Module 4: CLIMATE TECHNOLOGIES / EQUIPMENT

Lesson 4.1:

Microclimate Control in greenhouses

Co-funded by the
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Greenhouses

Greenhouses are sophisticated constructions and require optimal synergy between lighting, heating, cooling and ventilation.

Energy amounts to about 50% of the total production costs and is a significant obstacle to the economic viability of greenhouses

Due to climatic conditions, in the Mediterranean basin heating and artificial lighting are required during winter, cooling and reduction of lighting are required during the summer.

These conditions make the task of cost-effective controlling of the interior greenhouse conditions, a quite demanding one.

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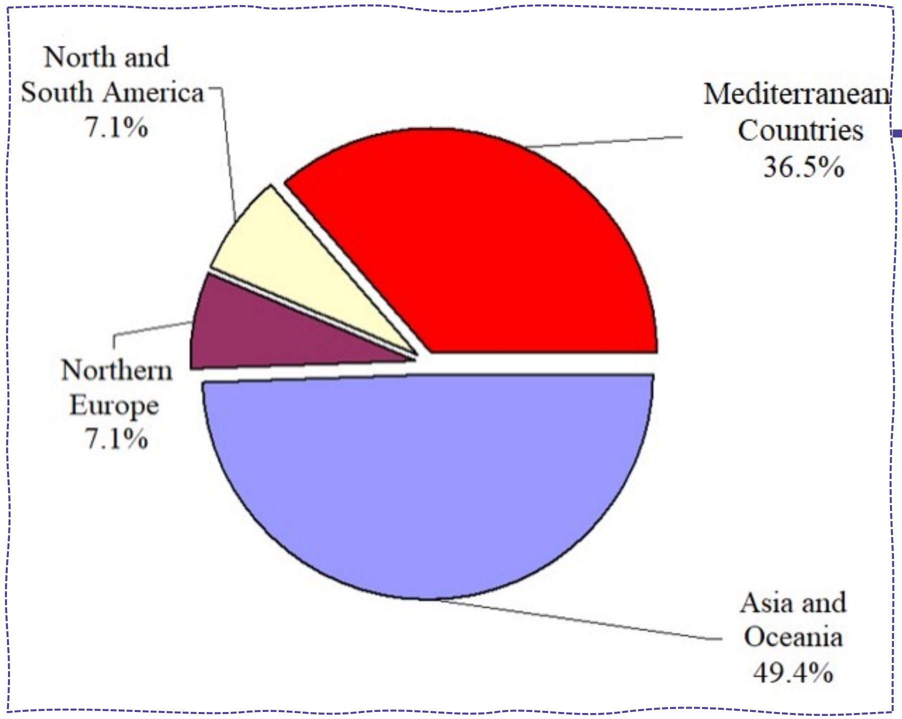
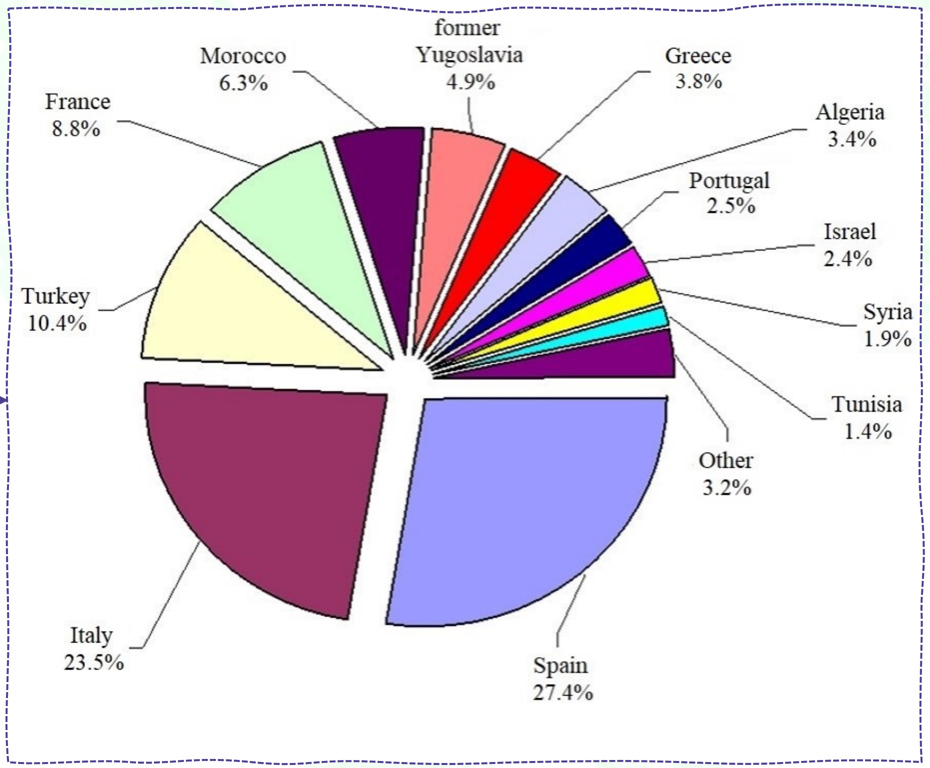
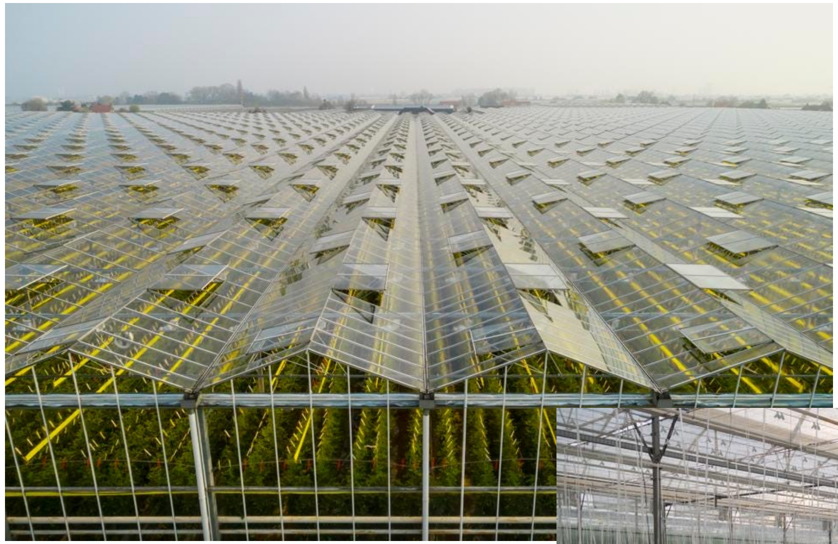
Global and Mediterranean basin greenhouse distribution





Greenhouses



High-tech greenhouses in the Netherlands. (Source: Forbes)

Growing cucumber on a stone wool substrate in a modern hydroponic greenhouse. (Source: ID 213034913 © Olga Soe. Dreamstime.com)

Soilless tomatoes cultivation using hanging gutters. (Source: Israeli Agriculture International Portal)

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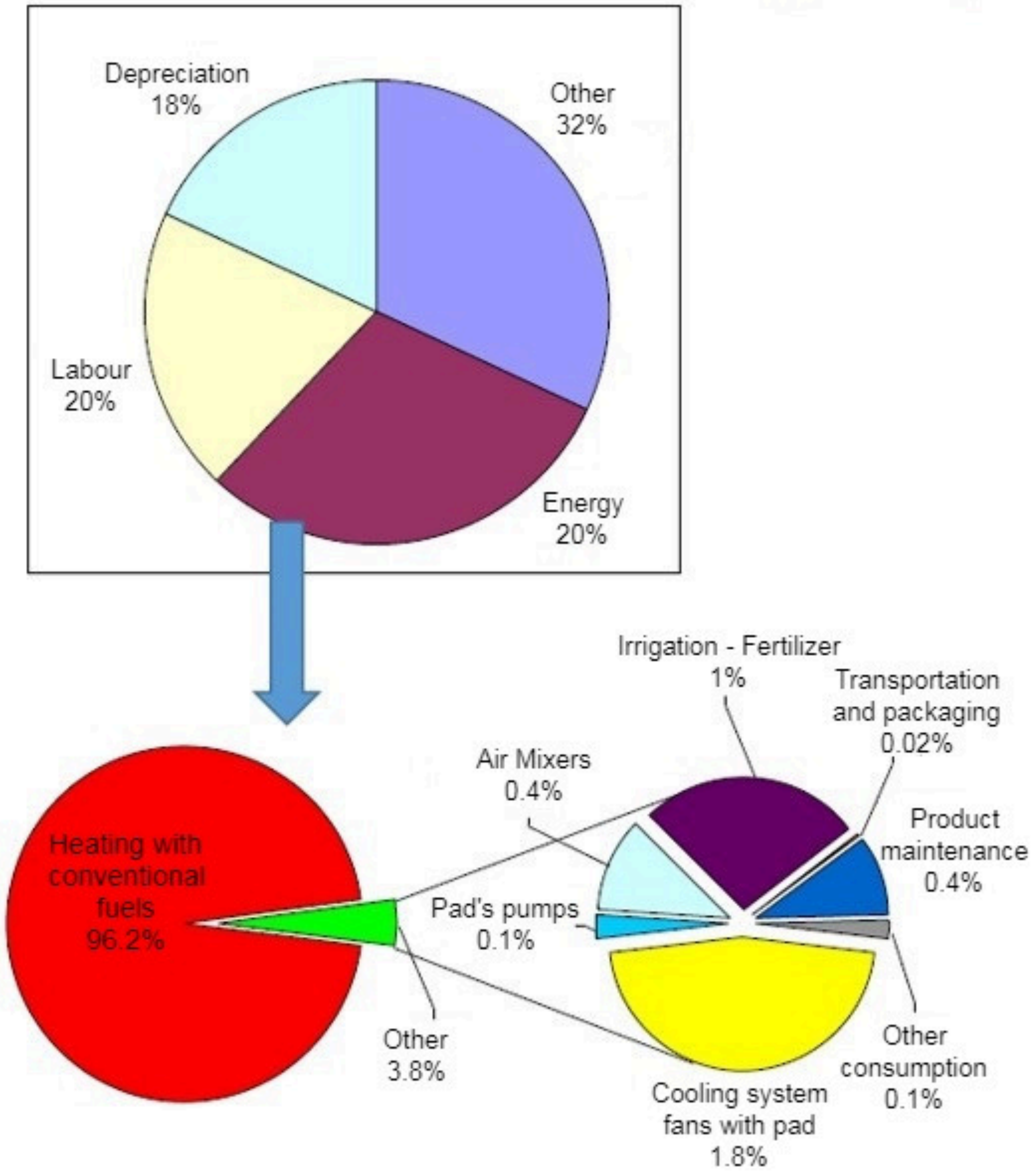
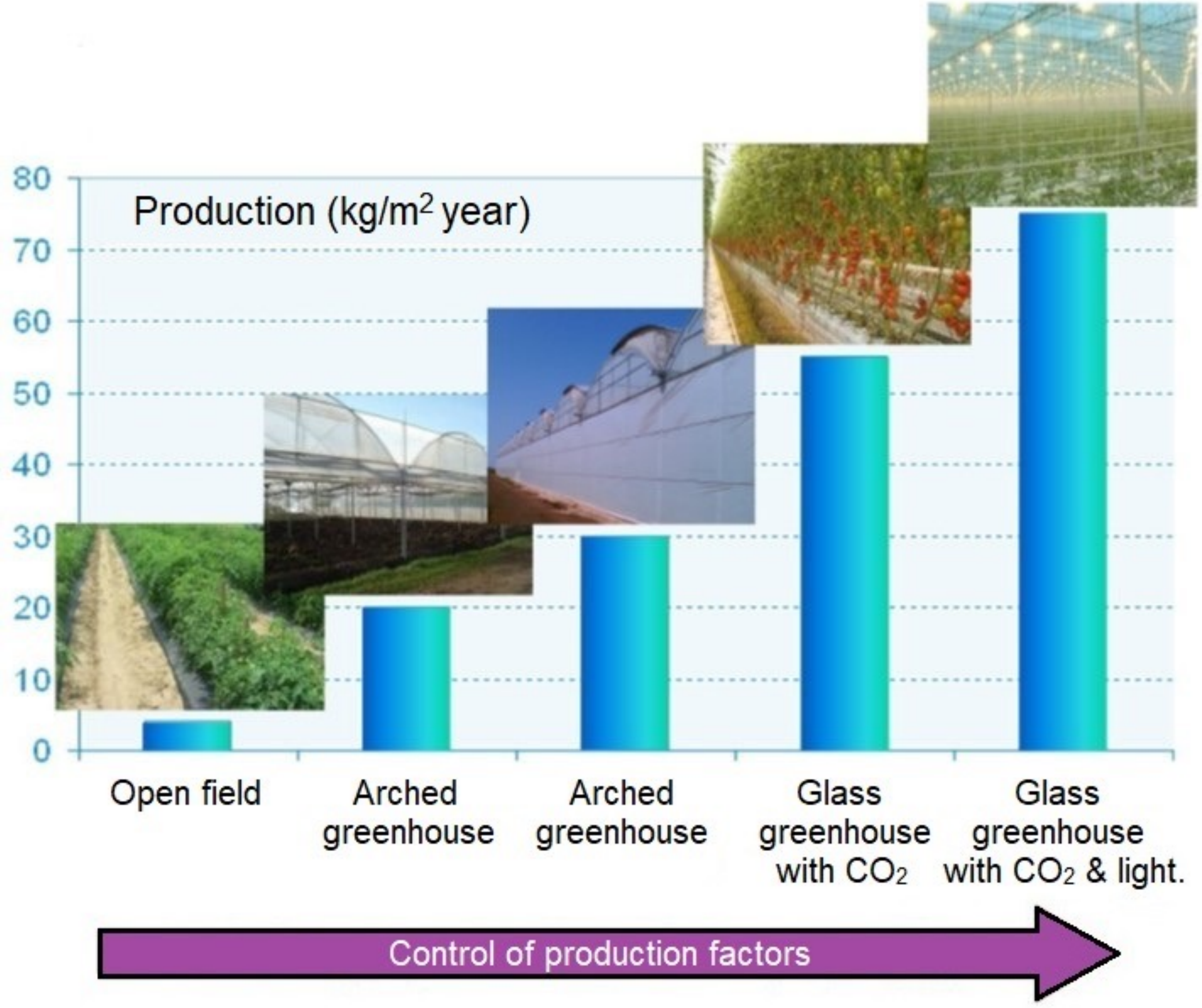
Greenhouses – Almeria area, Spain

