International Training Workshop on
Protected Horticulture in China

Researches and Application of Protected Agriculture Technologies on the Cultivation of Vegetables

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Content

- **Development of protected horticulture in China**
- **Environmental control in protected horticulture**
  - **Light (light intensity, light period and light quality)**
  - **CO_2**
  - **Temperature (air/root/leaf temperature)**
  - **Humidity**
  - **Air current speed**
- **Challenges and perspectives**

1 Development of protected horticulture in China

Necessity development of protected horticulture in China

------ Population explosion（now 1.3 billion, to 2030, will be 1.5 billion ,food demand rising）

------ Land resources reducing (only 0.08 ha per capita in China, 40% of world average level) & Agricultural pollution, desertification

------ Natural disasters (drought, flood , etc.)

------ Demands increasing for fresh, clean, pesticide-free vegetables

------ Agricultural labors' aging problem (Young people don't like to be engaged in agriculture, more than 60% farmers in China are over 60 years old)

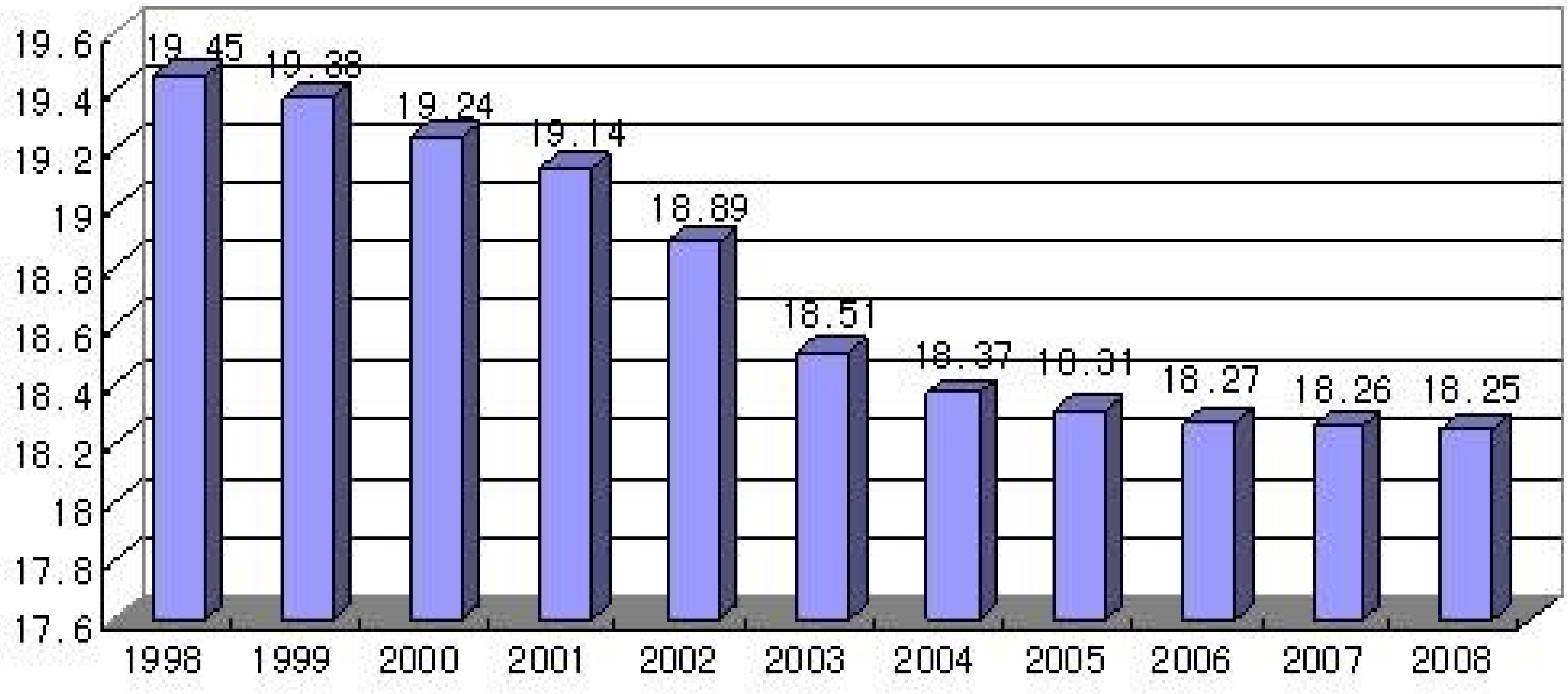
……

Ratios of Chinese urban population

Up to 2025, nearly 70% of Chinese will live in cities with more than 1 million people.

Land resources reducing & Agricultural pollution, desertification **(reducing cultivated land 300,000hm^2 each year)**

