340
360
380
400

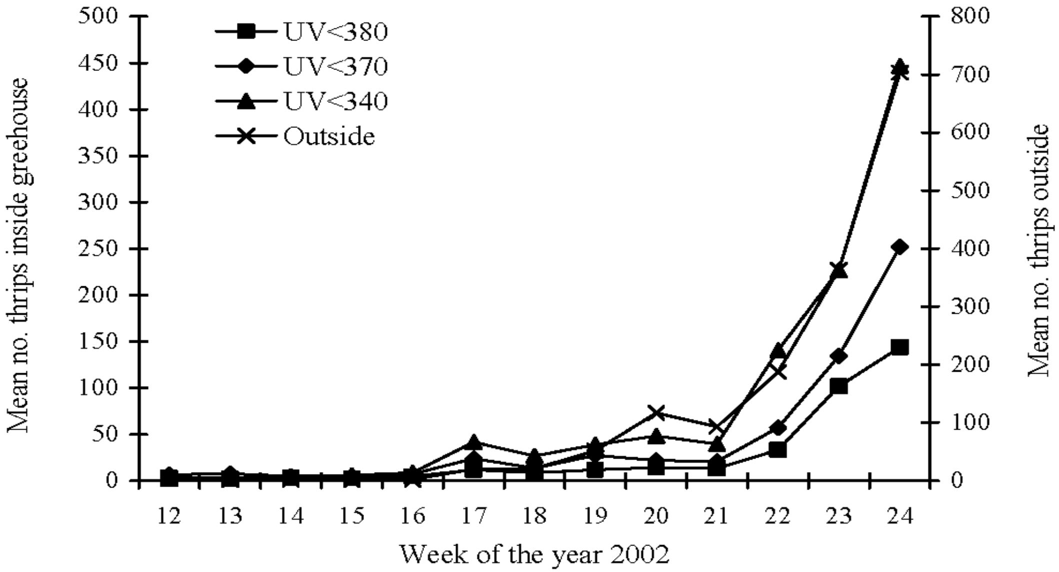
UV covering materials

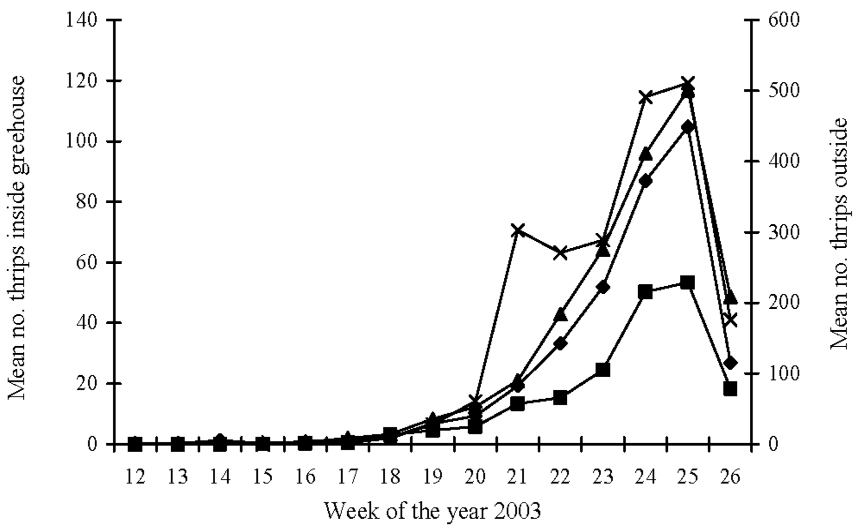
Covering materials with UV-absorbent (< 380 nm) can significantly reduce insects population

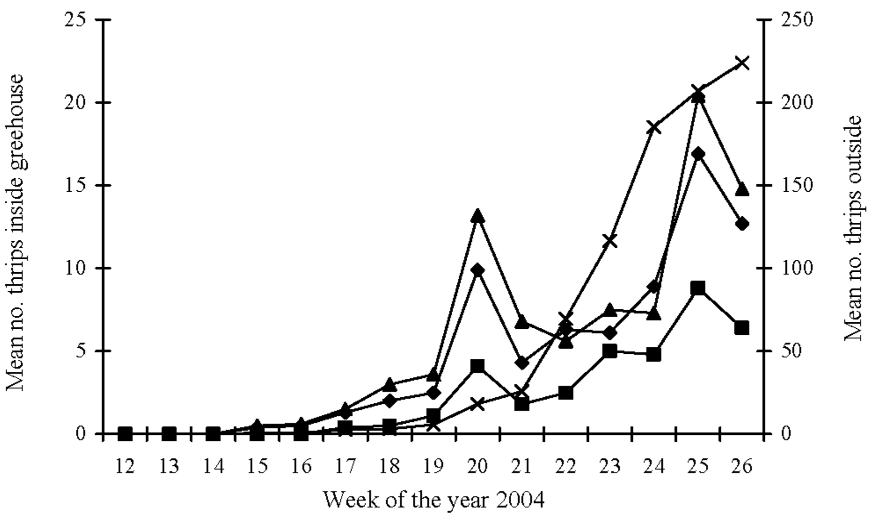


Hypericum calycinum
Thomas Eisner Cornell University

Number of thrips per sticky trap in greenhouses covered with plastics that blocked the entrance of UV light

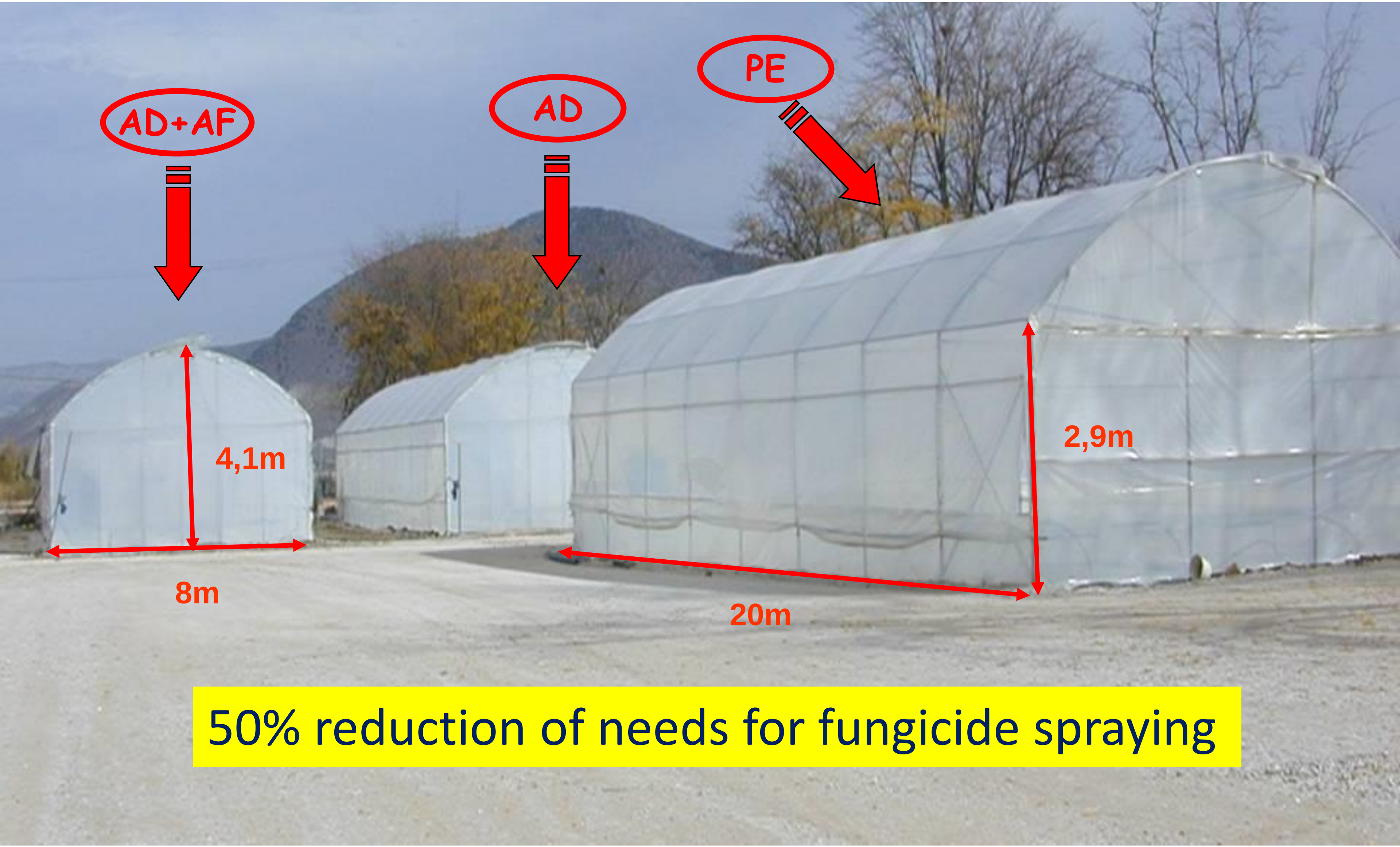




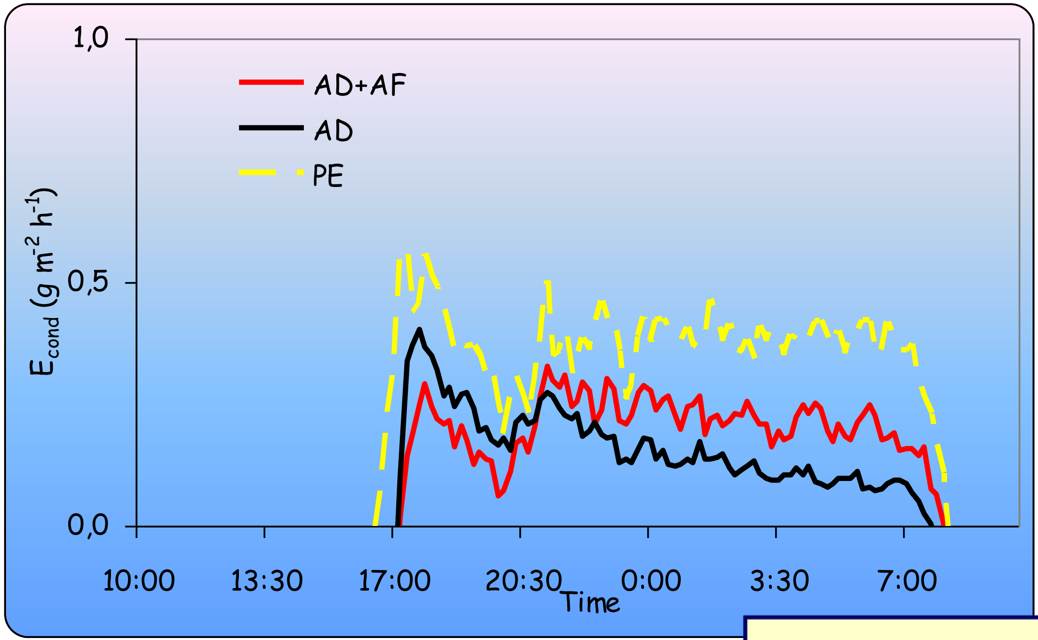



"ΘΕΡΜΟΛΟΥΞ" PLASTIKA KRITIS SA

Anti drop / fog covering materials



50% reduction of needs for fungicide spraying



But under the new material we used 50% less fongicides

Crop production

Greenhouse	Total fruit production kg/plant	Total number of fruits per plant	Mean fruit weight (g)
AD+AF	2.8a	10.1a	374a
AD	2.4a	9.2a	345a
PE	2.6a	10.3a	358a