Challenges

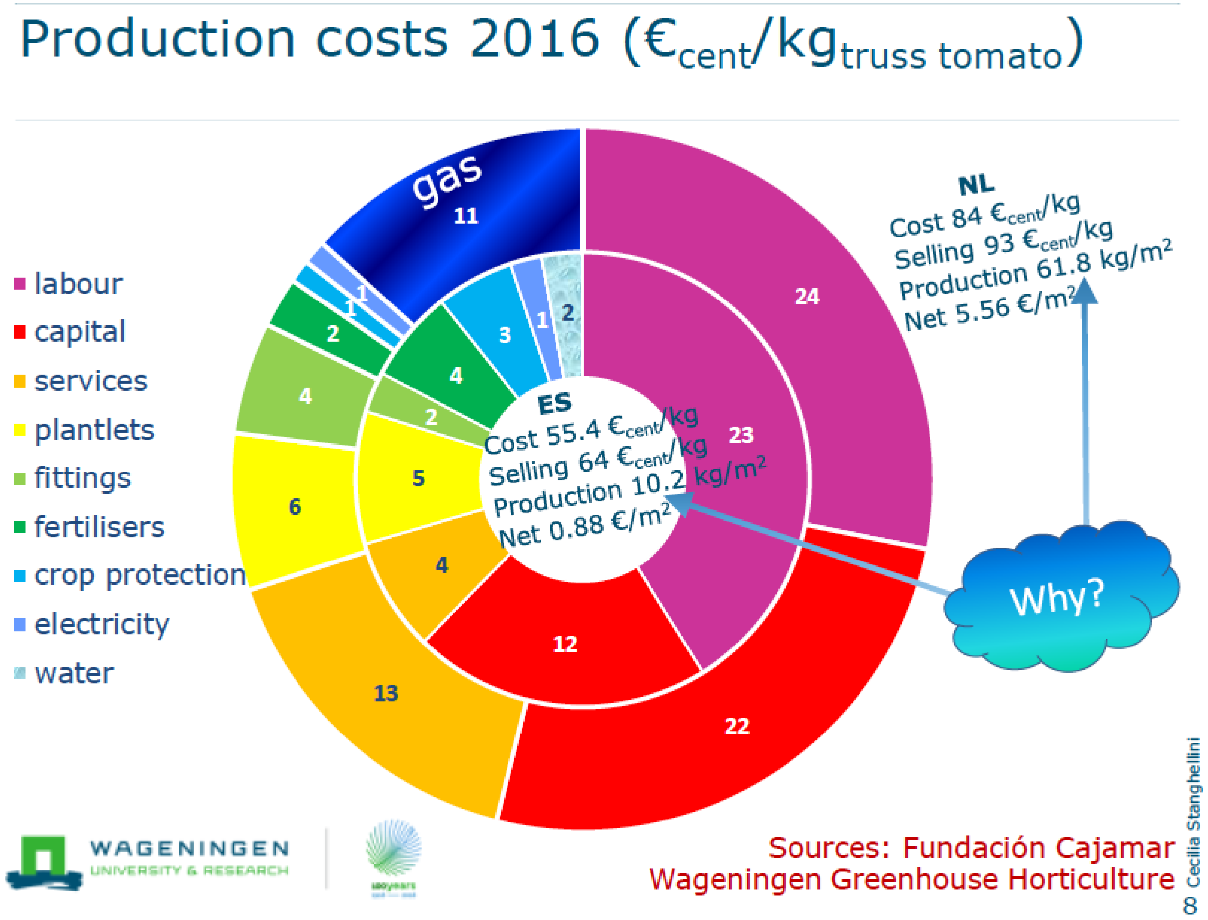

Depreciation
18%
Other
32%
Labour
20%
Energy
20%
Irrigation - Fertilizer
1%
Transportation
and packaging
0.02%
Air Mixers
0.4%
Product
maintenance
0.4%
Heating with
conventional
fuels
96.2%
Pad's pumps
0.1%
Other
3.8%
Other
consumption
0.1%
Cooling system
fans with pad
1.8%

Technology

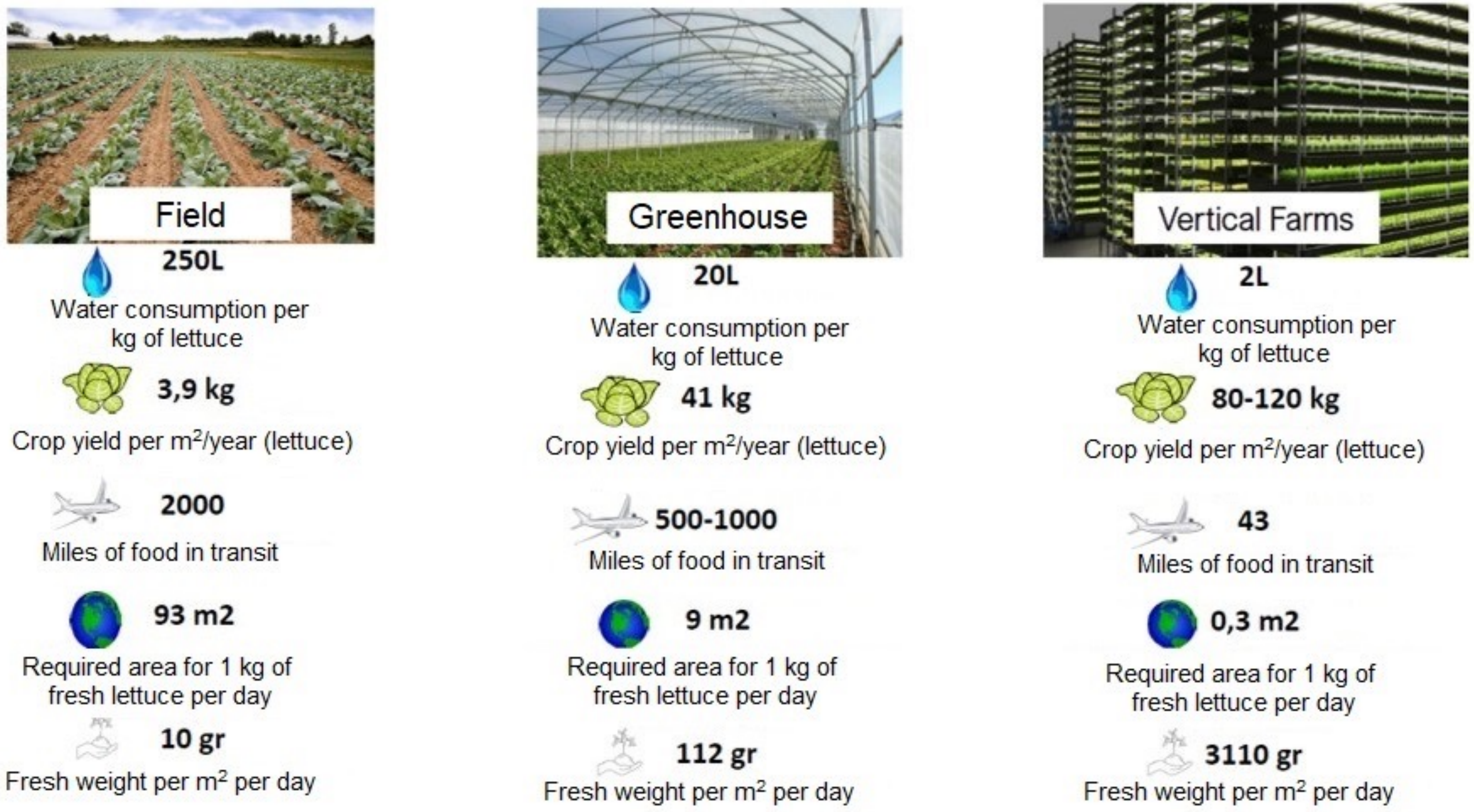


Production (kg/m2 year)
80
70
60
50
40
30
20
10
0
Open field
Arched greenhouse
Arched greenhouse
Glass greenhouse with CO2
Glass greenhouse with CO2 & light.
Control of production factors