Greenhouse / Sustainability issues

Water / hydroponic systems

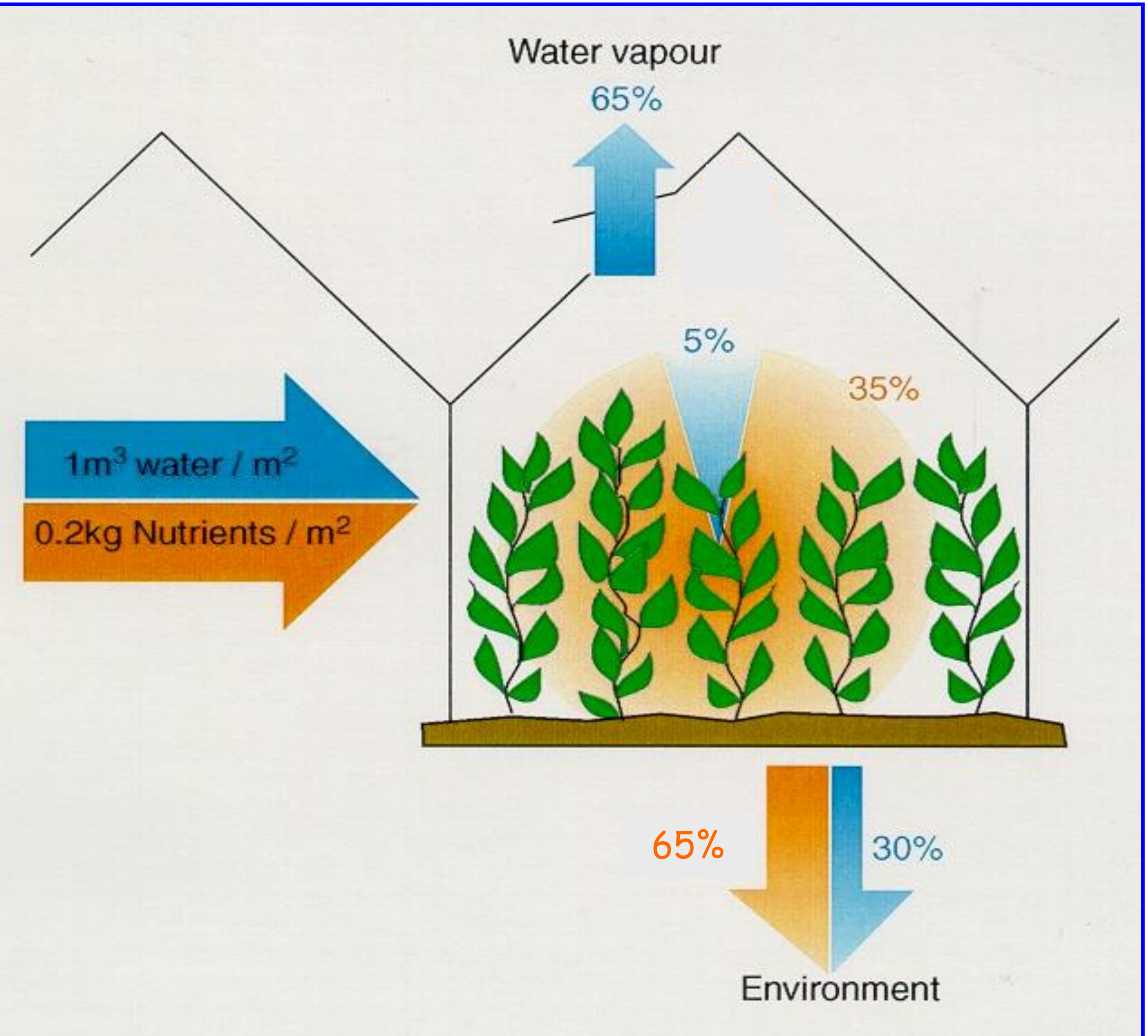
High inputs in water and fertilizers

325 kg N
220 kg P,
550 kg Ka and
4.500 lt of water

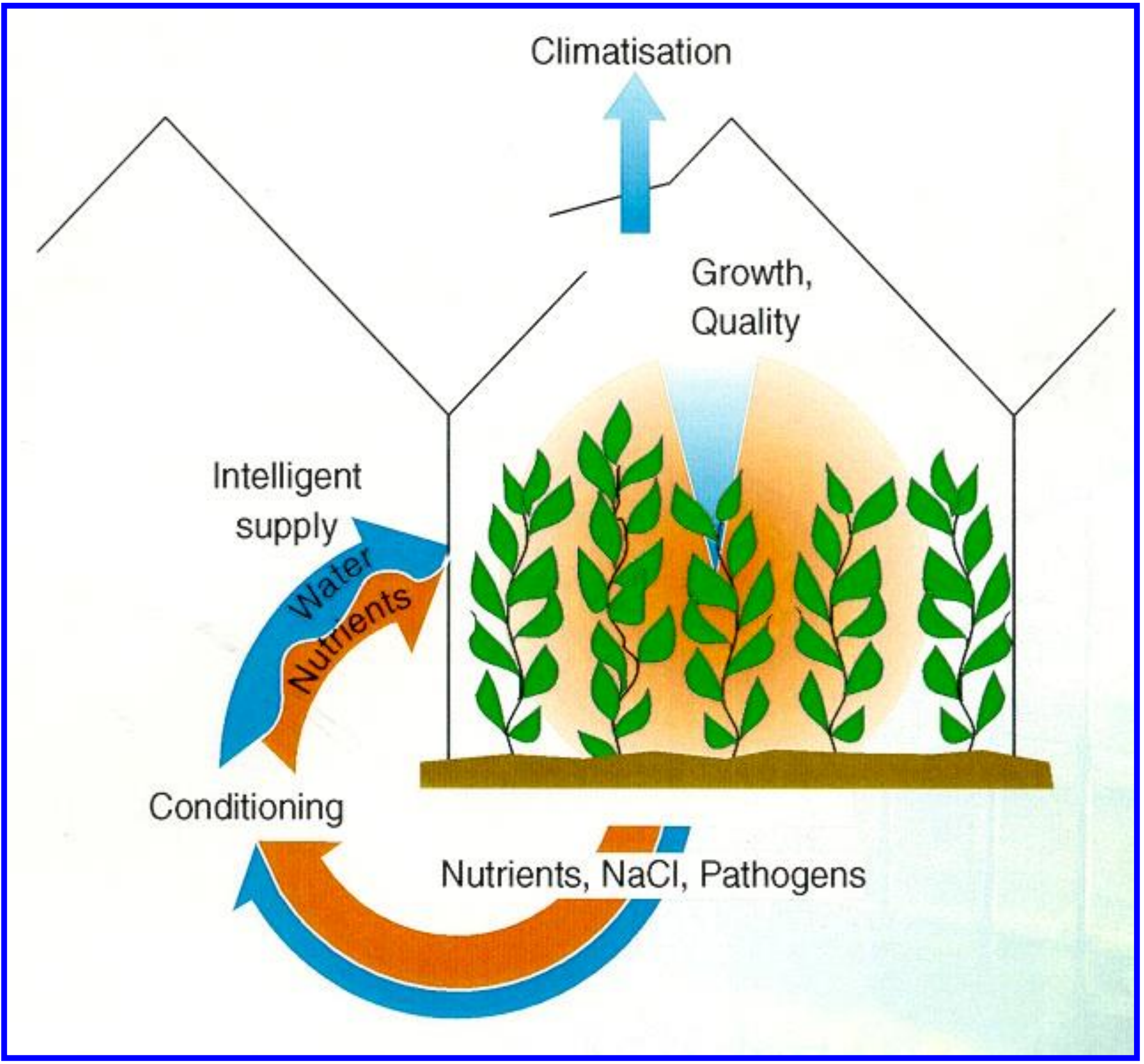
are yearly consumed per ha in Mediterranean greenhouses

Solutions

- Rational use of water
- Hydroponics



Water vapour
65%
5%
35%
1m³ water / m²
0.2kg Nutrients / m²
65%
30%
Environment



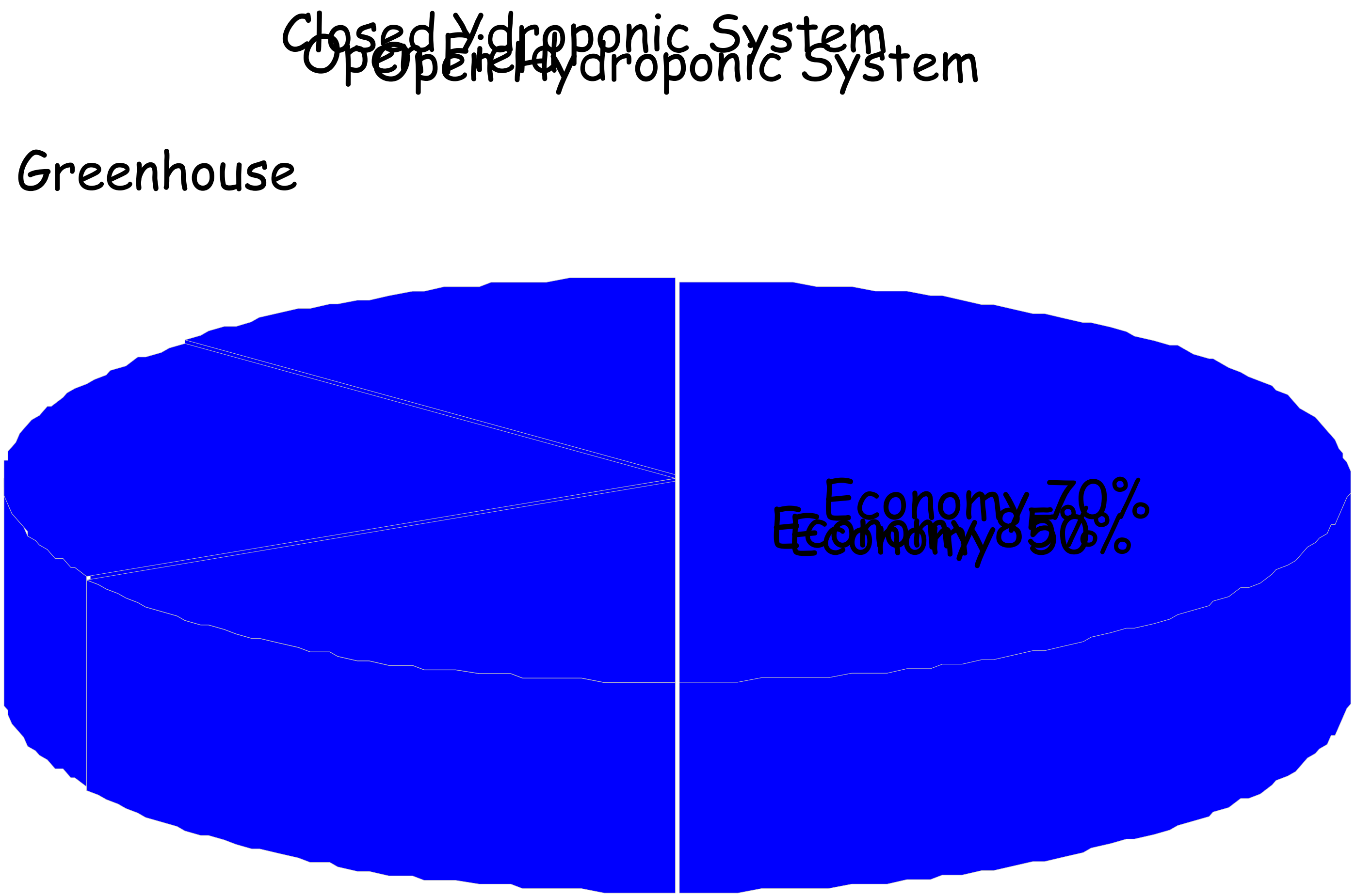
Goal:

Reduction of water ant nutrient losses with simultaneous increase of production. Therefore, an increase of Water Use Efficiency (kg/m^3) is expected

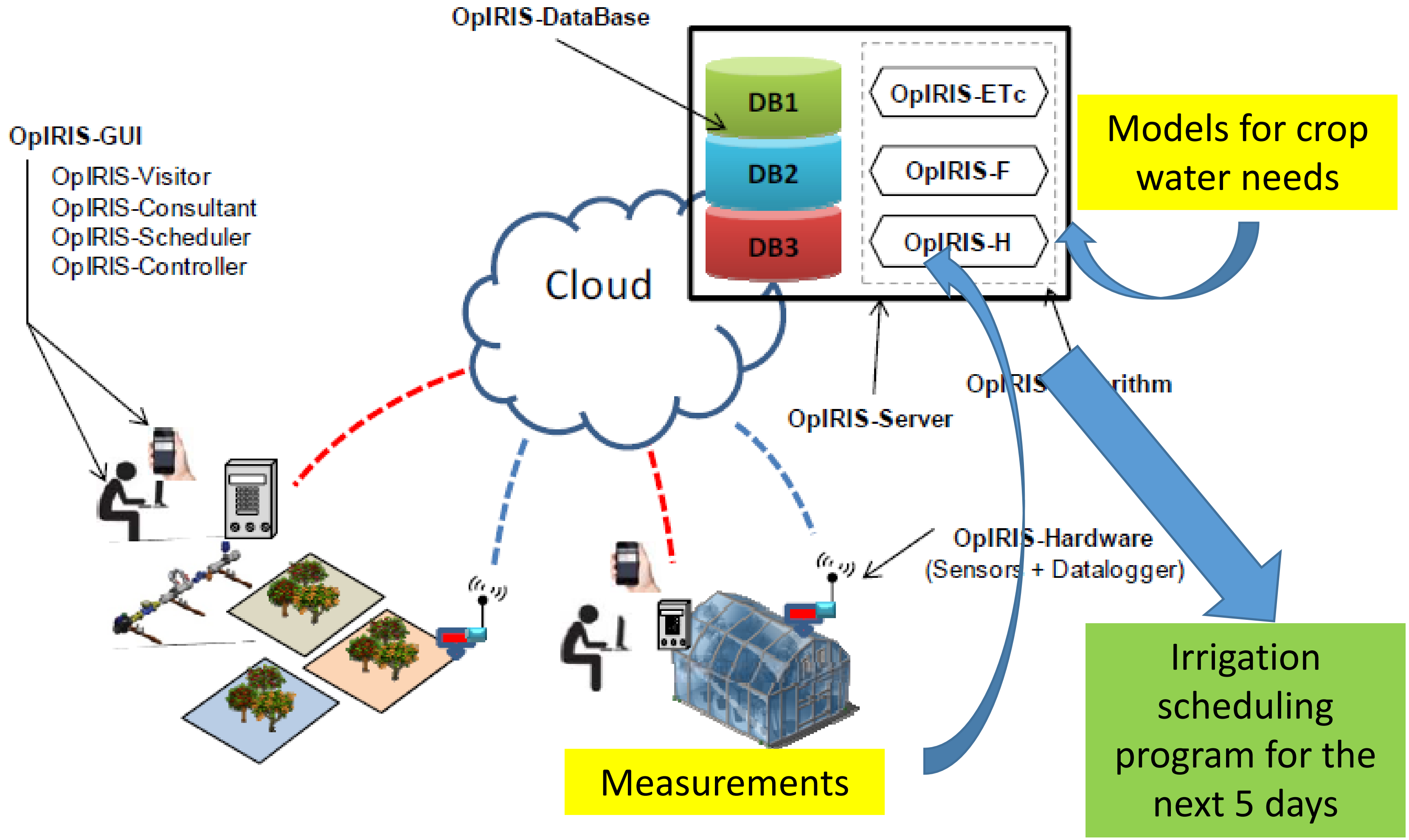
Water use efficiency

Growing conditions	Country	WUE (kg/m^3)
Open field	Israel (soil)	17
	France (soil)	14
Non-heated greenhouse	Spain (soil)	25
	France (soil)	24
	Israel (soil)	33
Heated greenhouse / hydroponic crop	France (open)	39
	Netherlands (open)	45
	Netherlands (close)	66