Technology – Cost (Spain – Netherlands)



Resources usage efficiency



Greenhouse microclimate

Monitoring and control of the micro-climate is a necessary condition in modern greenhouses

The microclimate factors that decisively affect the growth and production of plants in the greenhouse, are:

- Radiation, heat, humidity and carbon dioxide (CO_2), in the aboveground part
- Heat, water, oxygen, inorganic nutrients and pH, in the roots

By controlling these factors, growers are able to maximize production and quality

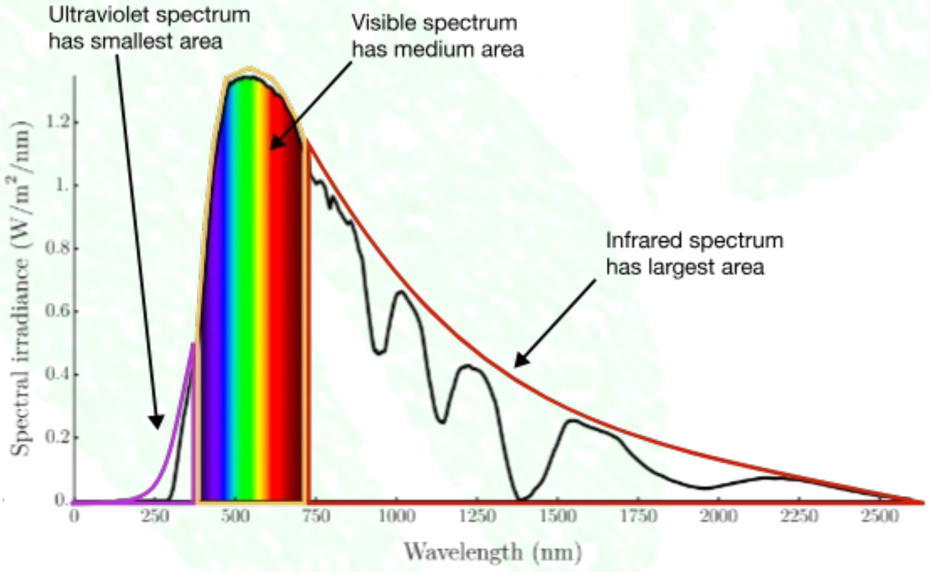
Handling greenhouse design and production cost management with a high degree of precision.

Solar radiation

- The Sun emits thermal radiation. With an average surface temperature of about 5760 K, the main amount of energy emitted is between 0.1 <λ <3 μm. This part of the spectrum is known as solar radiation.

- Solar radiation is the source of energy for the photosynthesis of plants, as well as the natural source of heat in the greenhouse.

- Solar radiation includes:
  - Ultraviolet radiation 190-380 nm, which has the highest energy and destroys the bonds of organic compounds that falls upon
  - Photosynthetically active radiation (PAR) 400-700 nm which is necessary for photosynthesis which is the basic process of plant development
  - Near infrared 700-3000 nm (NIR) that affects plant respiration because it significantly affects the heating as well as the shaping processes of plants.

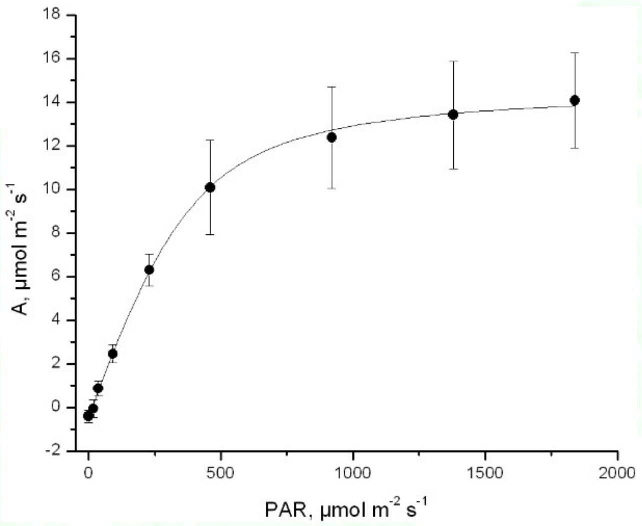


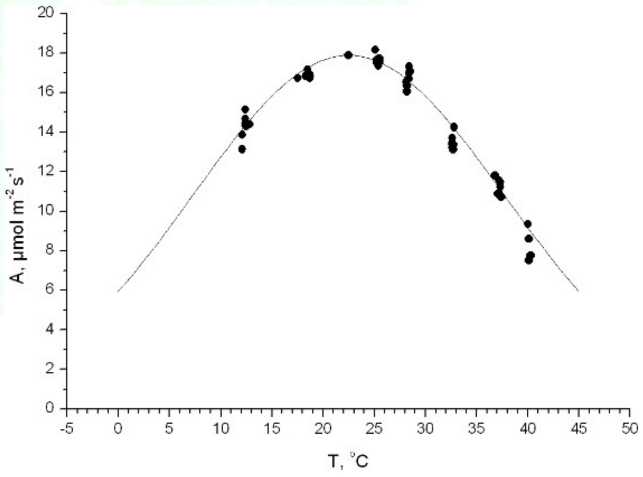
Photosynthesis - Photosynthetically Active Radiation (PAR) (1)

- Photosynthesis is the process by which plants absorb atmospheric CO_2 and, through complex biochemical reactions powered by light, convert it into biomass.

$$6CO_2 + 6H_2O \xrightarrow{Light} C_6H_{12}O_6 + 6O_2$$

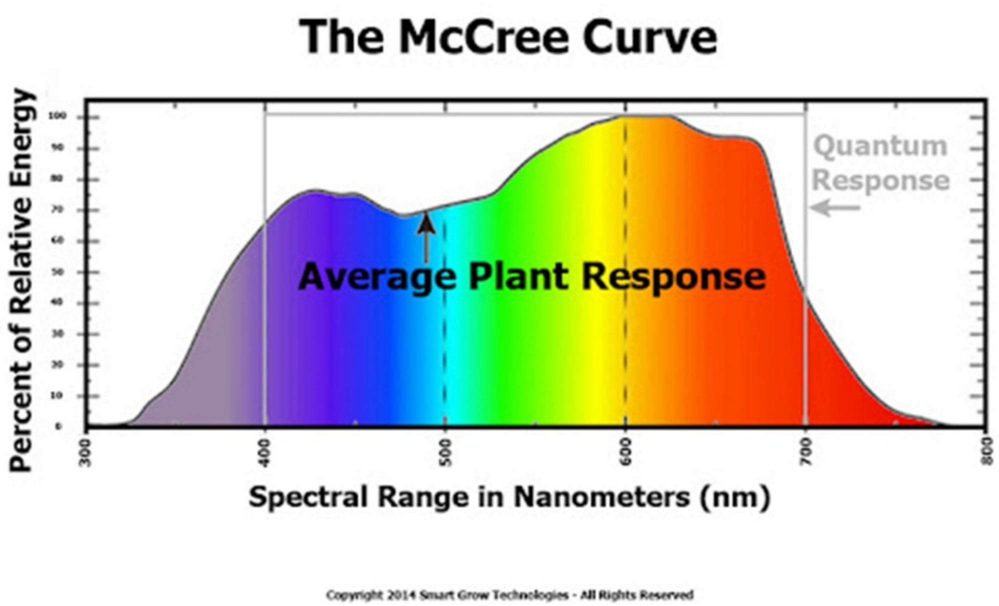
- The main environmental parameters that affect photosynthesis are light (in PAR terms) and temperature (T). The photosynthesis rate response (A) in PAR is described by a hyperbola while the photosynthesis response to temperature by a Gaussian curve





Photosynthesis - Photosynthetically Active Radiation (PAR) (2)

- Plants recognize and use solar radiation between 400-700nm.
- The efficiency (n) of solar energy utilization (Photosynthetic quantum efficiency) is given by the relation:
- n = energy used (delivered in the form of radiation) / absorbed energy.
- The absorption of chlorophyll - the energy collector of plants - shows a maximum in the region of blue (350-450 nm), which is a region of high energy and,
- A second higher maximum in the red region (600-700 nm), which is a lower energy region than the blue region.



Heat and Thermal environment of the greenhouse (1)

- The main factor that determines the greenhouse thermal environment is solar radiation.
- The greenhouse cover absorbs a small part of the radiation, another part is reflected, while the rest passes inside the greenhouse.
- Heating-cooling costs are a big part of the total cultivation cost and cause a significant contribution to the environmental footprint.
- The heat losses of a greenhouse, due to its thin walls and construction, are particularly large, 6-12 times greater than those of a typical building of equal volume.
- On sunny days, the temperature rises to very high levels, while on cold nights the temperature drops to very low levels

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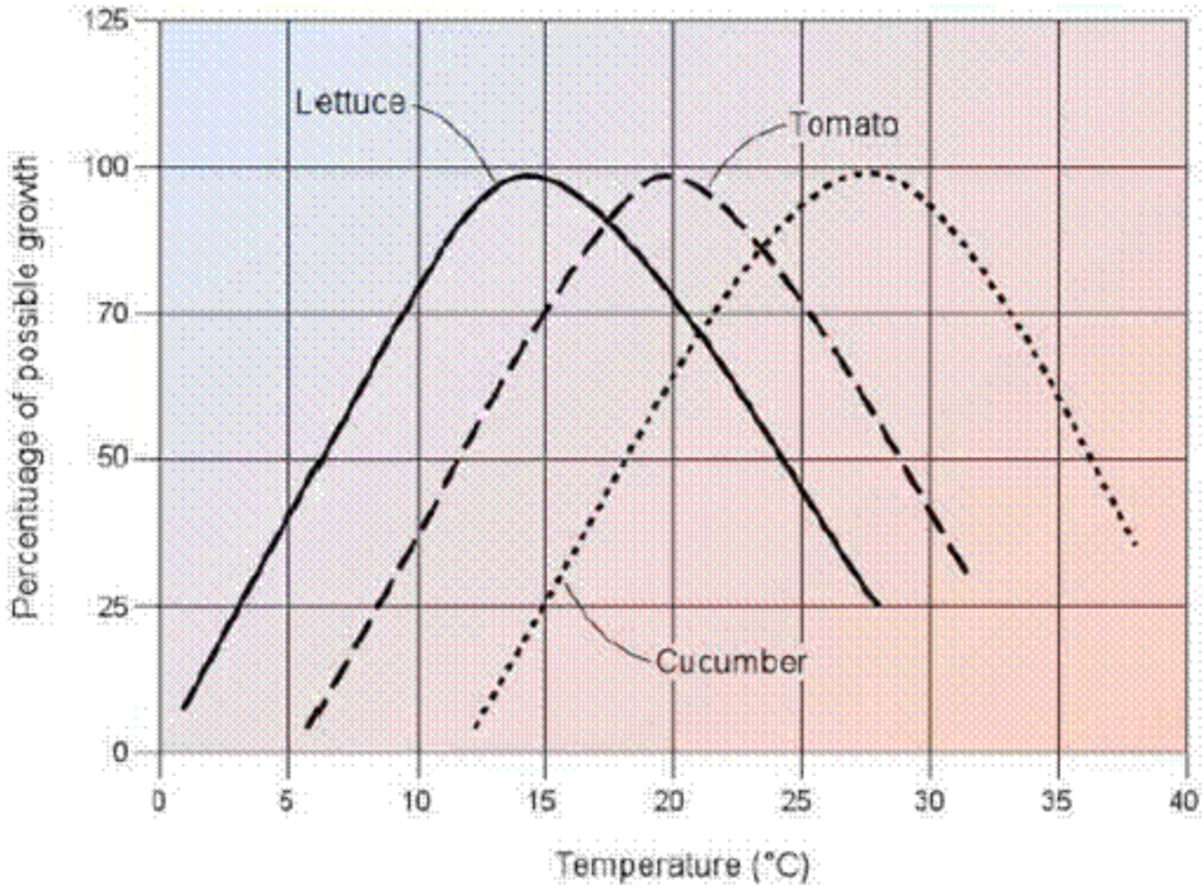
Heat and Thermal environment of the greenhouse (2)



Percentage vegetable growth in relation to temperature

Module 4: CLIMATE TECHNOLOGIES / EQUIPMENT

Lesson 4.2: Heating

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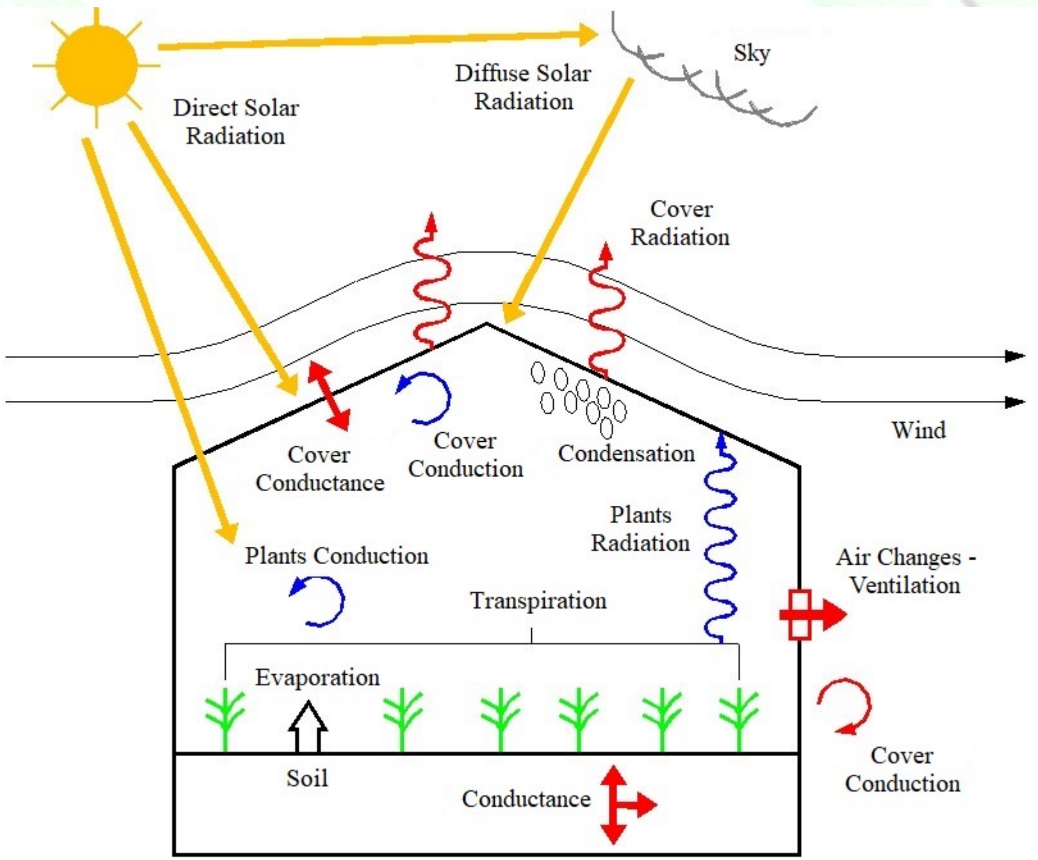
Energy exchanges (1)

- Changes that occur in the greenhouse environment are the result of energy exchanges that occur between the elements of the greenhouse and the surrounding outdoor space.
- Studying energy exchange leads to:
  - Better evaluation of the heating and ventilation challenges of the greenhouse
  - Evaluation of the various energy-saving solutior in the greenhouse
  - Understanding changes in temperature and relative humidity (RH) in the greenhouse



Energy exchanges (2)

$$\underbrace{q_1 + q_2 + q_3 + q_4}_{} = \underbrace{Q_1 + Q_2 + Q_3 + Q_4 + Q_5}_{}$$

- q_1=solar radiation
- q_2=interior of the earth (0,002%)
- q_3= plant respiration (0.3-0.4 of solar radiation)
- q_4= heating system

- Q_1 : Leakage / Ventilation energy losses
- Q_2= conduction energy losses through cover
- Q_3= convection energy losses from the cover
- Q_4= radiation energy losses from the cover
- Q_5= conduction losses from the soil to the subsoil

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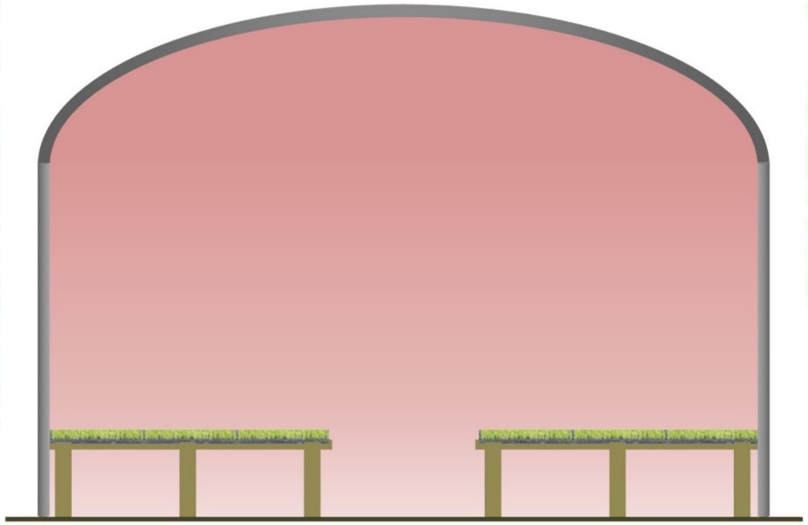
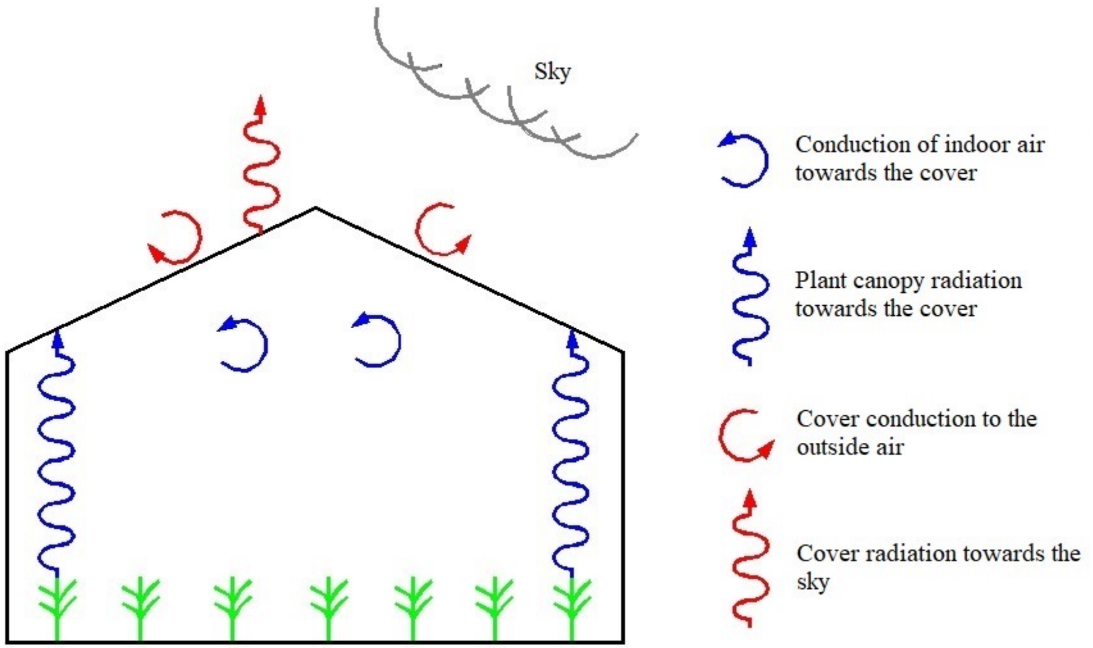
Conventional heating systems

- Conventional greenhouse heating systems are based either on the circulation of hot water through a piping system or on direct use of air heaters.
- Heating is supplied to the greenhouse air that is maintained at temperatures close and a little higher than the value targeted for the plants.
- To avoid temperature stratification due to buoyancy, conventional systems have to be combined with horizontal airflow fans to circulate air and obtain an even temperature distribution.
- The design and operational objective of conventional systems is aimed to maintain air temperature in the greenhouse at values optimal for the plant growth.