Water Saving



Intelligent climate control – Water management-



Greenhouse irrigation scheduling management system

Greenhouse / Sustainability issues

Climate control

Greenhouse climate control

Conventional climate control → Air temperature and humidity only measured at a single point in the middle of the greenhouse

The current trend of greenhouse crop management towards a tighter control of inputs and outputs implies:

...A more Intelligent greenhouse climate control

- characterising intra-greenhouse climate distribution
- using crop-based information
- enhanced analysis, interpretation and valorisation of the collected data.

In sensors we have to move from the traditional strategy of monitoring one variable in the center of the greenhouse and monitor as much variables in as many points we can

Greensense

Wireless System **Non Destructive Crop Status Measurements**

OpiRis

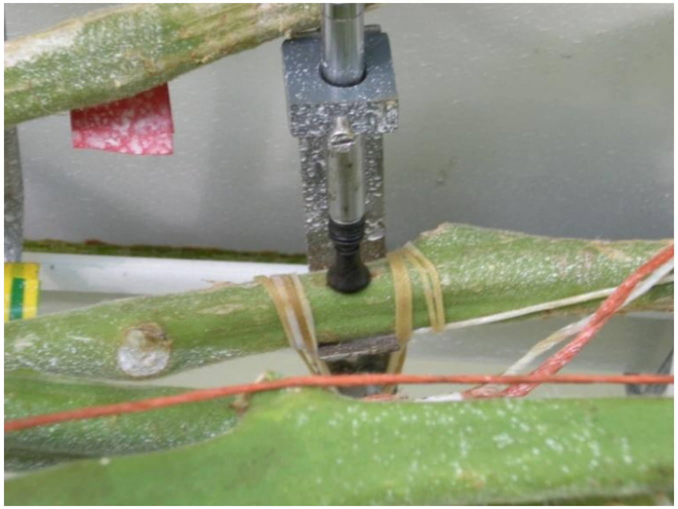
Smart Irrigation Management

Sensors for climate variables

Sensors for crop growth and development

Sapflow

Stem diameter



Leaf aerodynamic conductance

Leaf temperature

Wirelles Systems

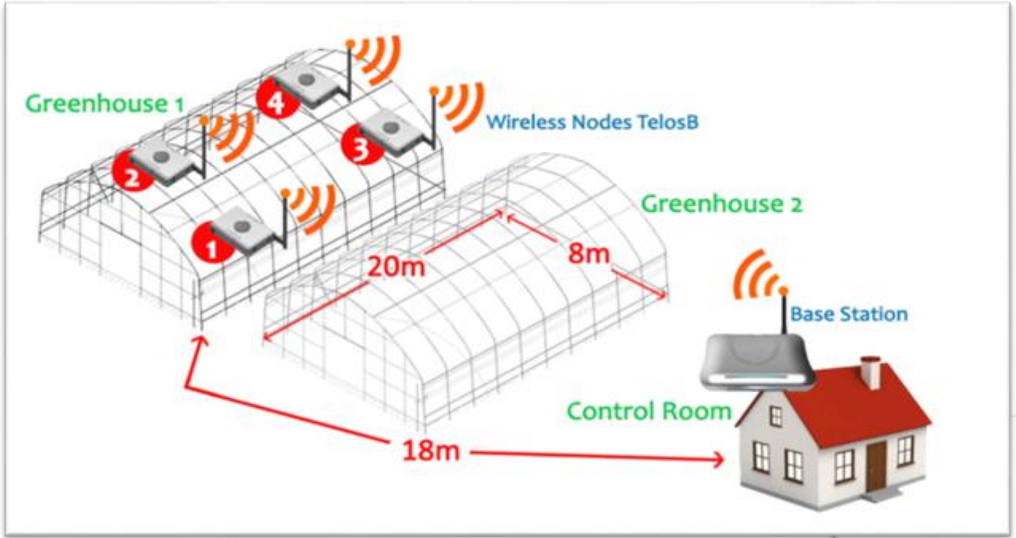
Air temp and relative humidity

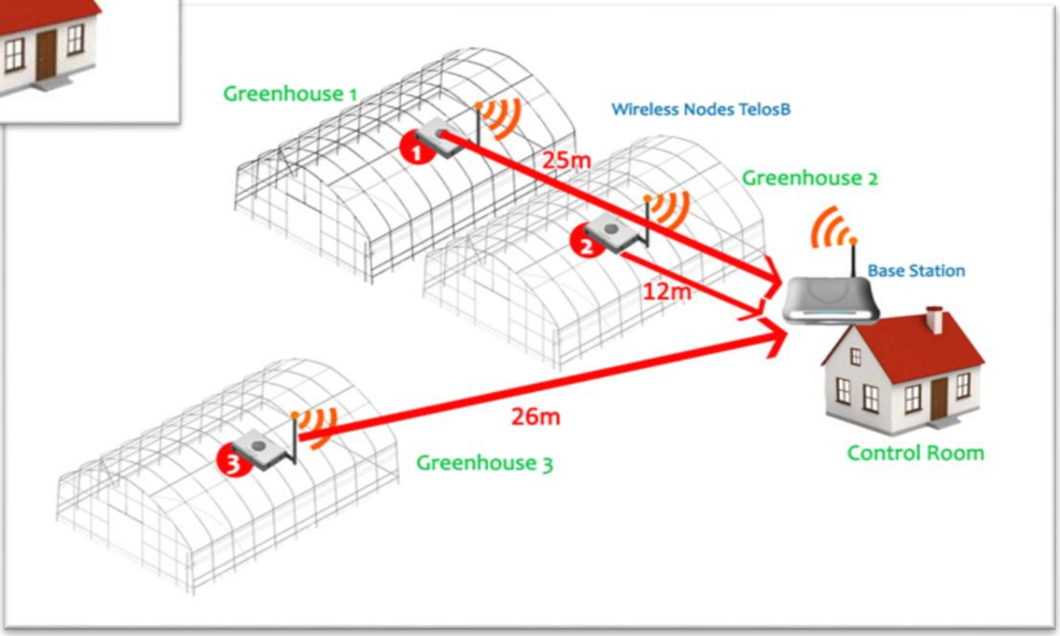
Leaf temperature

Of course in the market there are plenty wireless, but in in our Lab we tried to develop and evaluate our wireless system and adapt these to our needs. Our system is based on measurements of air temperature, air humidity, solar radiation, leaf temperature and gradually we will add air velocity and CO_2 concentration

Wirelles Systems

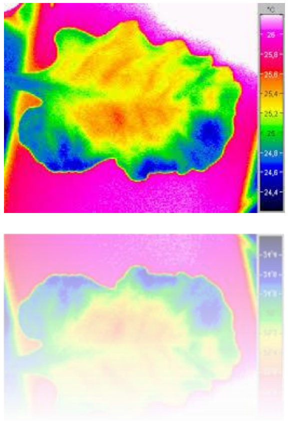
System Deployment

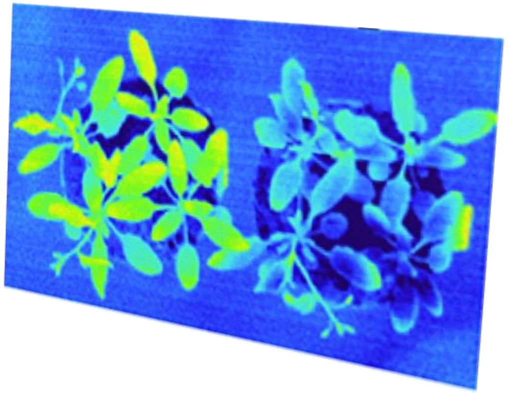




Non destructive measurements

Leaf or Plant temperature sensors



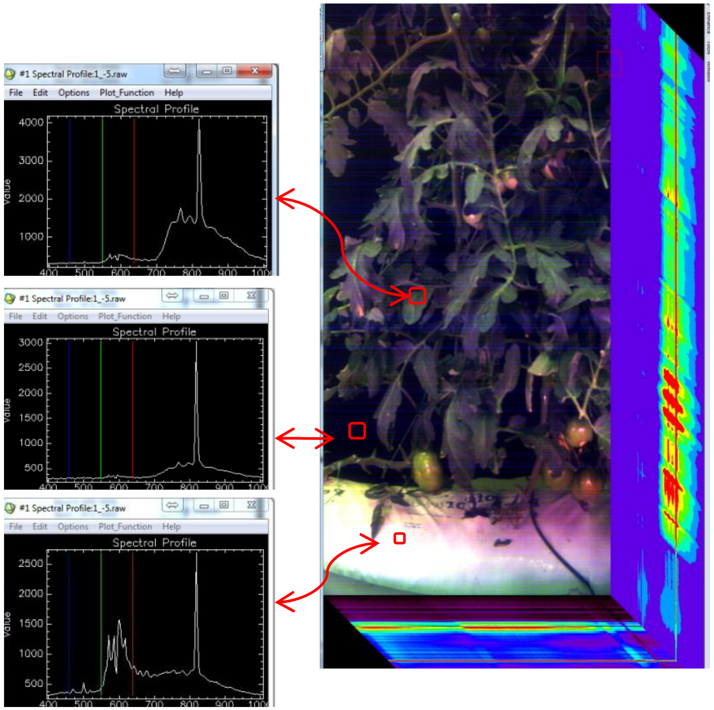


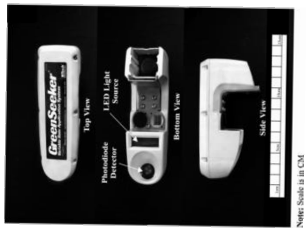
- ❑ Different types of effective leaf or plant temperature sensors can detect plant water stress in real time

- ❑ Basic types:
  - Thermocouples
  - Infrared thermograph (point or optic systems)

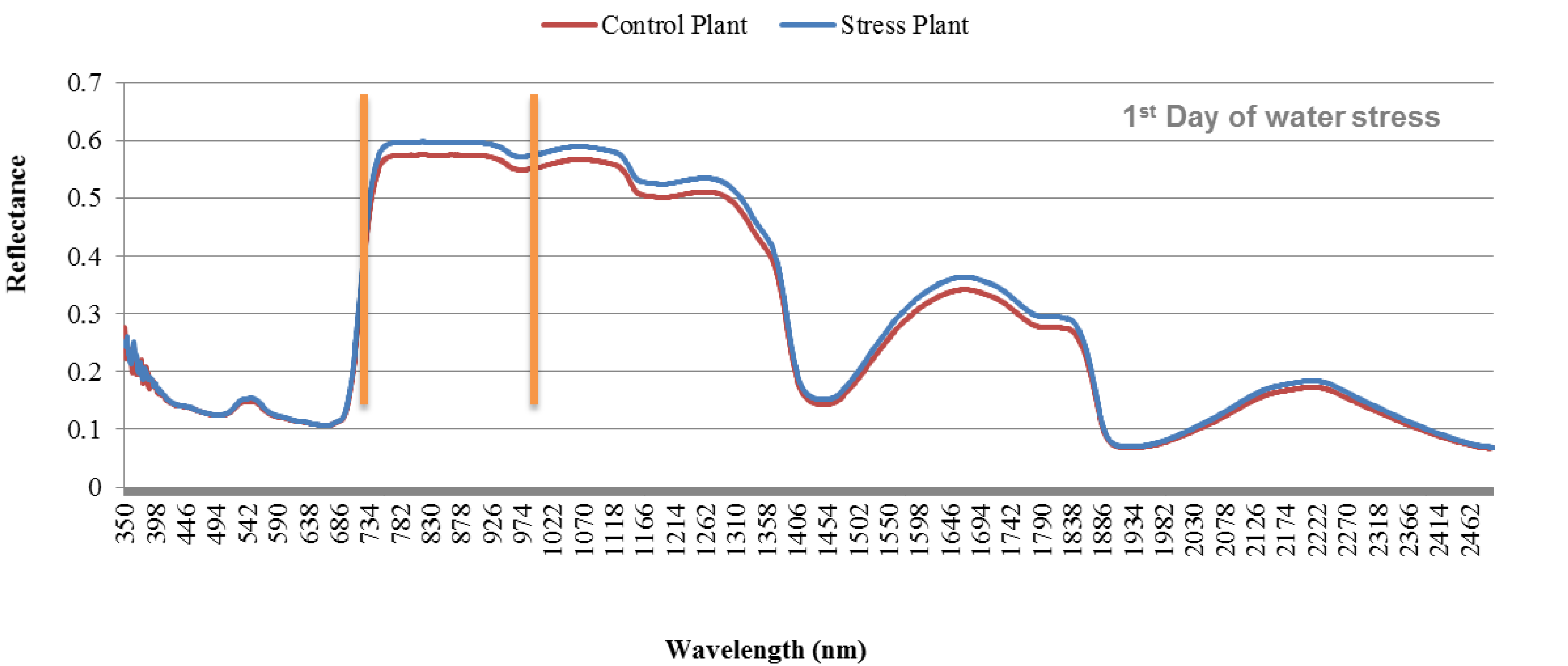
Crop reflectance measurements: Remote sensing