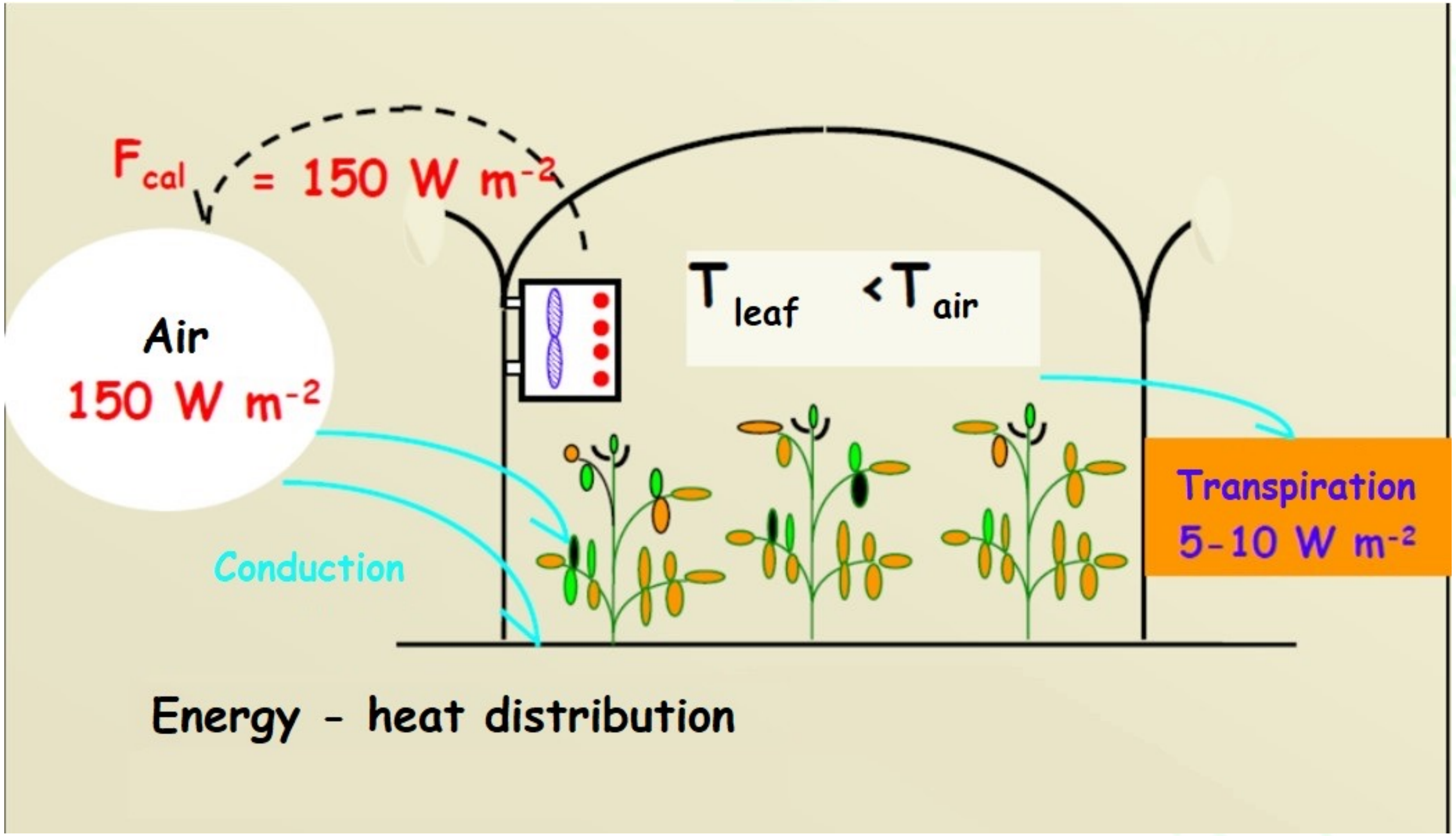


Conventional heating systems - Energy Exchanges (1)

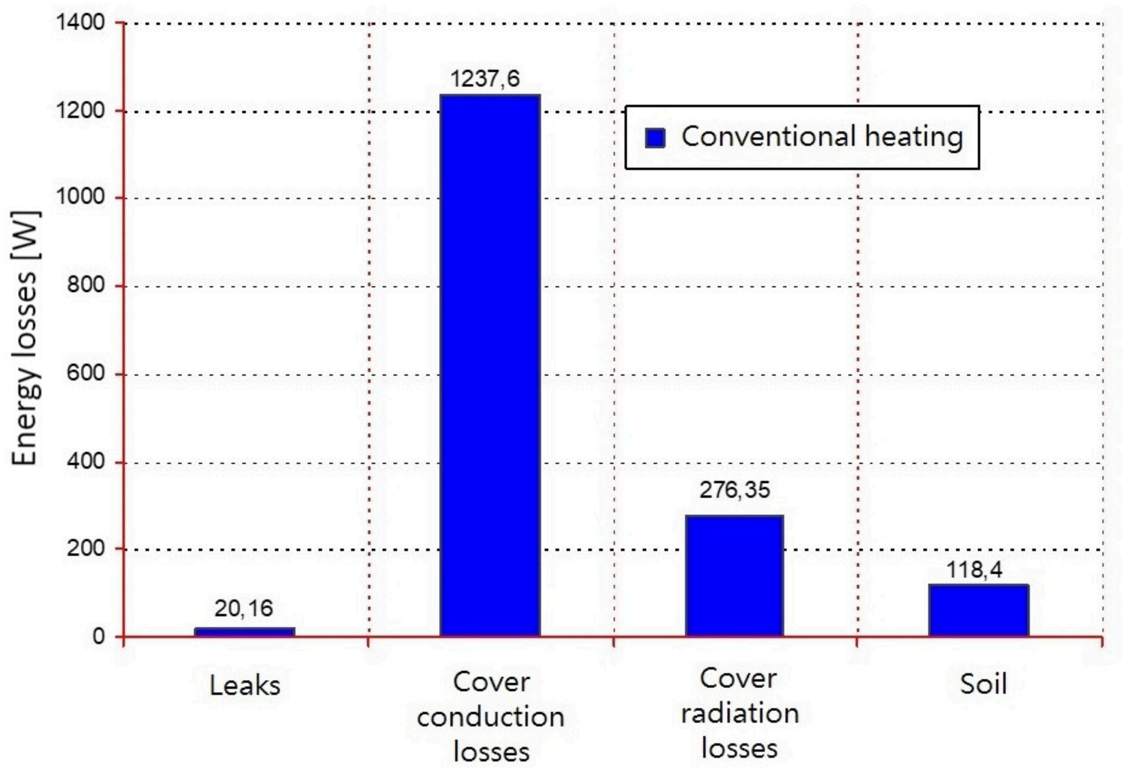
- Creation of an isothermal climate throughout the greenhouse (whole climate)
- The temperature of the indoor air and the plants is almost the same ($T\alpha \approx Tp$) or slightly higher when restoring stable conditions.
- In practice, the indoor greenhouse is a little warmer than the plants.
- The total energy losses are high.



Conventional heating systems - Indirect heating system (2)

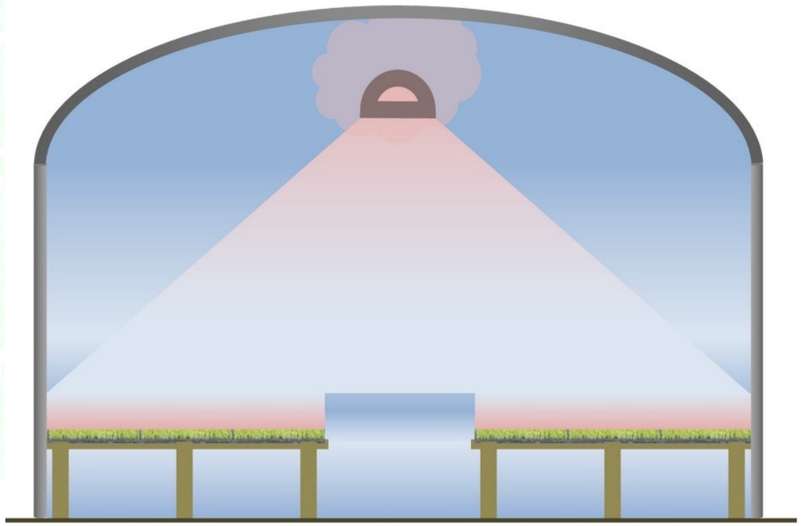


Contribution of each greenhouse component to energy losses in a conventional heating system



Infrared Heating (IR)

- Infrared radiation (IR) heating has the advantage of targeted directivity and replenishment of energy losses in specific areas
- It is particularly suitable for creating a local climate in areas with low thermal insulation such as greenhouses and livestock buildings.
- IR heating achieves: Reduction of energy requirements and environmental footprint by 40-50% due to direct uniform heating of the plant canopy alone, with no need to heat the interior of the greenhouse (Cold Greenhouse).
- IR achieves a significant reduction in plant surface moisture, which in turn reduces pests and diseases that are a very serious problem in greenhouses.



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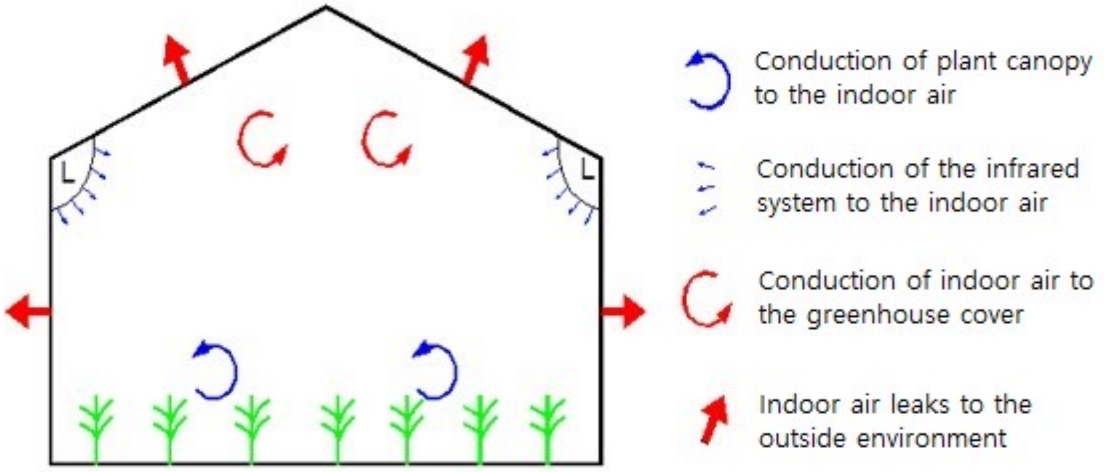
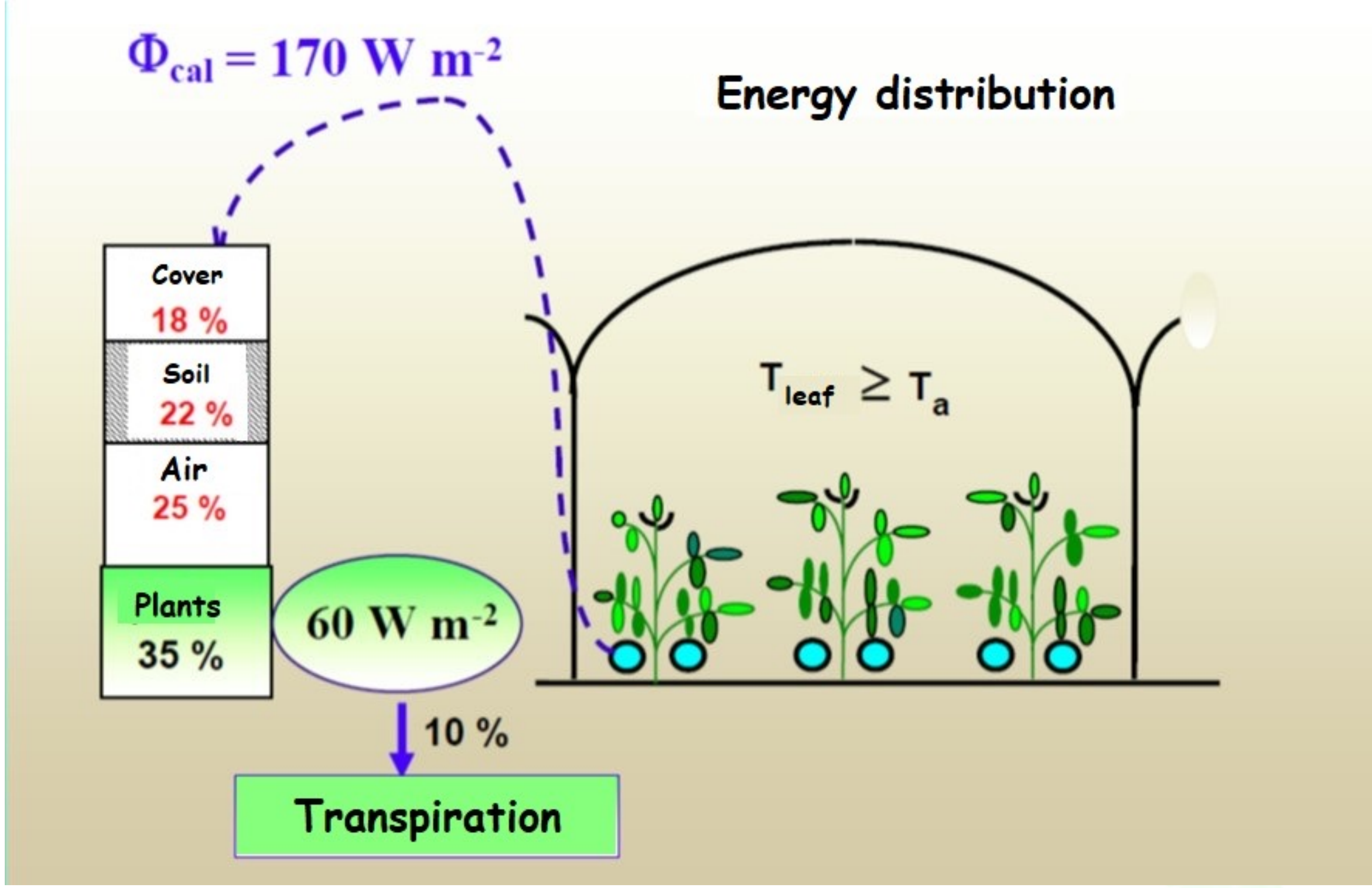
Infrared Heating (IR) - Energy exchanges (1)