- Different types of sensors and methodologies are used for crop reflectance measurements
- The data obtained need special treatment for index calculations





Radiation reflectance-correlation with crop stress



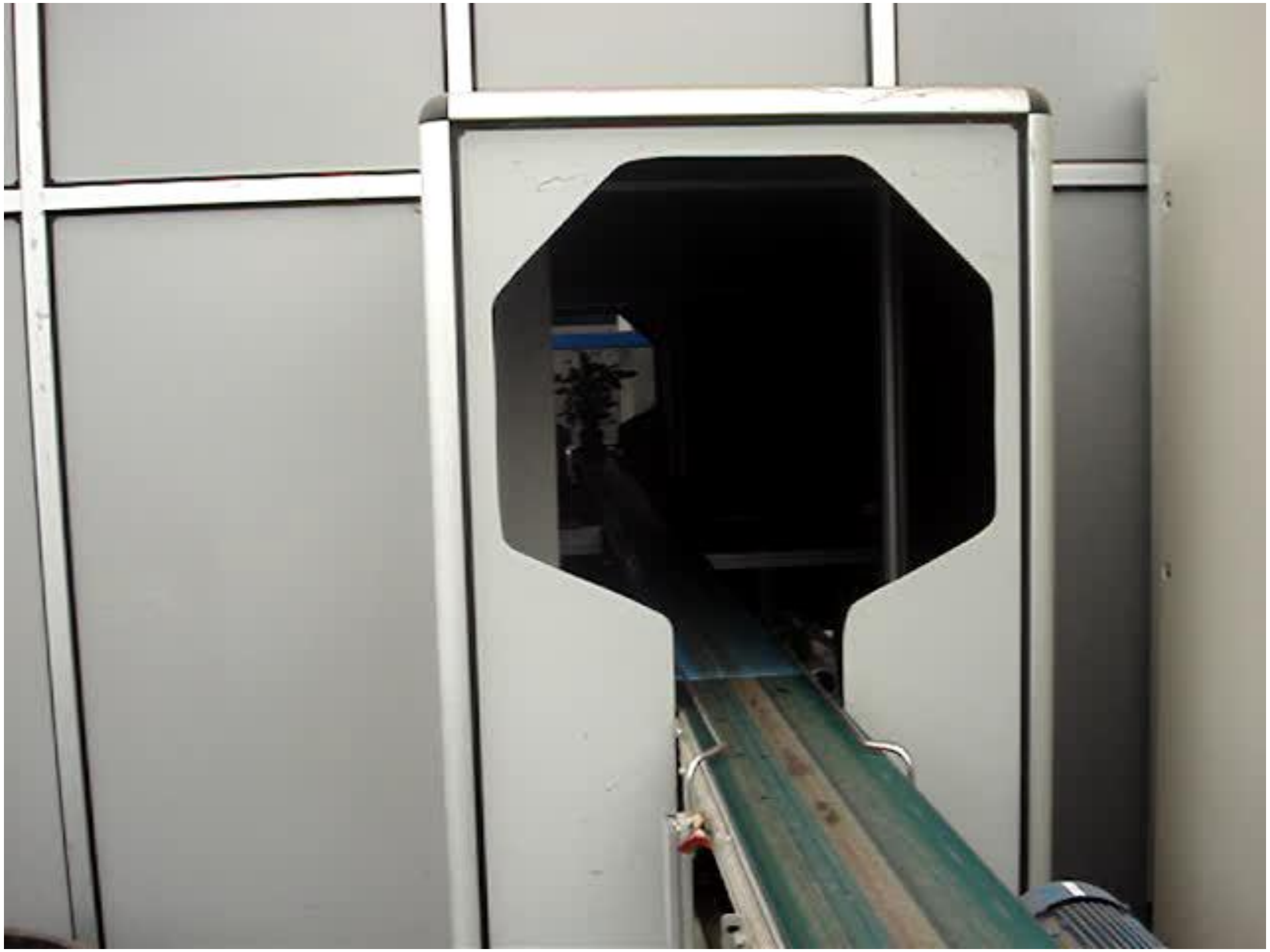
➢Increase of water stress leads to increase of leaf light reflectance

Ψηλά Θερμοκήπια



Αυτοματισμοί

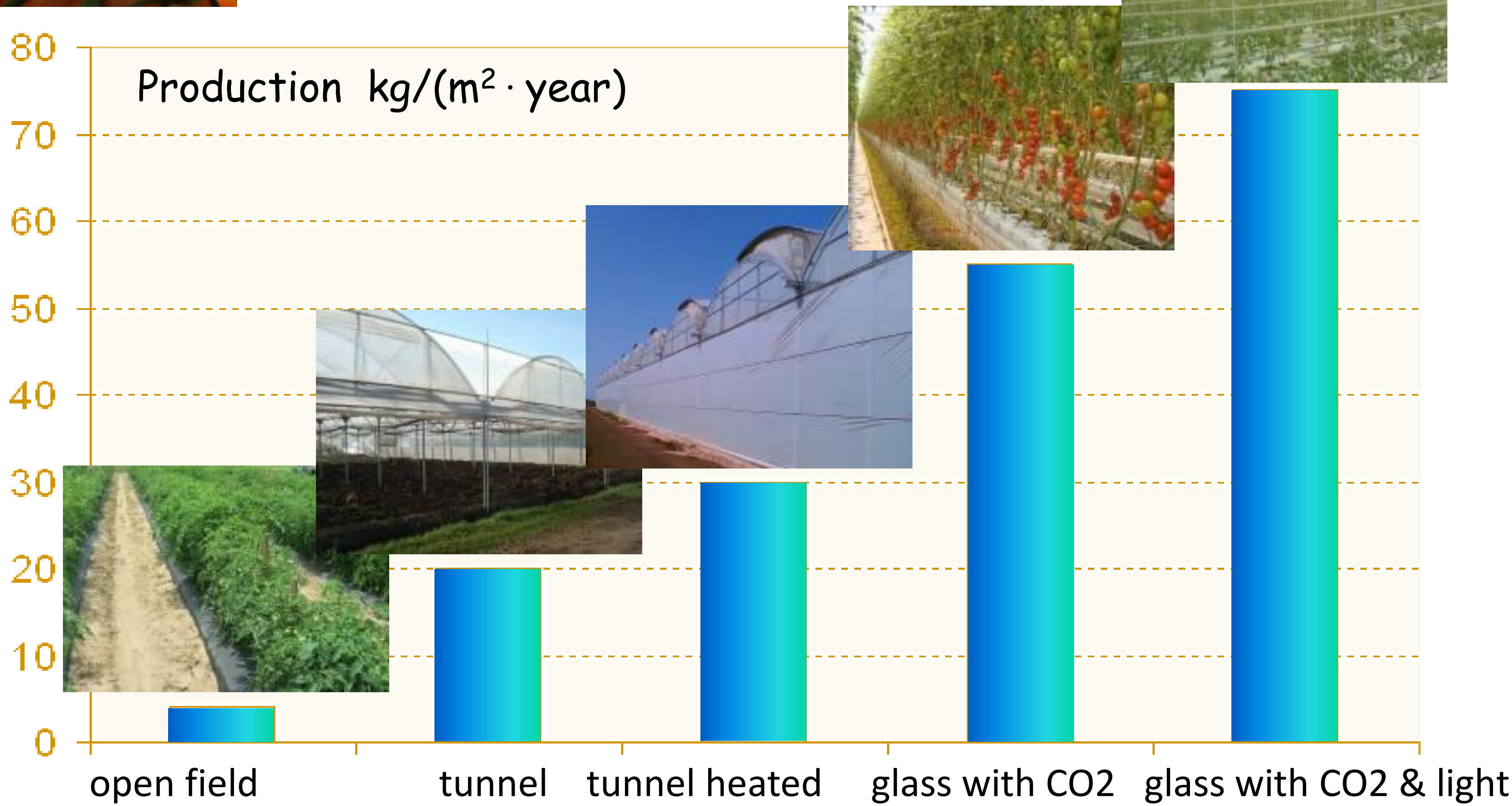
anthourio-2-.MPG



anthourio-6.MPG

anthourio-7.MPG

Tomato production

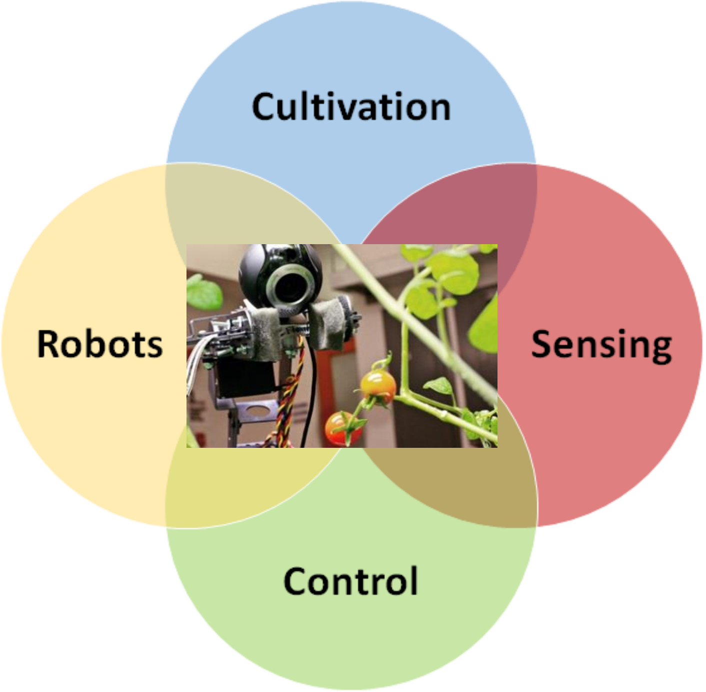


Control of production factors

Tomato crop profit and loss planning and analysis for different technological level greenhouses and for the "Closed" prototype geothermal greenhouse (percentage of own participation = 20%, subsidy rate=40%)

	Low tech level PE greenhouse	**Medium tech level PE greenhouse**	**High tech level PE greenhouse**	**High tech level glass greenhouse**	**Prototype Geothermal "Closed greenhouse"**
Initial investment	630,000 €	1,412,500 €	1,799,700 €	2,805,600 €	3,142,272 €
Investment cost per m^2	30.0 €	67.3 €	85.7 €	133.6 €	149.6 €
Percentage own participation	20%	20%	20%	20%	20%
Equity participation	126,000 €	282,500 €	359,940 €	561,120 €	628,454 €
Subsidy rate	**40%**	**40%**	**40%**	**40%**	**40%**
Lending	252,000 €	565,000 €	719,880 €	1,122,240 €	1,256,909 €
Lending rate	**5%**	**5%**	**5%**	**5%**	**5%**
Years repayment	**10**	**10**	**10**	**10**	**10**
Annual annuity	-32,074 €	-71,912 €	-91,625 €	-142,837 €	-159,978 €
Total debt interest payments	-320,742 €	-719,124 €	-916,253 €	-1,428,372 €	-1,599,776 €
Difference of total amortization to initial investment amount	-68,742 €	-154,124 €	-196,373 €	-306,132 €	-342,867 €
Annual operating costs	207,800 €	319,693 €	319,693 €	351,662 €	404,412 €
Annual cost (annuity + operation)	239,875 €	391,605 €	411,318 €	494,499 €	564,389 €
Average selling price (A + B)	**0.53**	**0.60**	**0.60 €**	**0.71 €**	**0.66 €**
Production required for a balanced Budget.	**21.4 kg**	**30.9 kg**	**32.7 kg**	**33.2 kg**	**40.5 kg**
Expected production	**27.0 kg**	**42.0 kg**	**47.0 kg**	**52.0 kg**	**63.0 kg**
Profit before tax	**63,000 €**	**141,250 €**	**179,970 €**	**280,556 €**	**314,211 €**
Profit before taxes per m^2	3.0 €/m2	6.7 €/m2	8.6 €/m2	13.4 €/m2	15.0 €/m2
Payback period	**10.0 years**	**10.0 years**	**10.0 years**	**10.0 years**	**10.0 years**
ROI	**10.0%**	**10.0%**	**10.0%**	**10.0%**	**10.0%**

Conclusion

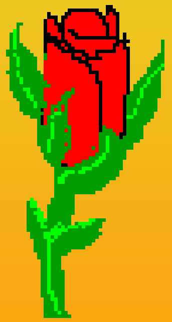


The technologies for greenhouse climate control do exist. However, the greenhouse microclimate control must combine:

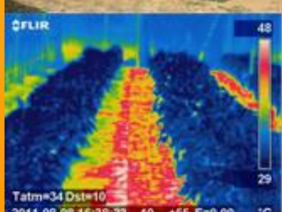
- Efficient sensing of climate and crop variables
- Appropriate dimensioning of the heating, ventilation and cooling system
- Choice of the appropriate system and intelligent control of the systems

If the appropriate technologies are applied in practice then greenhouse horticulture would have a **good substantial progress** towards its **sustainable development.**

Thank you for your attention



Screenhouses



The use of porous screens to cover agricultural crops is constantly increasing.

Advantages:

- ✓reduce high radiation loads and wind speed,
- ✓decrease water consumption
- ✓protect the crop from hail storms and
- ✓minimize the invasion of insects, thus, allowing a significant reduction in pesticide application


Advantages of screenhouses with respect to open field

They consist of a low cost construction that can give effective solution to the problems of insects and of extreme climate conditions (wind, rain).

They can also reduce the effects of high solar radiation on the quality of the yield, decreasing the sunscalds and sunburns.

In this way, screenhouses can effectively increase the marketable production and give better results with respect to open field.

Advantages of screenhouses with respect to greenhouses

Compared to greenhouses, screenhouses are low cost constructions.

Cultivation in screenhouses can take place, in most of the regions, during 7-8 months. Compared to the rudimentary equipped (no heated) greenhouses, screenhouses may result to better climate conditions during summer and reduce the problems of cooling needed in greenhouses, and accordingly, reduce crop temperature stress and increase fruit yield during summer.

Shading

Decrease solar radiation

↓

Decrease air and crop temperature

↓

Modify crop physiological response

Porosity

Decrease insects invasion

↓

Decrease air exchanges

↓

Increase of air temperature

Screenhouses

Experimental screenhouses

a green shading net with SI = 36%

a white anti-thrip net (50-mesh) with SI = 34%

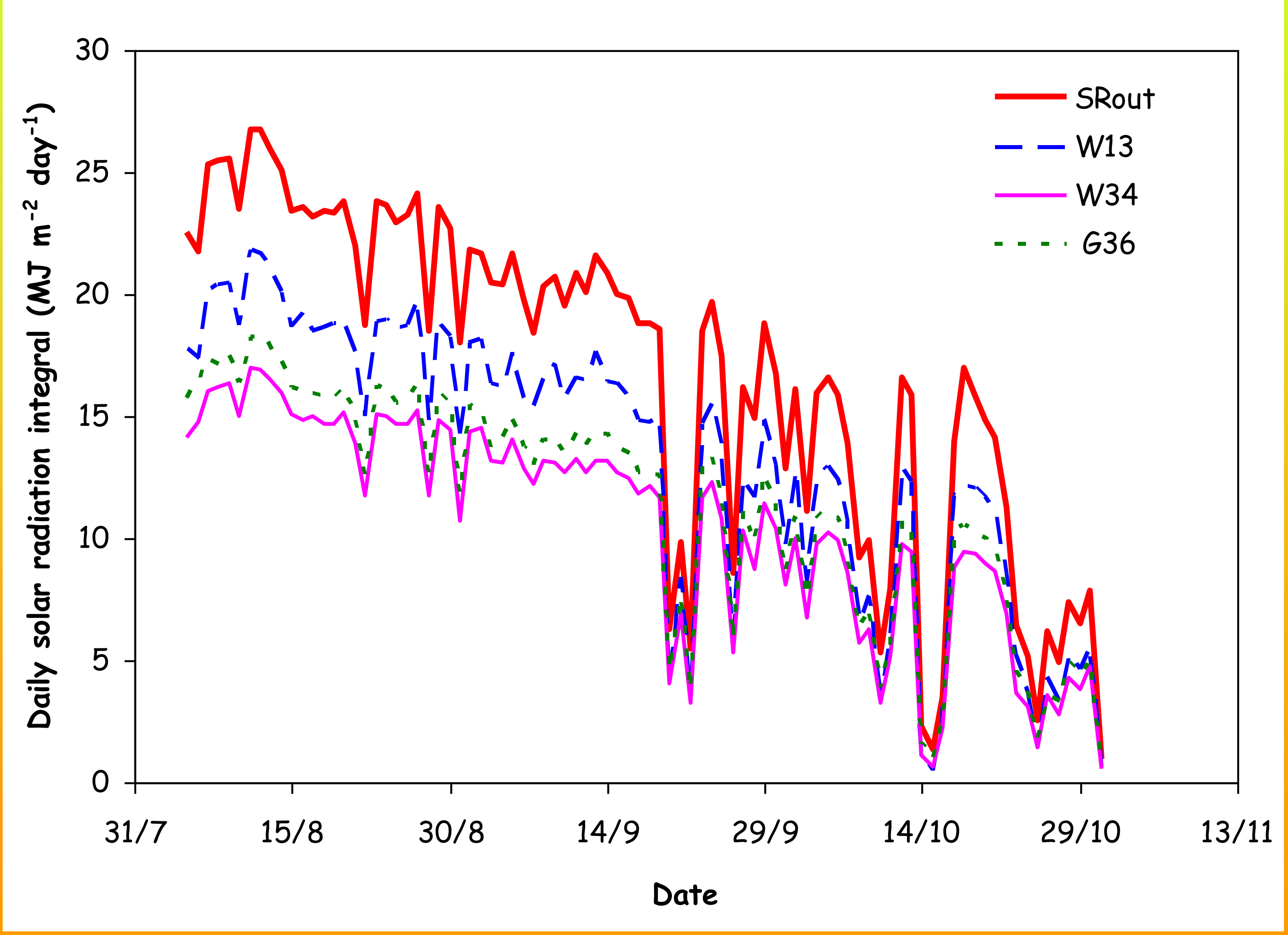
a white anti-thrip net (50-mesh) with shading intensity (SI) of about 13%

Sweet pepper plants (*Capsicum annuum* L., cv. Dolmi)
Plants density of 1.8 plants per m^2

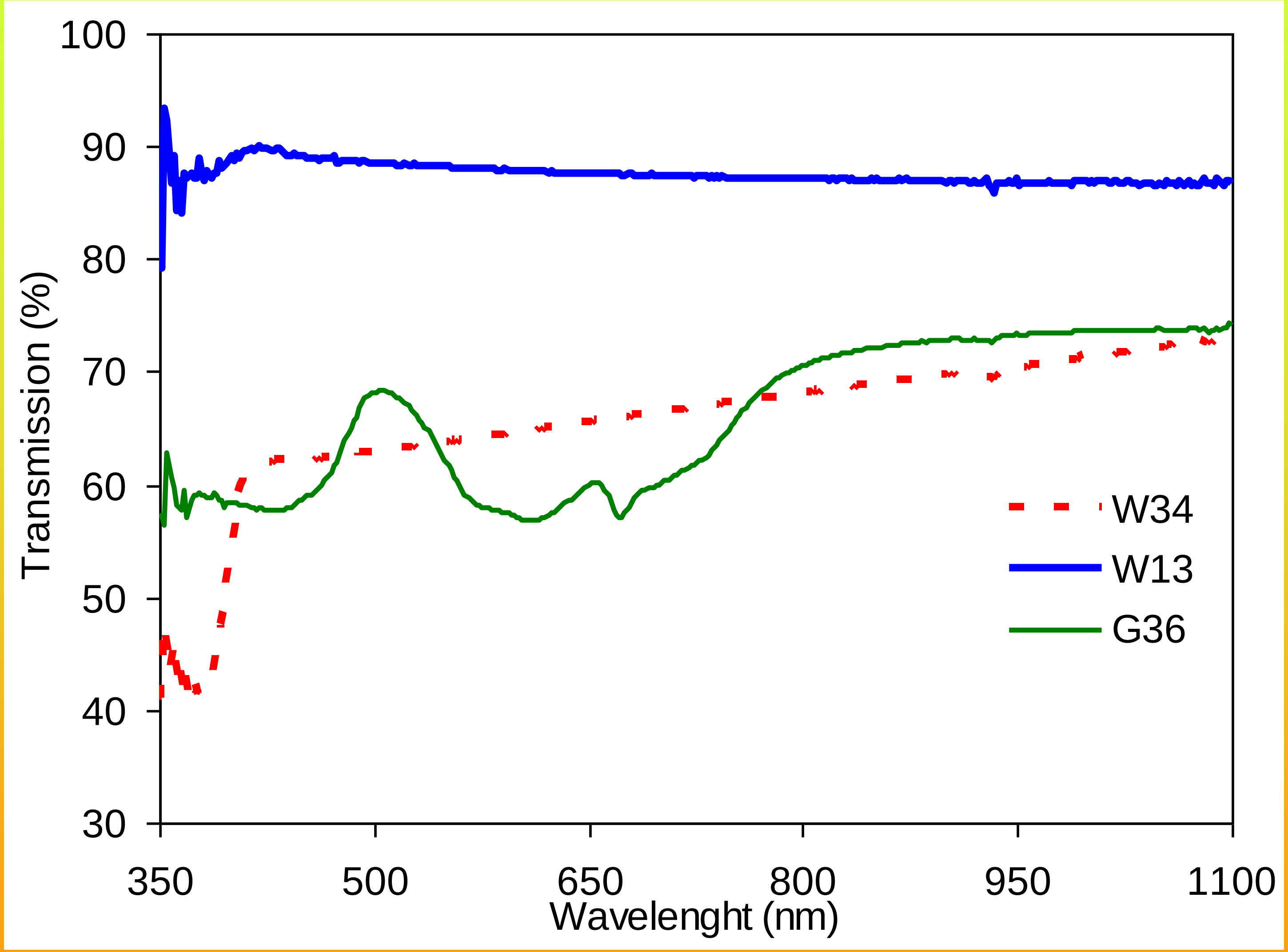
Screenhouses

Light related parameters

Solar radiation



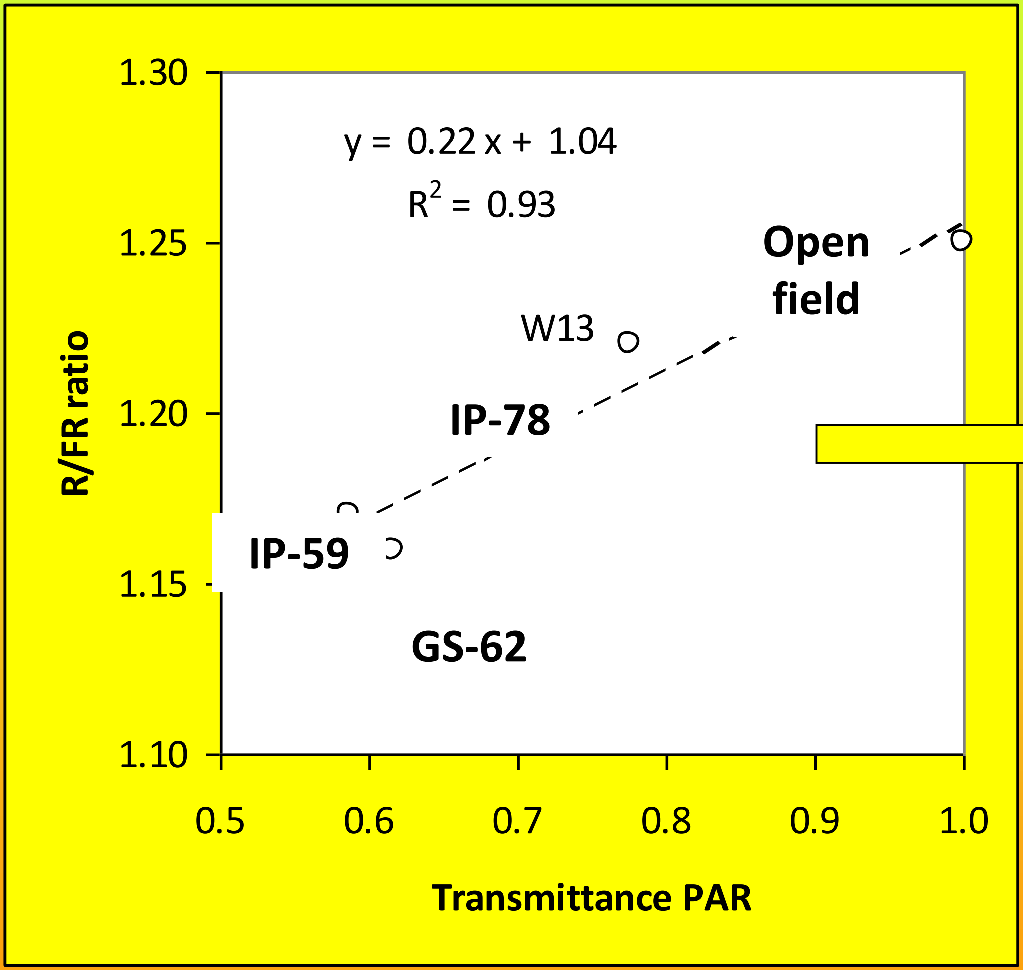
Shading intensity



Mean spectral transmittance determined *in situ* during the 2011 growing season for the three screenhouses, Kitta et al. 2014