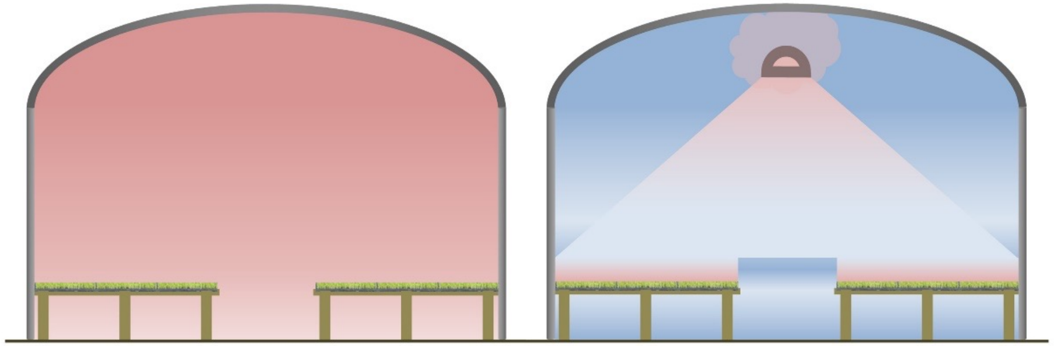
- Creation of an isothermal climate in the area of the plant canopy (local climate)
- Clear differentiation between plant temperature, T_p, air temperature T_a and cover temperature T_c
- The air and cover temperatures are unknown and lower than the temperature of the plants



Infrared Heating (IR) - Direct heating system (2)



Schematic Illustration of Heating Systems



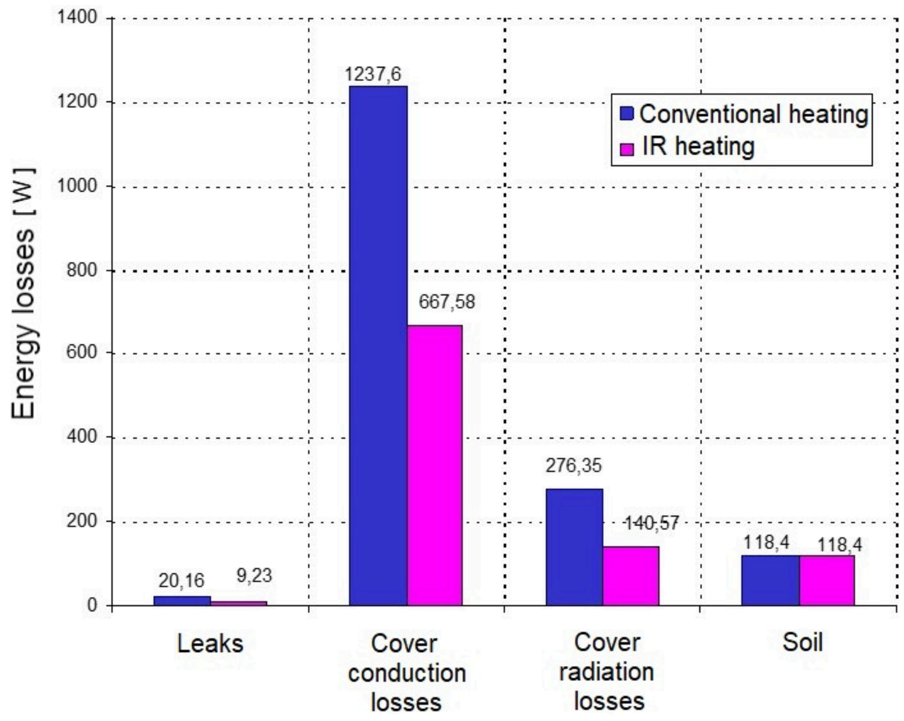
(a) (b)

Operation principles of conventional and IR heating

In conventional heating (a), the greenhouse air is heated to the temperature required for the plants with consequent thermal stratification and significant heat losses due to the low thermal insulation capacity of the cover (whole climate).

In infrared heating (b), only the area of the plant canopy is heated to the required temperature (local climate) while the greenhouse air remains at a temperature of 3-5 ° C lower, with a significant reduction of energy losses (40-50%)

Comparison of greenhouse energy losses between conventional and IR heating system



- Energy loss values for IR heating system show a significant improvement over the conventional
- Losses from the cover are reduced in absolute terms. They continue to represent the most significant contribution to total energy losses
- The result is a 40-50% reduction in the energy consumed during the restoration of stable operating conditions of the greenhouse (steady state)

Conventional Heating Systems (1)

- Distinction based on the energy source
  - Conventional Heating Systems
  - Infrared Heating Systems (IR)
- Distinction based on heat carrier
  - Air Heating
  - Hot water heating
  - Steam Heating
  - Radiation Heating
- Local heating systems
  - Fan heaters (electric, hot water, gas/oil/ solid fuel)
- Central heating system
  - Hot air boilers
  - Hot water boilers
  - Steam boilers

Conventional Heating Systems (2)

- Conventional Heating Systems include:
  - a site for the generation of thermal energy
  - a distribution network (required in central systems)
  - the heat dissipation system in the greenhouse area
  - Regulation and security devices

- In small greenhouses the elements of the heating system are usually located inside the greenhouse space (local heating systems)
- In large greenhouses, the site of thermal energy production is independent of the greenhouse (central heating system)

Conventional Heating Systems - Fan heaters

- Fan heating is widely used in greenhouses
  - It requires an average investment capital because the initial installation costs less than a central heating system
  - It has high efficiency, it is easily automated, and responds quickly to control actions
- The disadvantages are:
  - In case of malfunction, the greenhouse cools down quickly
  - The soil is not heated as much as with a central heating systems
  - Electricity consumption (15 -25% more energy required for heating than other types of conventional heating systems)

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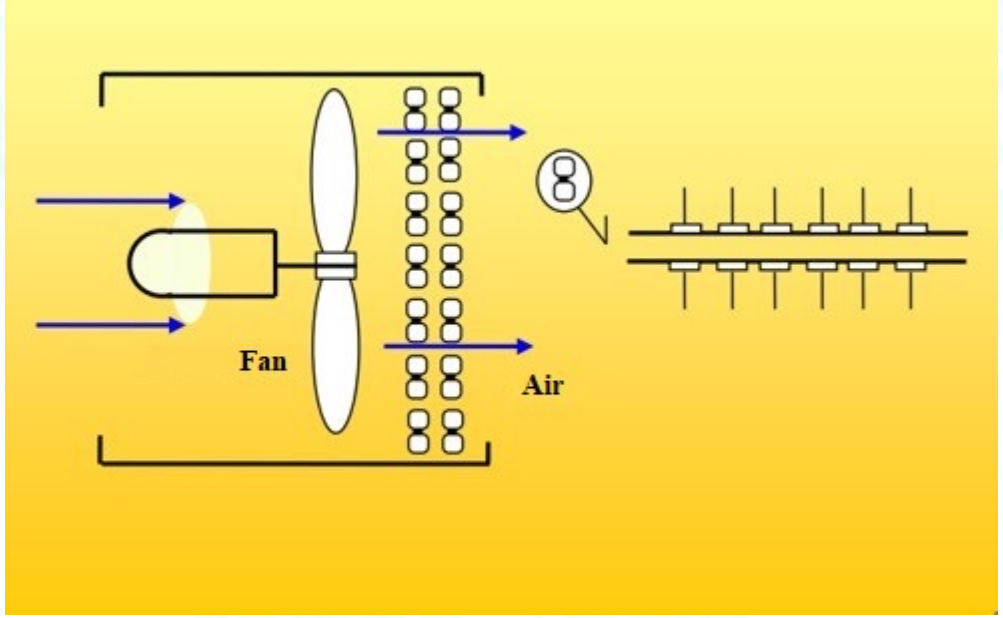
Hot water fan heaters (1)

- The hot water comes from a hot water boiler which circulates in a system of large surface pipes.
- An electric fan pushes the greenhouse air to pass between them and heat up.
- These fan heaters are usually used as additional heating in central heating systems with hot water pipes.
- They are placed high in the greenhouse, to improve air circulation in the greenhouse