Light quality parameters

Screen materials ⟹ Decrease of the R:FR ratio



The decrease of the R:FR ratio is proportional to shading intensity

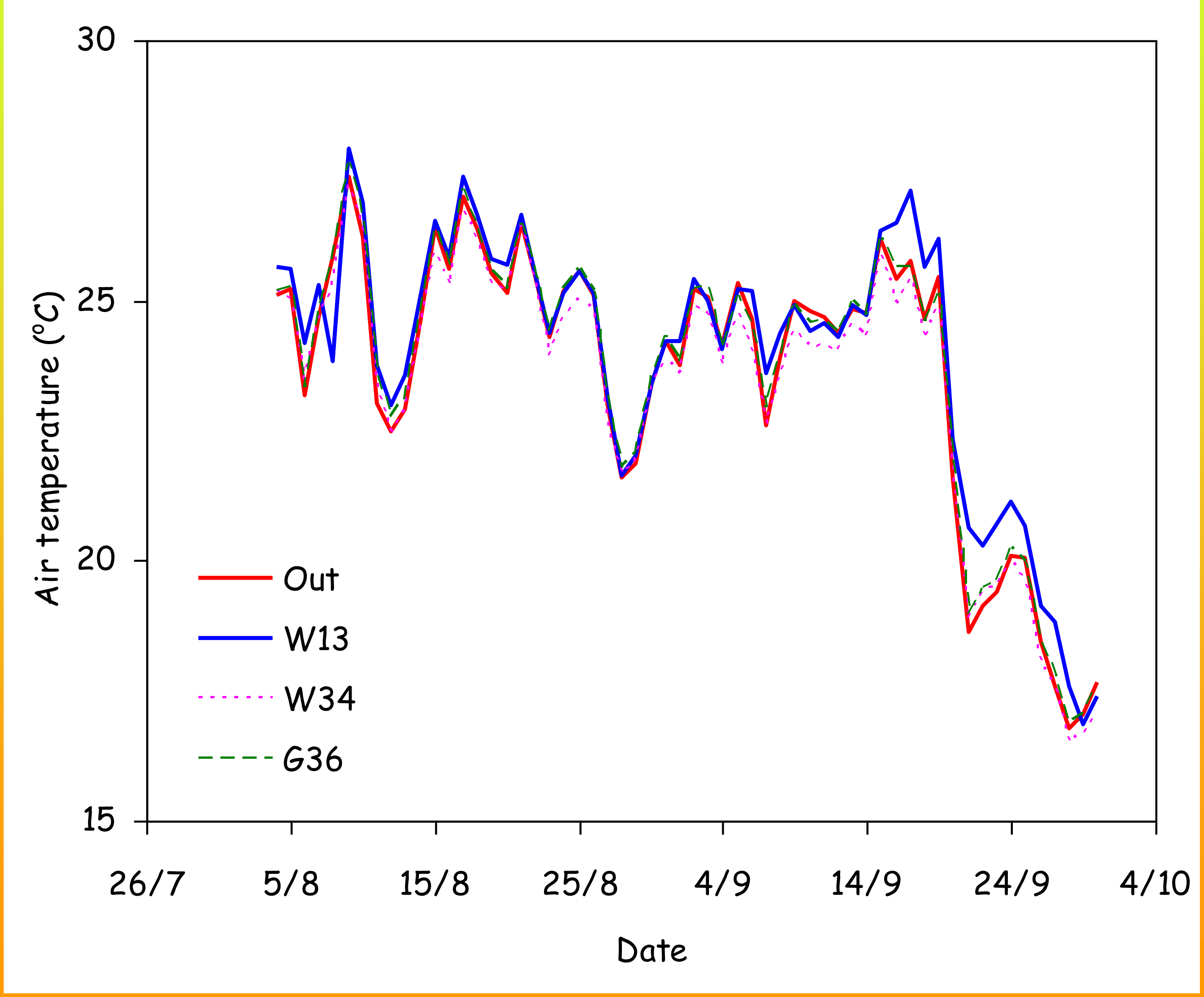
High correlation between the ratio R:FR and the PAR transmittance (R2 = 0.93)

Relationship between PAR transmittance (τ_{PAR}) and the ratio R:FR. (Kitta et al. 2014)

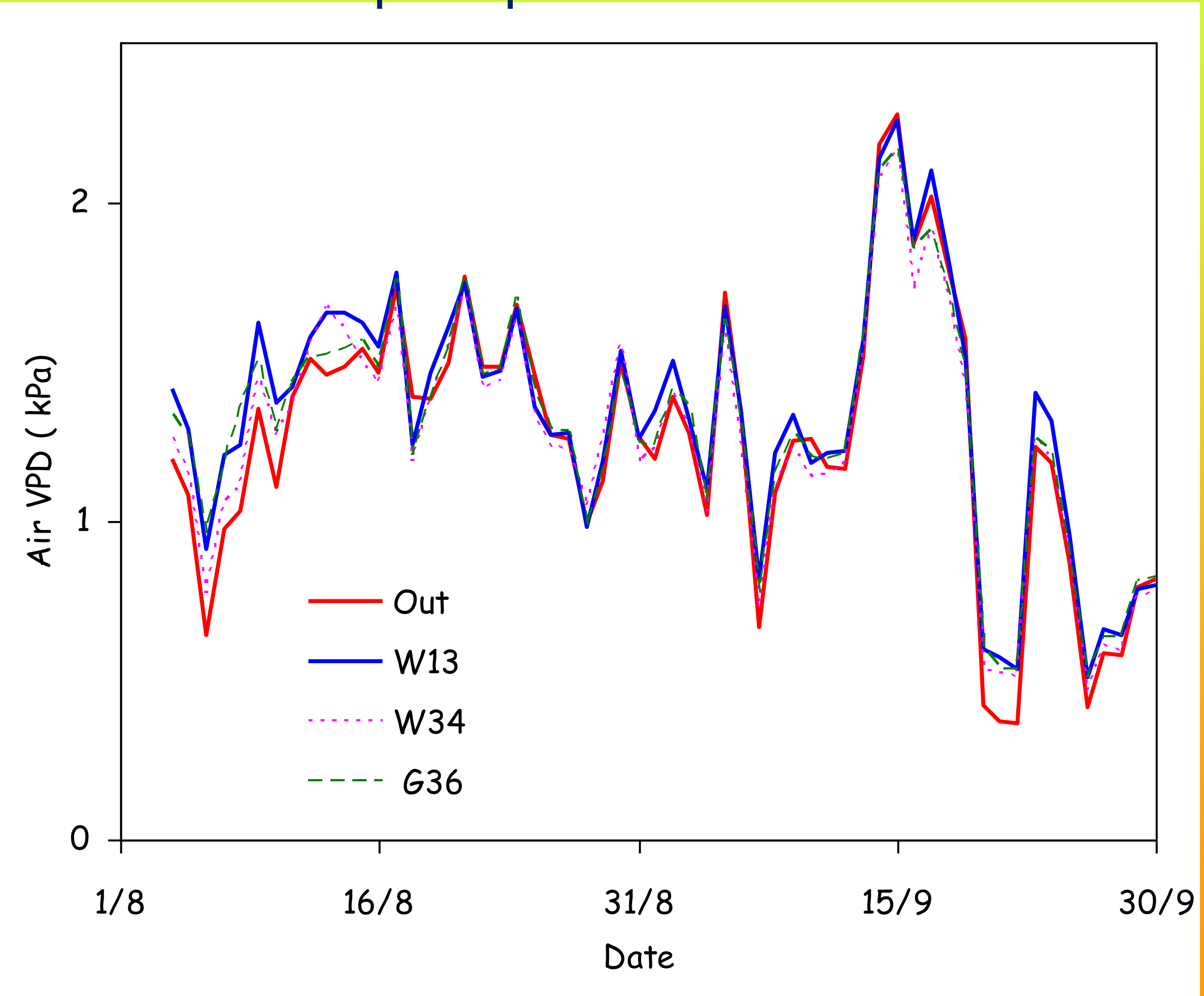
Screenhouses

Climate parameters

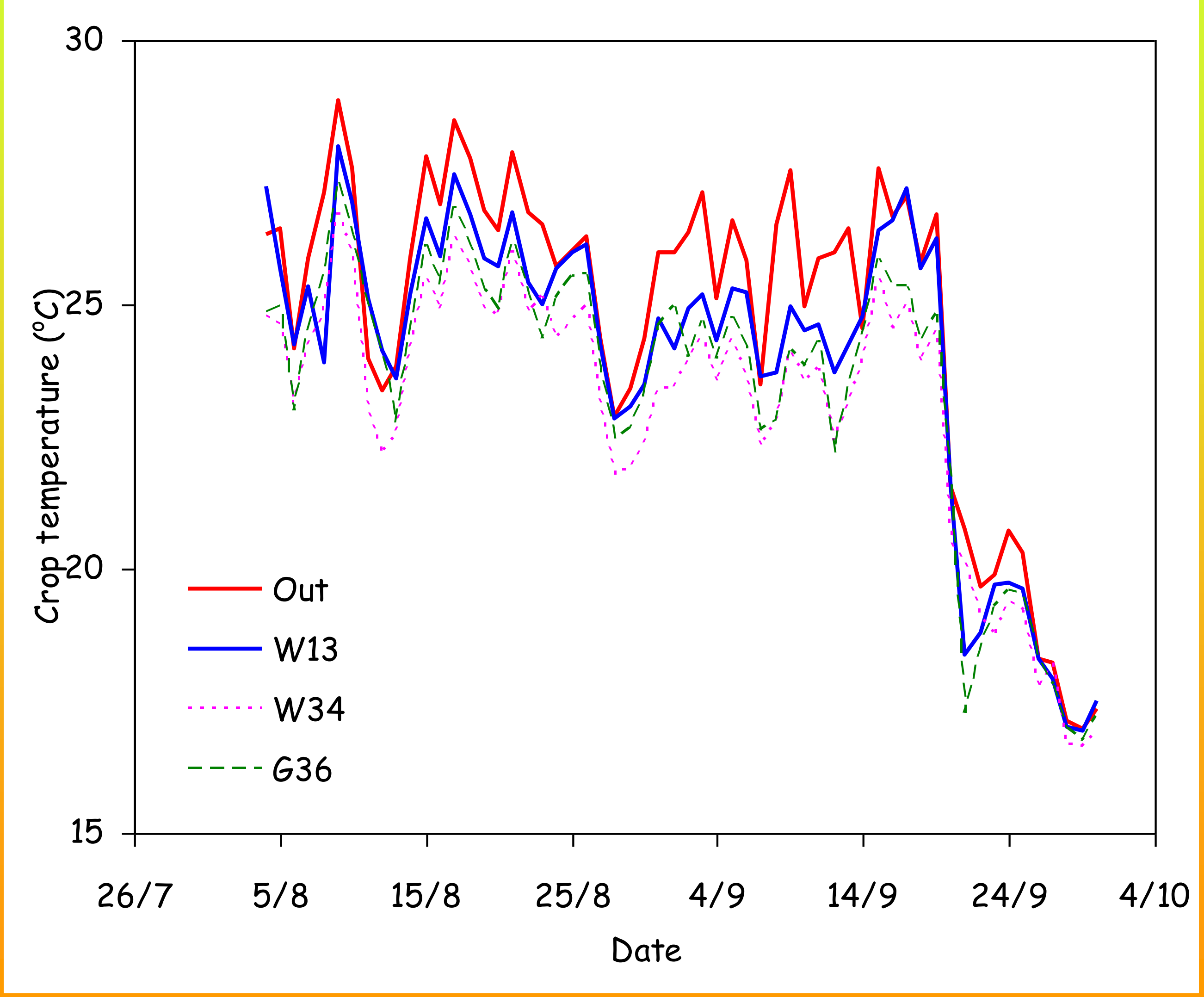
Air temperature



Vapour pressure deficit

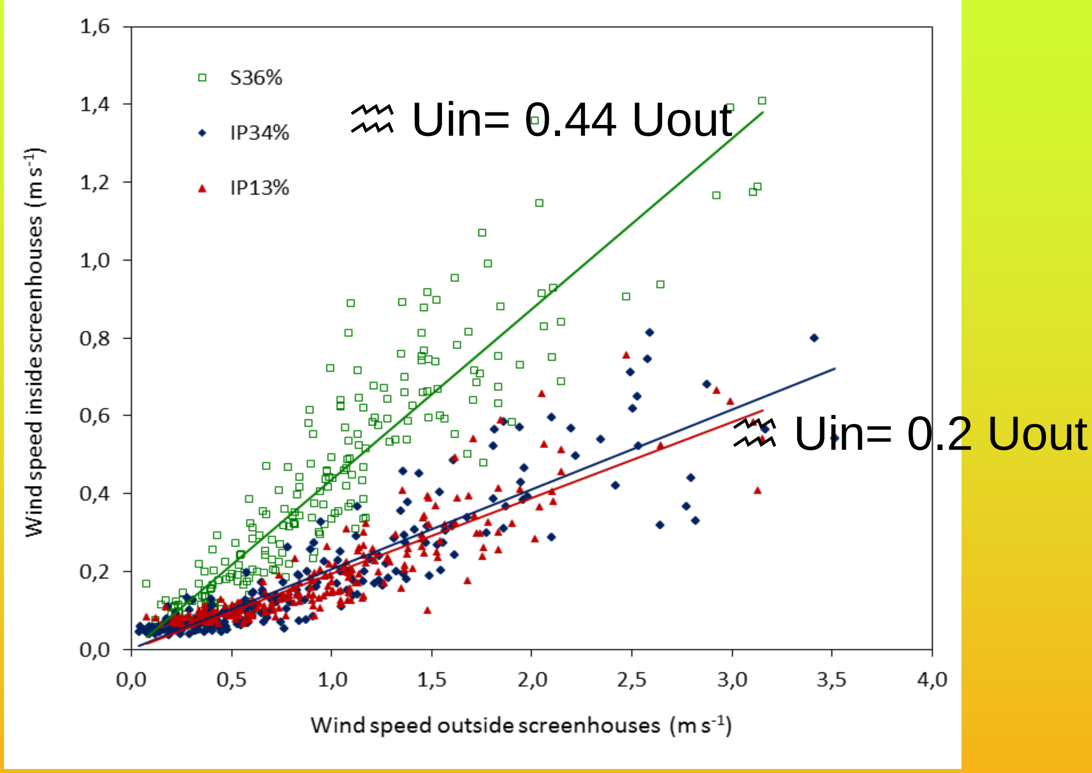


Crop temperature

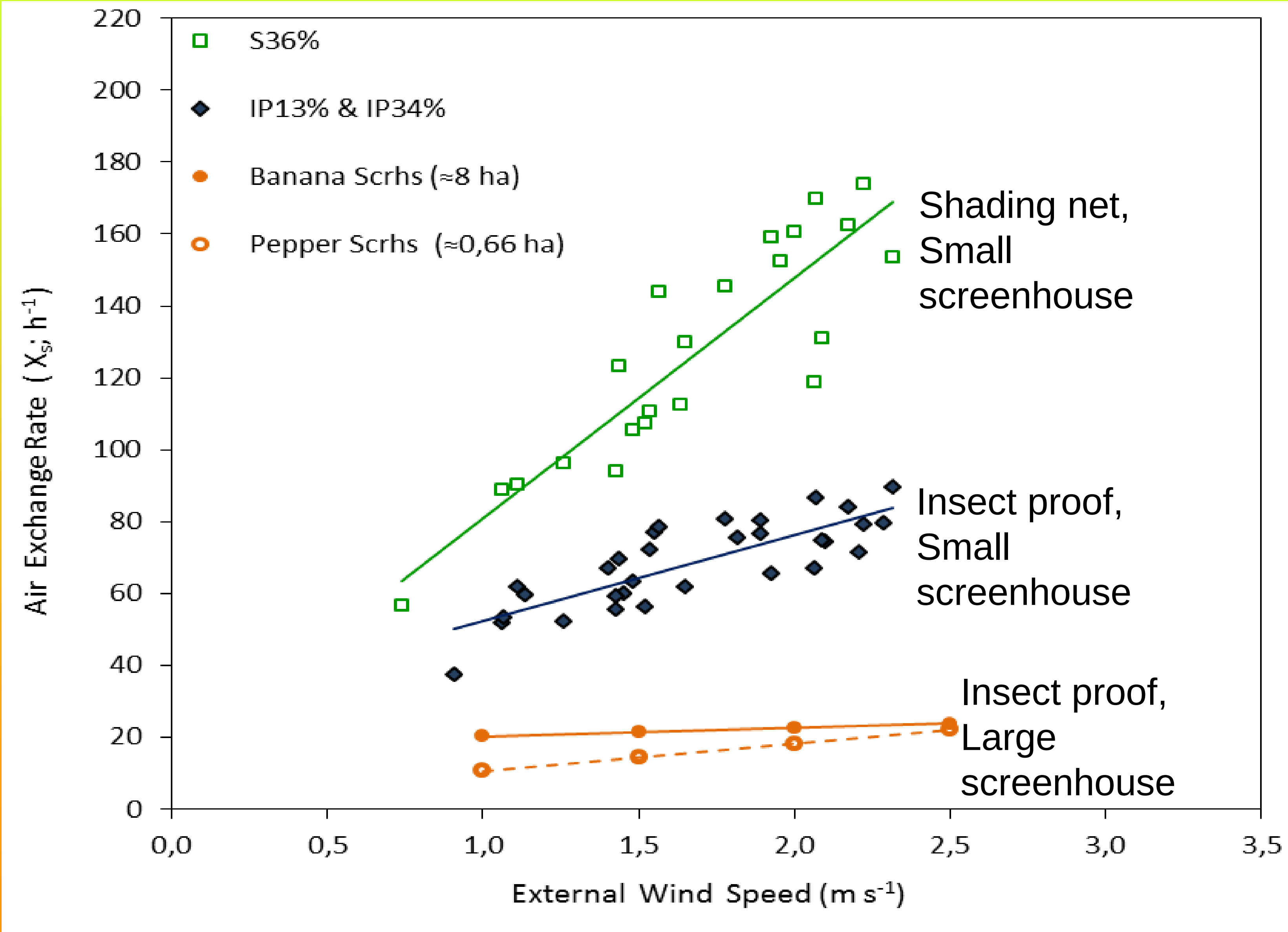


Screenhouses

Air velocity



Measured wind speed inside the screenhouse at 1.5 m height (u_{int}) plotted as a function of external wind speed measured at 10 m height by the meteorological station (u_{ext}), Kittas et al. , unpublished data

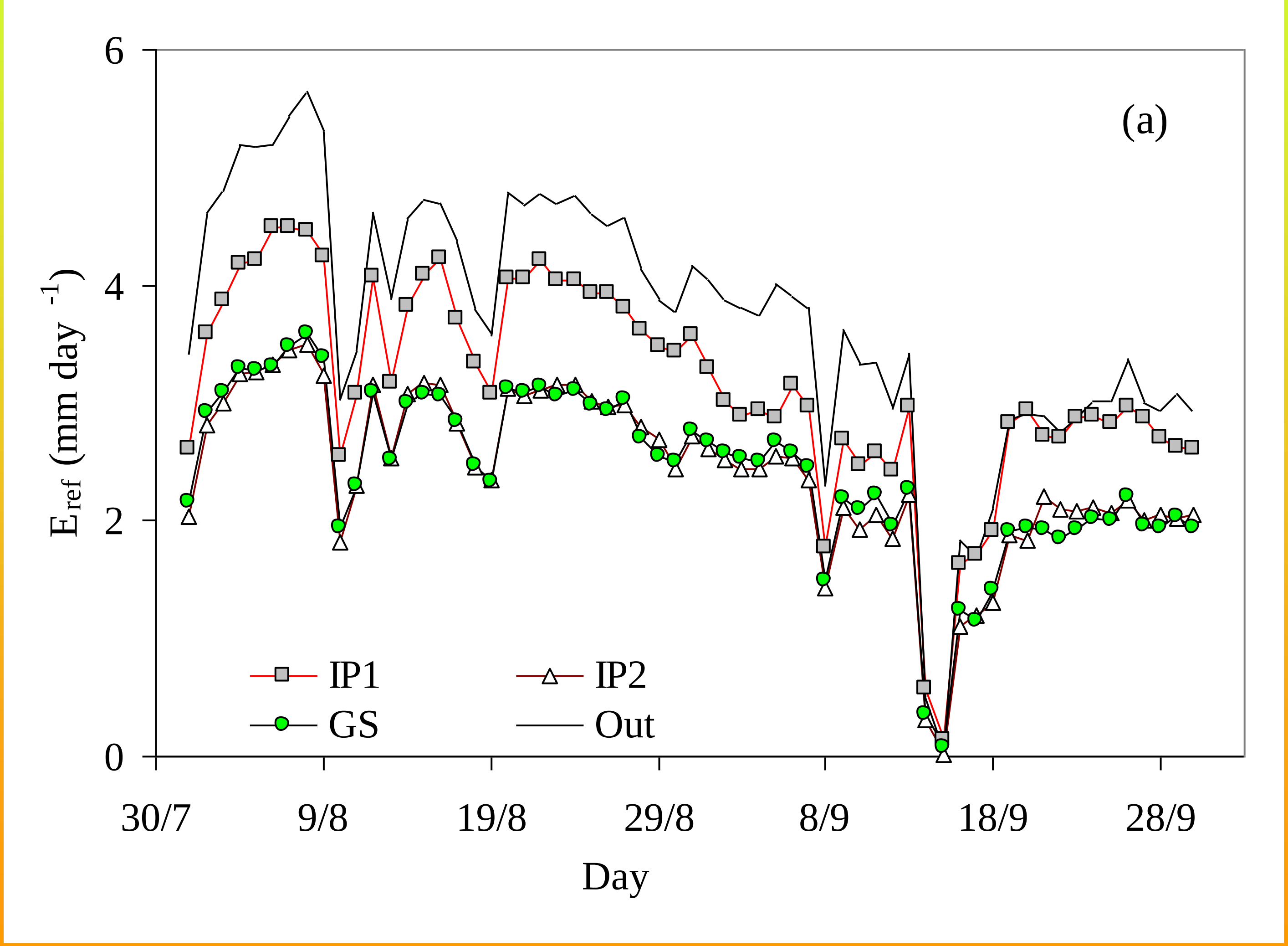


S36%
IP13% & IP34%
Banana Scrhs (≈8 ha)
Pepper Scrhs (≈0,66 ha)
Shading net, Small screenhouse
Insect proof, Small screenhouse
Insect proof, Large screenhouse
Air Exchange Rate (X; h-1)
External Wind Speed (m s-1)
0
20
40
60
80
100
120
140
160
180
200
220
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5