Schematic illustration of hot water fan heater operation

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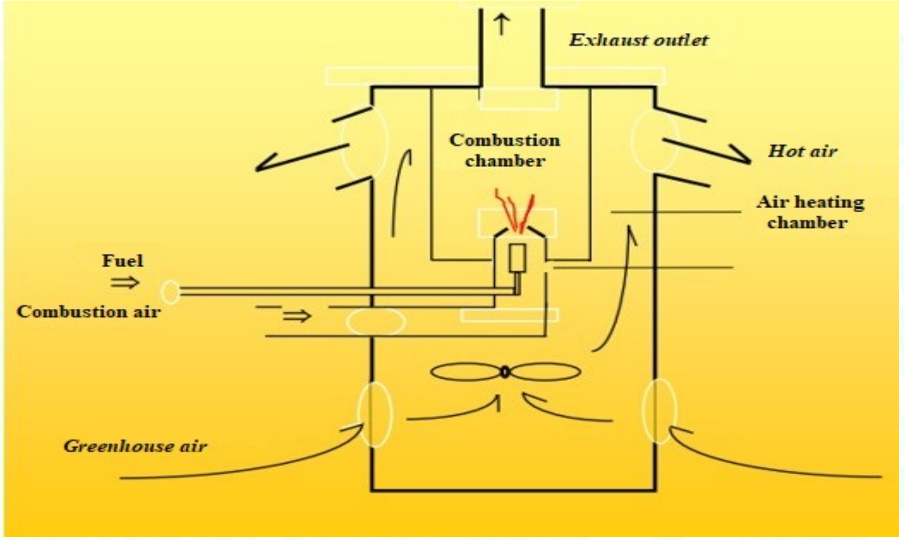
Hot water fan heaters (2)

Virtual representa-tion of hot water fan heater

Location of the hot water fan heater in the greenhouse

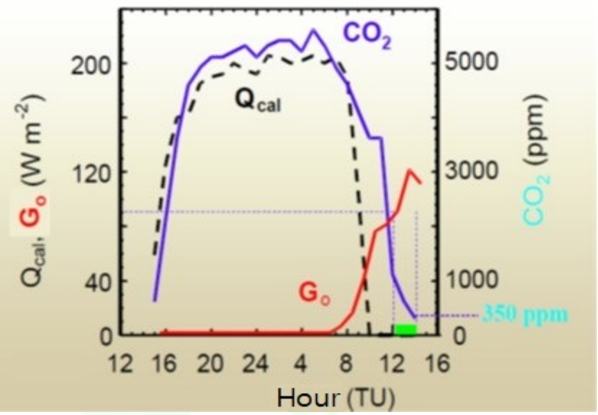
Gas/oil/solid fuel fan heaters

- They consist of the combustion chamber (open or closed), the heat exchanger and the greenhouse air circulation fan.
- In open combustion chambers, (in relatively small units), the O_2 needed for combustion comes from the greenhouse air and the exhaust gases are released into the greenhouse space.
- During daytime with photosynthesis taking place, while the fan heaters are working, the plants benefit from the CO_2 released into the greenhouse space.



Graphic illustration of Gas / oil / solid fuel fan heater operation

CO_2 production level



Heat distribution

- In large greenhouses plastic perforated pipes, which distribute hot air, are either placed at ground level or hung from the ceiling above the plant canopy line.
- Each tube is closed at its end and has pairs of round holes 4-6 cm in diameter.
- The hot air from the fan heater comes out of the holes with high speed and mixes quickly with the surrounding air.
- This system ensures uniform heat distribution.

Plastic perforated pipes placed at ground level

Plastic perforated pipes hung from the ceiling

Conventional Heating Systems - central heating system (1)

- Heat is generated in a boiler (inside or outside the greenhouse) and is transferred by heated water or steam produced in the boiler
- The heat is transferred to the greenhouse and is delivered to the greenhouse space by pipes
- Various types of fuels are used such as LPG, oil, fuel oil, and / or biomass

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Conventional Heating Systems - central heating system (2)

Heat distribution/transfer piping in the greenhouse area, act as water-air or steam-air exchangers

They are long metal pipes that run through the greenhouse and create a large heat-conducting surface with convection and radiation at approximately equal rates.

This system has the advantage of satisfactorily heating both the air and the greenhouse soil.

It has greater thermal inertia than fan heaters

It takes quite some time to achieve the required temperature.

Hot Water piping (1)

Hot water (usually 85 ° C - 95 ° C) is pumped to the greenhouse pipes

The pipes used to distribute heat around the greenhouse are black iron pipes 5 cm in diameter(2")

The length of the pipes needed in the greenhouse area is determined by the required calories (Cal) and the pipe efficiency

The required total pipe length is greater than twice the length of the perimeter of the greenhouse

Hot Water piping (2)

Positioning of the distribution pipes plays an important role for the uniform distribution of heat in the greenhouse.

Planting lines of plants with considerable height must be N-S oriented

The heating pipes, in order not to obstruct movement in the greenhouse, should be placed parallel to the plant lines

The central pipes, which carry the water from the boiler, and the return pipes, which collect the water returning from the greenhouse, are usually placed in the periphery of the greenhouse.

Hot Water piping (3)

Heat is lost faster in the periphery than in the center of the greenhouse

In order to achieve uniform temperature, a large part of the energy must be delivered to the periphery of the greenhouse by installing a sufficient piping length.

About 1/3 of the piping (not more than 6 rows of pipes or less than two) is placed around the perimeter.

The rest of the pipes are placed in the interior, either all of them at a low height between the plants, or some between the plants and the rest on the roof.

Hot Water piping - Efficiency (4)

<u>Pipes efficiency</u>

Thermal efficiency of iron pipes for greenhouse heating with hot water and temperature difference between hot water and the greenhouse space 60℃

Pipe Diameter	Surface of one m long, in m^{-2}	Efficiency in Watt*m^{-1}	
		Layout: horizontal o o o	Layout: vertical o o o
¾'' (1.9 cm)	0.084	70	59
1'' (2.54 cm)	0.105	88	73
1 ¼'' (3.17cm)	0.133	111	93
1 ½'' (3.81cm)	0.152	127	106
2'' (5.08cm)	0.160	134	112
2 ¼'' (5.71cm)	0.179	150	125
2 ½'' (6.35cm)	0.199	167	139
2 ¾'' (6.98cm)	0.220	184	153
3'' (7.62cm)	0.239	200	167

Hot Water piping (5)

Vertical Layout of Hot Water Piping (Trombone system connection)

Horizontal Layout of Hot Water Piping (Trombone system connection)

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Hot Water piping (6)

- The location of the heating pipes, which are placed inside the greenhouse, depends on the greenhouse and the cultivation type:
- In small width greenhouses, piping usually 5 cm (2 ") in diameter is placed along the poles, leaving the soil free for cultivation in one direction.
- In benches for potted plants and plant propagation, the heating pipes are placed under the benches.
- In cut-flowers, some heating pipes are placed high in the greenhouse, so that the heat radiation balance is positive for the plants and water vapor condenses on them are avoided.

Heating pipes on the periphery and inside the greenhouse

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Hot Water piping (7)

Often the metal heating pipes in vegetable greenhouses are combined with mechanical movement and are placed on the ground surface, in the corridor area, where they also serve as rails of a transport wagon.

This placement achieves very good heating of the soil and the root system of the plants. The temperature distribution is quite good. In some cases, however, problems with increased evapotranspiration have been observed.

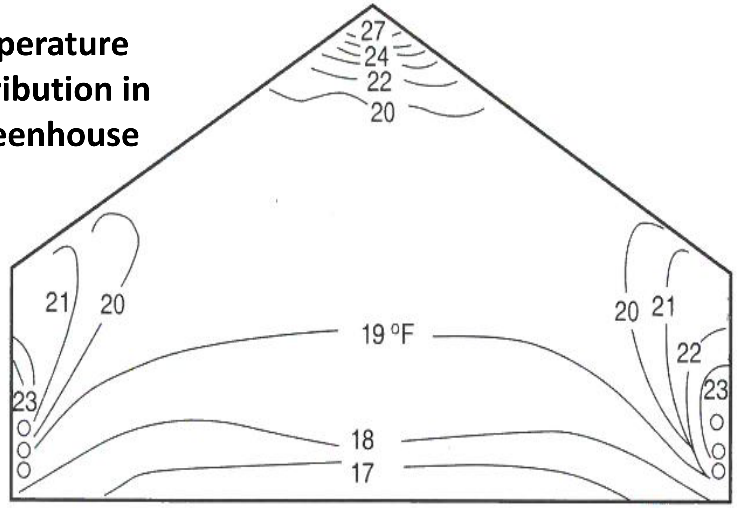
When the greenhouse is located at snow-covered areas, placing a few pipes high so that the snow melts faster near the gutters, protects the greenhouse from the risk of collapse and improves the thermal radiation balance of the plants.

Hot water piping on the ground surface combined with mechanical movement for harvesting

Horizontal Air Flow Fans (HAF)

- In greenhouses with conventional heating systems, a vertical change of temperature is created, because the hot air rises (1.5 °C for each meter of height) and stratification is created.
- To avoid such stratification that creates greater heat loss in the greenhouse and adverse effects on plant growth, horizontal air flow fans are used (> 12m / min)

Temperature distribution in a greenhouse



Horizontal Air Flow Fans virtual representation

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Low temperature hot-water heating systems (1)

- Heating systems that use water with a temperature of 20-60 °C, often combined with use of RES but also from conventional fuels
- Polyethylene (PE) or polypropylene (PP) pipes are used to distribute heat in the greenhouse
- The great advantage of low temperature water is that it allows the use of heating elements made from low-cost materials, such as polyethylene.

Low temperature hot-water heating systems (2)

- The most important differences of these systems in relation to the conventional ones are:
  - In order to dissipate the same amount of heat, the surface of the heating elements must be larger, or the heat transfer coefficient must be higher.
  - Due to the low temperature of water leaving the heat generator, it requires a larger mass of water and therefore larger diameter pipes.

Conventional fuel

In conventional heating the advantages of each fuel depend on its availability in the area, its price, its efficiency and the environmental footprint.

LPG is first in preference. The heating system can be easily automated, the installation has a lower initial cost, no storage tanks are needed, it burns with very high efficiency and less work is needed to maintain the burner.

Second comes oil and then fuel oil. The heating system can be easily automated, but the burner needs frequent maintenance (approximately every ten days in winter)

Infrared (IR) Systems / Applications (1)

The use of infrared (IR) for heating greenhouses and farm buildings can be a reliable alternative to conventional heating methods

Existing technology, reliability and ease of use allows efficient application of infrared heating systems in large-scale production greenhouses.

The cooperation of the companies SYSTEMA S.pa - Italy, NATURAL GAS - Thessaloniki and the Department of Agriculture of University of Patras, led to applications in commercial greenhouses for the production of seedlings and floriculture in Greece with excellent results

Infrared (IR) Systems / Applications (2)

System of gas-fired IR radiators comprising of six radiant tubes, of 18 m length and of 45KW thermal power each, placed at a height of 3.0 m above the plant canopy in an arched greenhouse in the region of Koropi, Attica, Greece.

Infrared heating systems type INFRA MONOTUBO 18MI, heat capacity 45KW each, powered by LPG (Propane) fuel (www.natural-gas.gr)

Infrared (IR) Systems / Applications (3)

BAF burner

IR tube with reflector

The “INFRA” propane gas radiant tube designed and manufactured by SYSTEMA S.R.l. (www.Natural-gas.gr) canopy in an arched greenhouse in the region of Koropi, Attica, Greece.