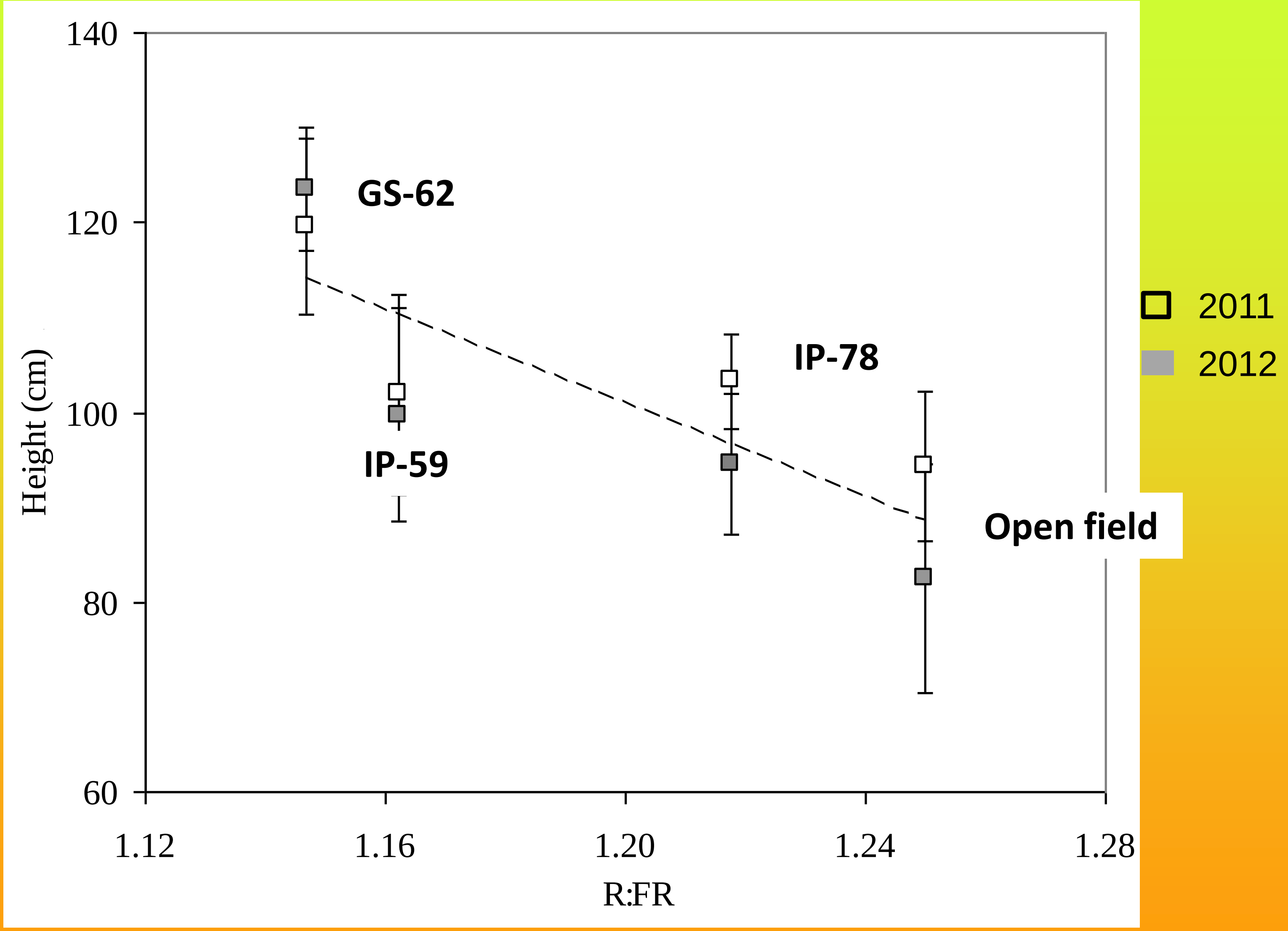
Screenhouses

Crop related parameters

Reference ET

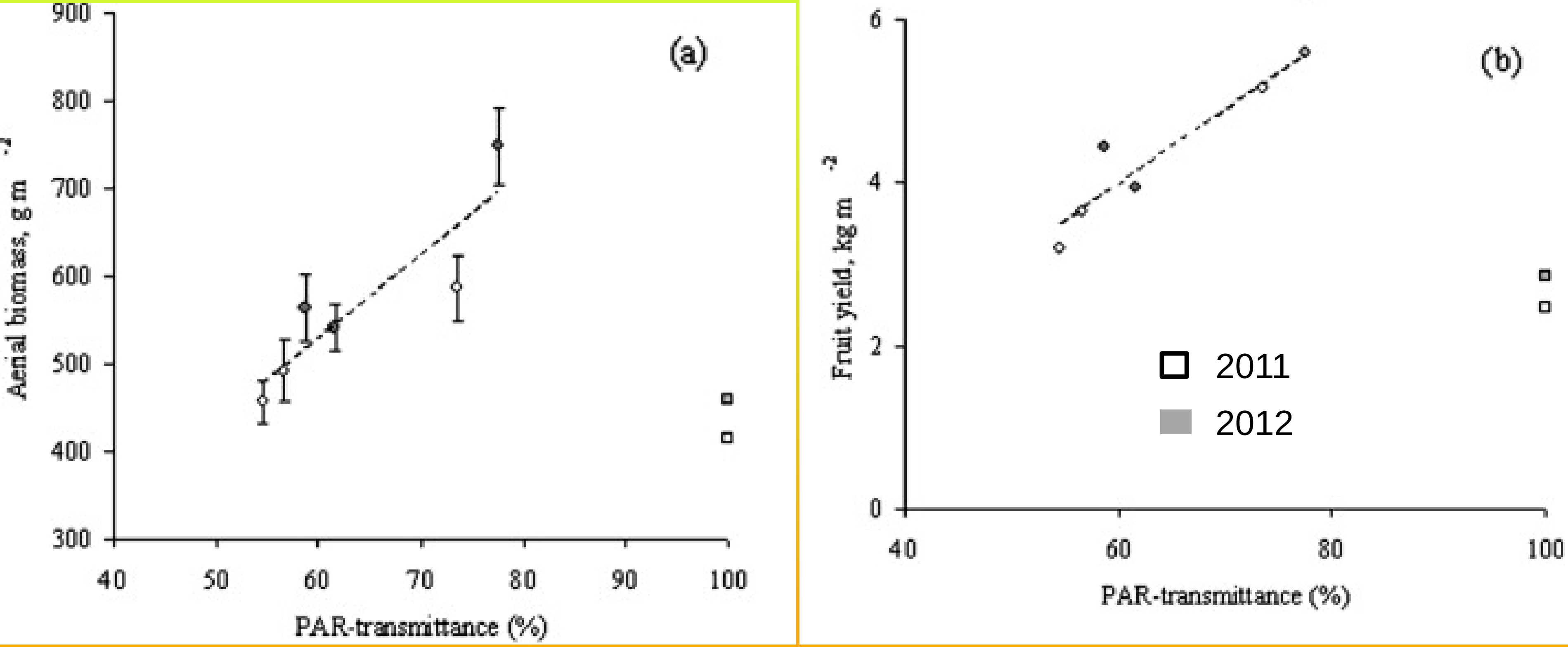


Effect on crop: plant height



Lower R:FR → higher plants

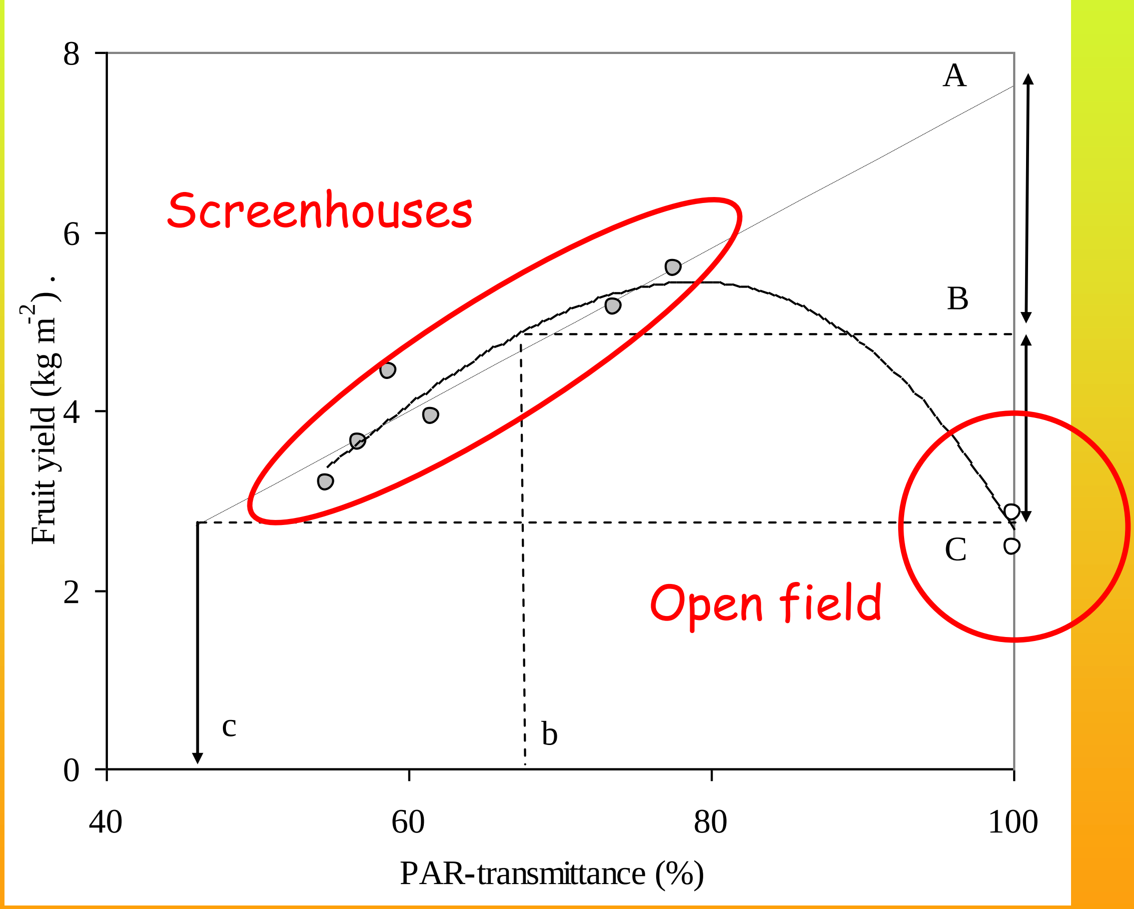
Biomass



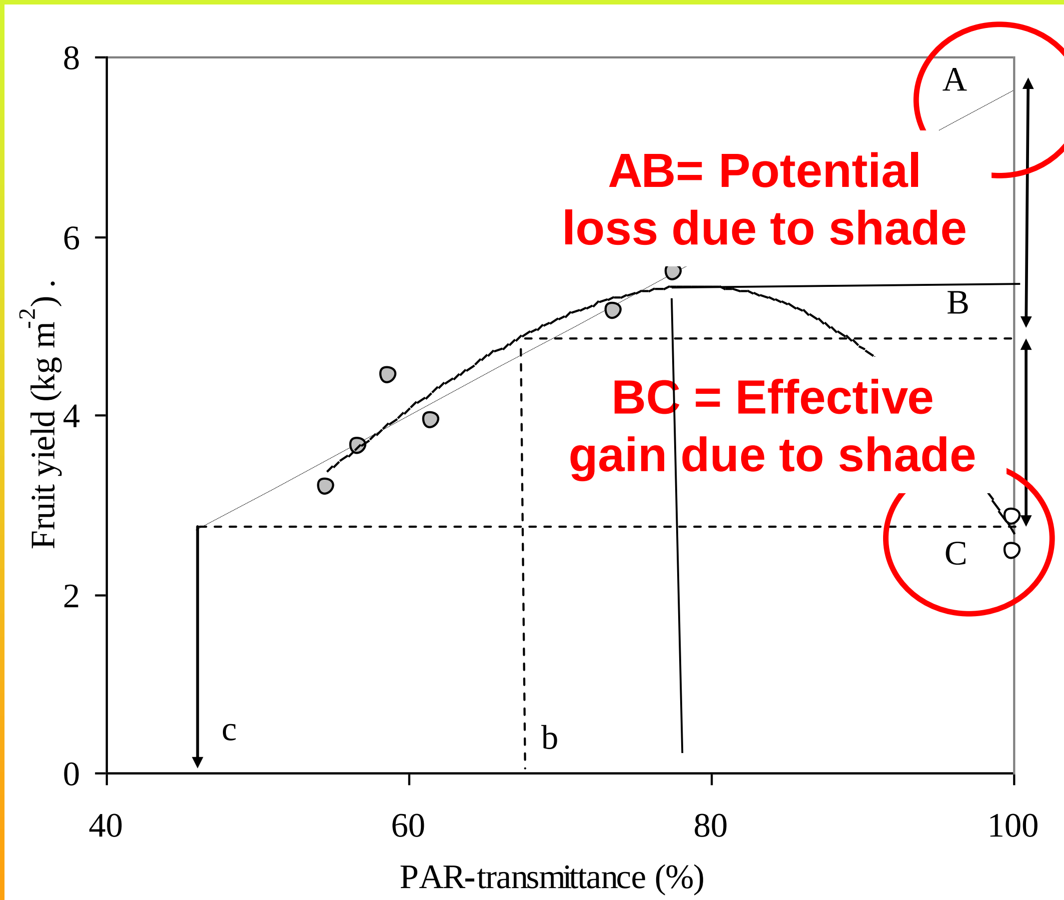
Relationship between PAR-transmittance and (a) aerial dry biomass, $W_{a,}$ and (b) yield, *Y*, at DAT 148, Kitta et al. 2014

higher PAR → higher biomass

Effect on crop: fruit yield



Effect on crop: fruit yield



A = potential yield in the open field under near optimal conditions

C = actual yield in the open field

Optimum shading intensity around 20%

c= % of shade that give the same yield (C) as in open field (Here ≈ 50%)

Benchmarking indicators

- Water Use Efficiency (WUE)

Reference values

Index	WUE Kg DM / m^3
Greenhouse	8
Screenhouse	6
Open field	2

Cost comparison. Pepper crop

Values per m^2	Cost of construction (Euro)	Yield for pepper (kg)	Gross income (euro)	Benefit (euro)
Greenhouse (mid tech)	50	25	17	5
Screenhouse	9	9	6.3	2.5
Open field	1.5	4	2.3	0.7

Conclusions

- Small changes in microclimate factors other than light were observed.
- Ventilation rate increases with wind speed and is much smaller than that of an open pepper field.
- Recommended shading factor no higher than 20% for sweet pepper in Mediterranean.
- Screenhouse crops consumed from about 20-40% less water than the open field crop.
- Biomass and yield were linearly related to PAR-transmittance, independent of screenhouse

Future Challenges

- Water needs and water use efficiency under screens
- Which technology to transfer from greenhouses to screenhouses
- New screens and netting materials
- New constructions