Infrared (IR) Systems / Applications (4)

Infrared heating systems type INFRA MONOTUBO 18MI, heat capacity 45KW each, powered by LPG (Propane) fuel (www.Natural-gas.gr)

Infrared heating systems type INFRA MONOTUBO 18MI, heat capacity 45KW each, powered by LPG (Propane) fuel (www.Natural-gas.gr)

Infrared (IR) Systems Results

IR infrared heating allows the creation of zones in individual parts of the greenhouse, with different temperature conditions, depending on the requirements of each crop.

The benefits of IR heating are not limited to plant growth but also reduce the possibility of diseases.

The relatively higher temperature of the plant canopy prevents the formation of condensation, reducing the relative humidity and consequently the development of fungal diseases.

The contribution of heated greenhouse installations in Greece to CO_2 emissions represents about 70% of the total agricultural caused emissions. By replacing conventional heating with IR, CO_2 emissions will be drastically reduced by up to 50%.

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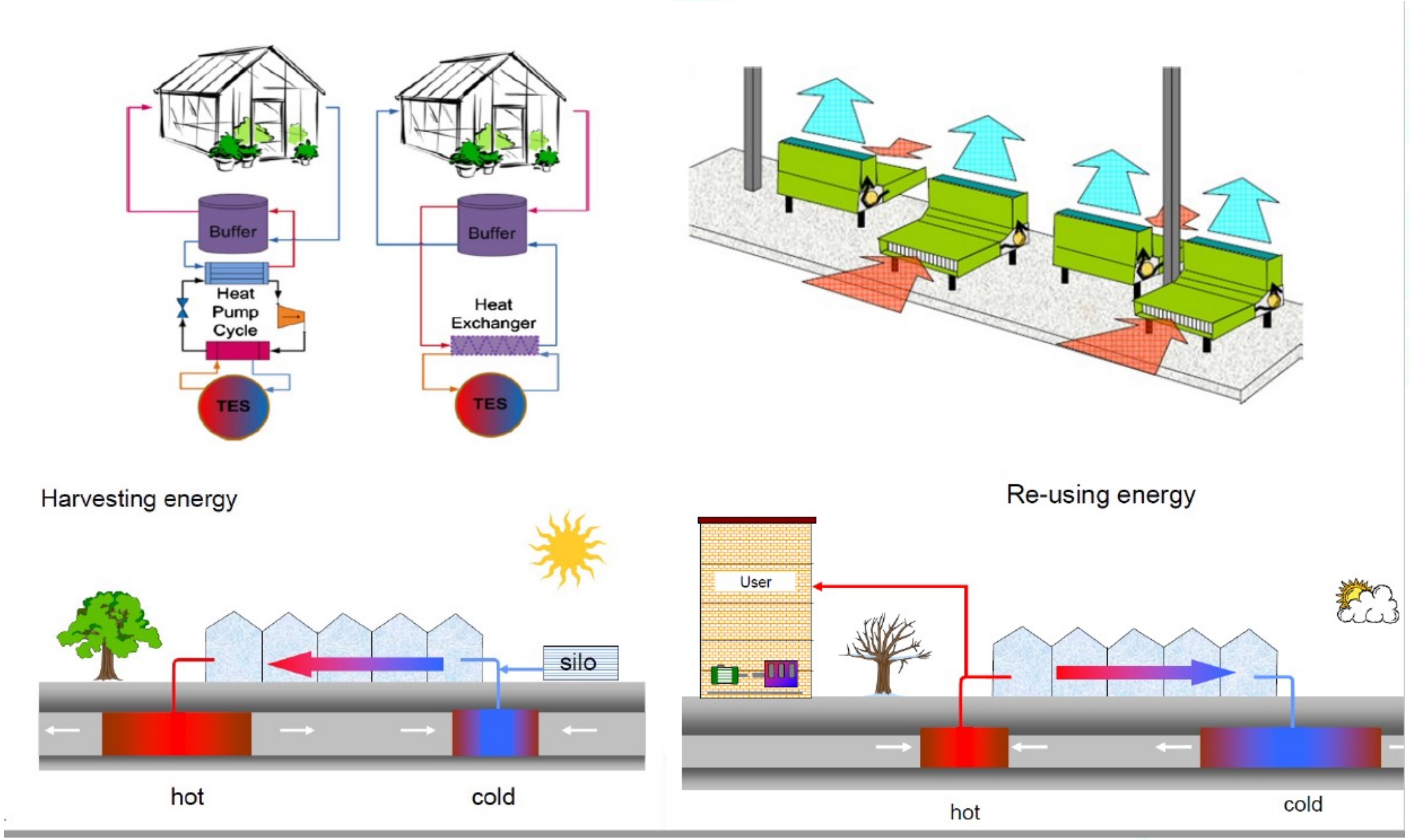
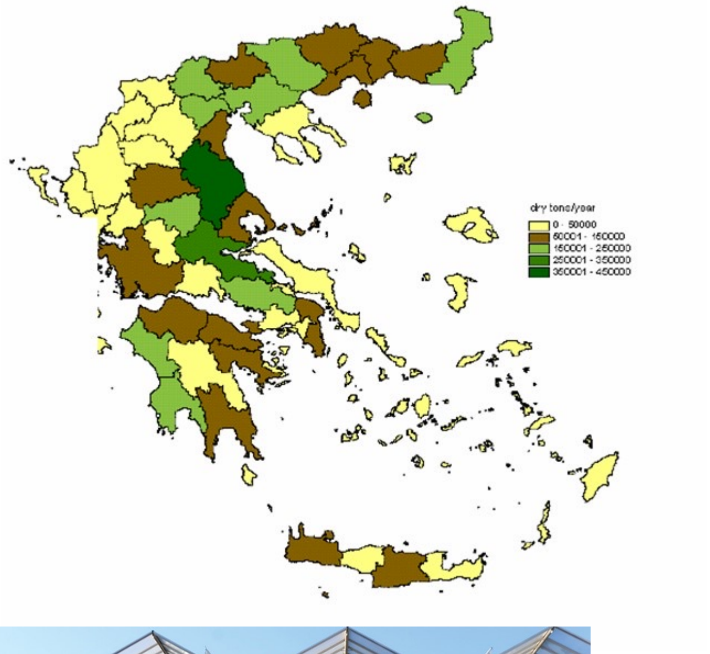
Energy autonomous greenhouses, geothermal energy



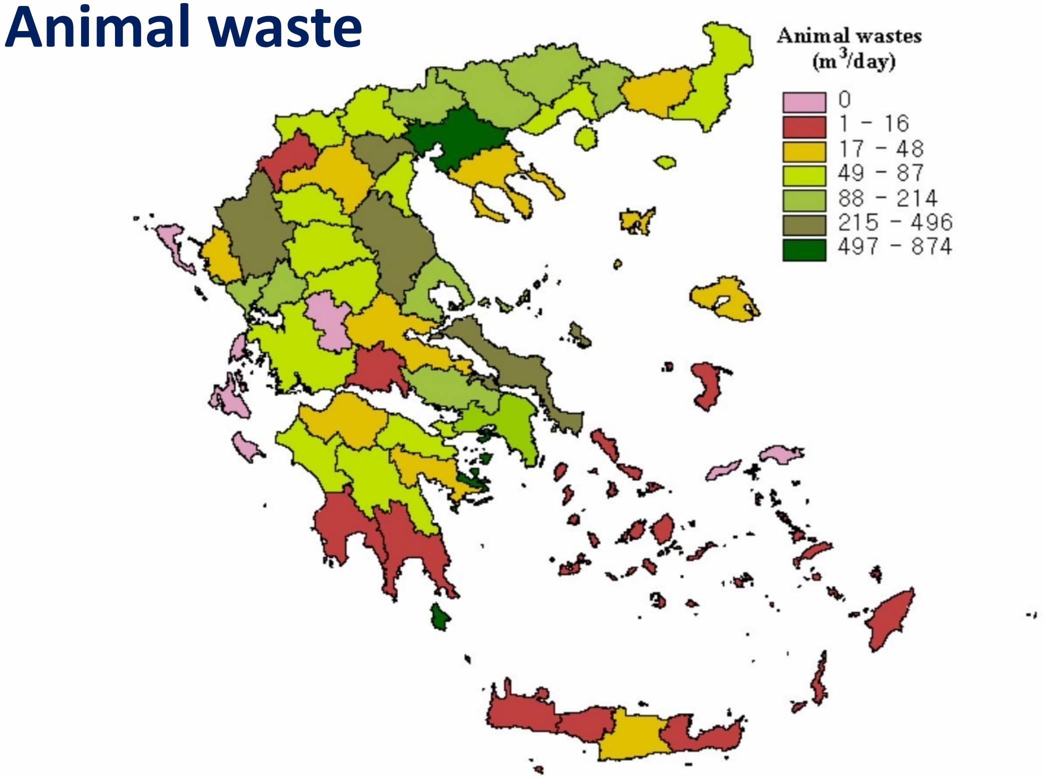
Greenhouses - inputs

Energy

Agricultural residues

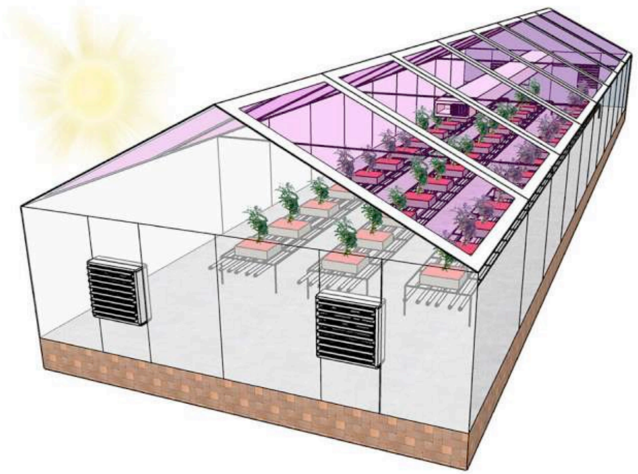


Animal waste



Research found that the clean energy that could be produced, theoretically, from the combustion of agricultural residues in the region of Magnesia amounts to 339,077 GJ per year, when heating greenhouses requires energy of 43,149 GJ per year

Energy autonomous greenhouses, solar energy



Cost comparisons estimation

Assumptions

- Greenhouse area of 1.000 m^2
- Temperature difference $T_{in} – T_{out}$ = 13 ^{0}C
- Energy losses coefficient U = 7 W/m^2K
- Coverage material area A_c = 1350 m^2
- Power demand: 120 kW
- Hot water heating: floor heating

Greenhouse of 1.000 m²			
	Conventional Systems		**IR Systems**
	Hot water heating (piping)	Air Heating	Radiation Heating
Energy	Petroleum	Biomass/Petroleum	LPG-Gas
Equipment cost	13.000-15.000 (1 boiler & pipes)	10.000-12.000 (3 air boilers)	18.000
Installation cost	1.500	1.500	3.000
Installation time	4d	2d	7d
Operating cost/year			
Glass/PC	34.500	8.400/10.000	16.500
PE (polyethylene)	36.000	10.600/12.500	19.400

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