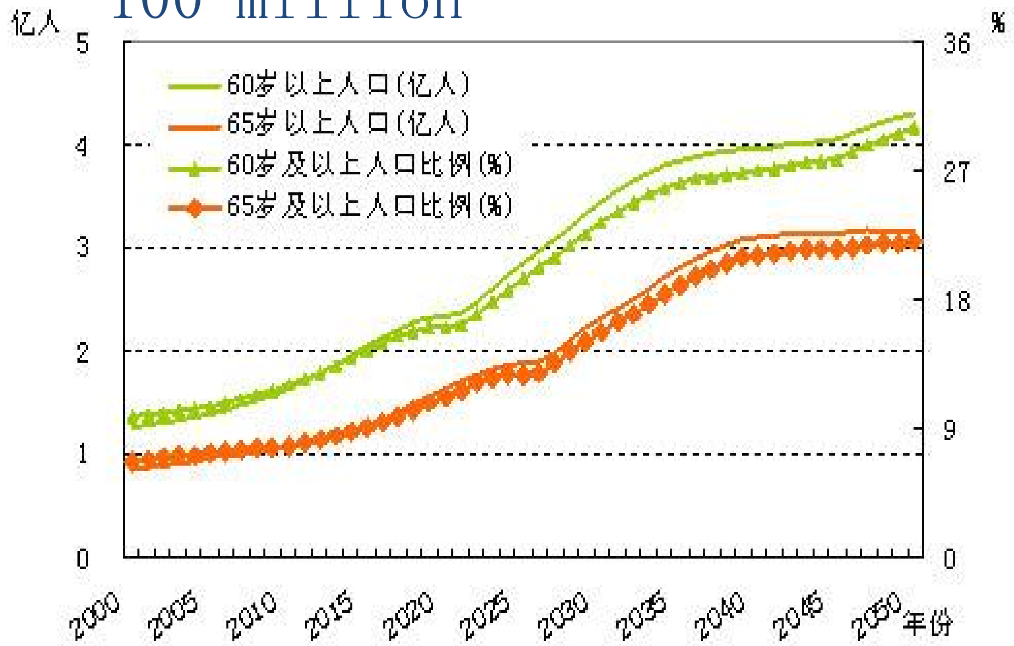
Natural disasters (drought, flood , etc.)



Cultivated land in China (100 million MU)(1MU=1/15 **hm^2**)

Rapid Aging of agricultural population, shortage agricultural labor

100 million



Food demands increasing (470 million tones of vegetables each year (330 million tones of vegetables for the residents in cities)

How to solve the above problems?

Population explosion

Large number of people in cities

More requirements for food (vegetables)

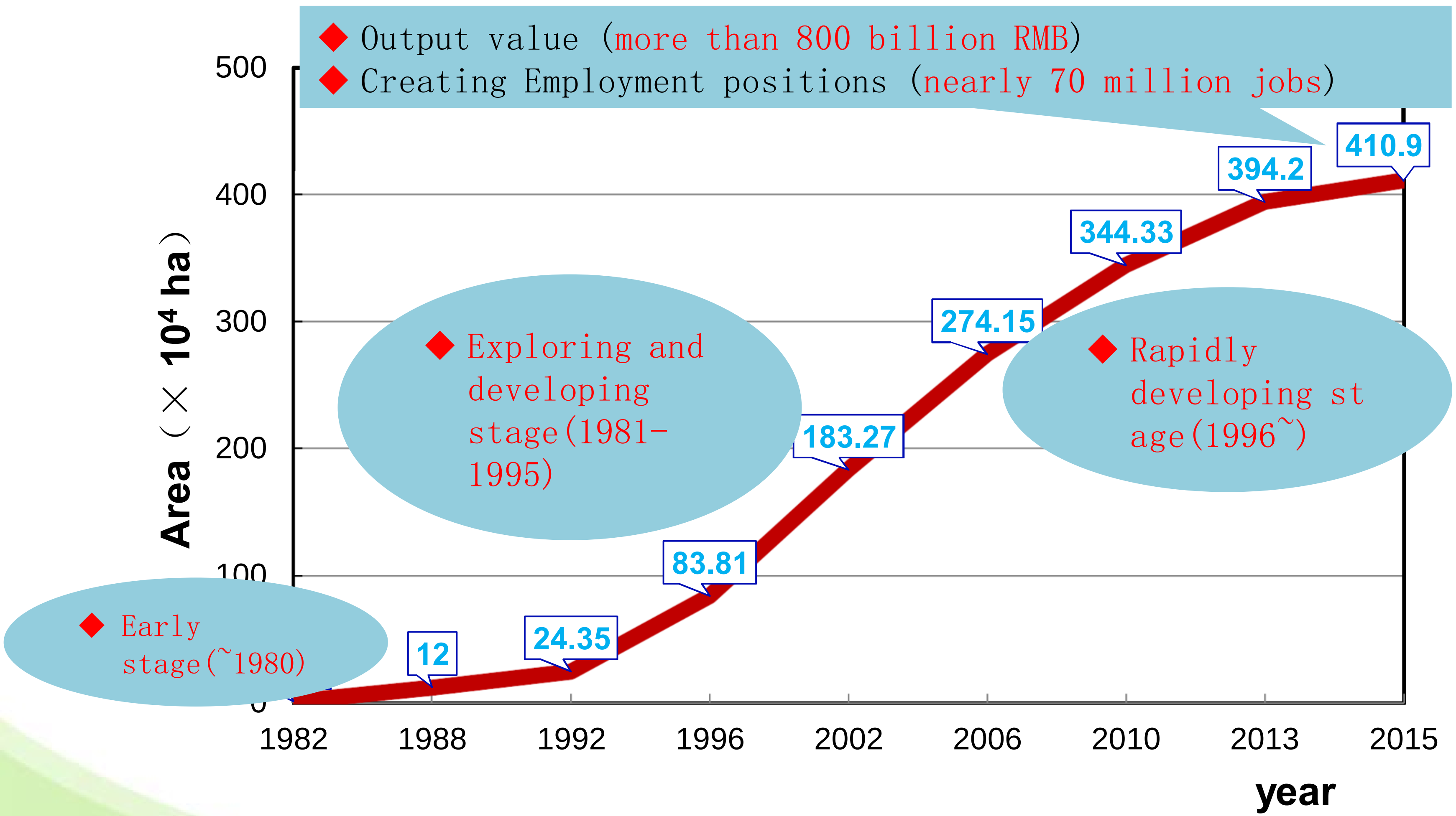
Land resources reducing

Natural disasters

Agricultural labors' aging problem

Development of protected horticulture is the best way to solve the problems

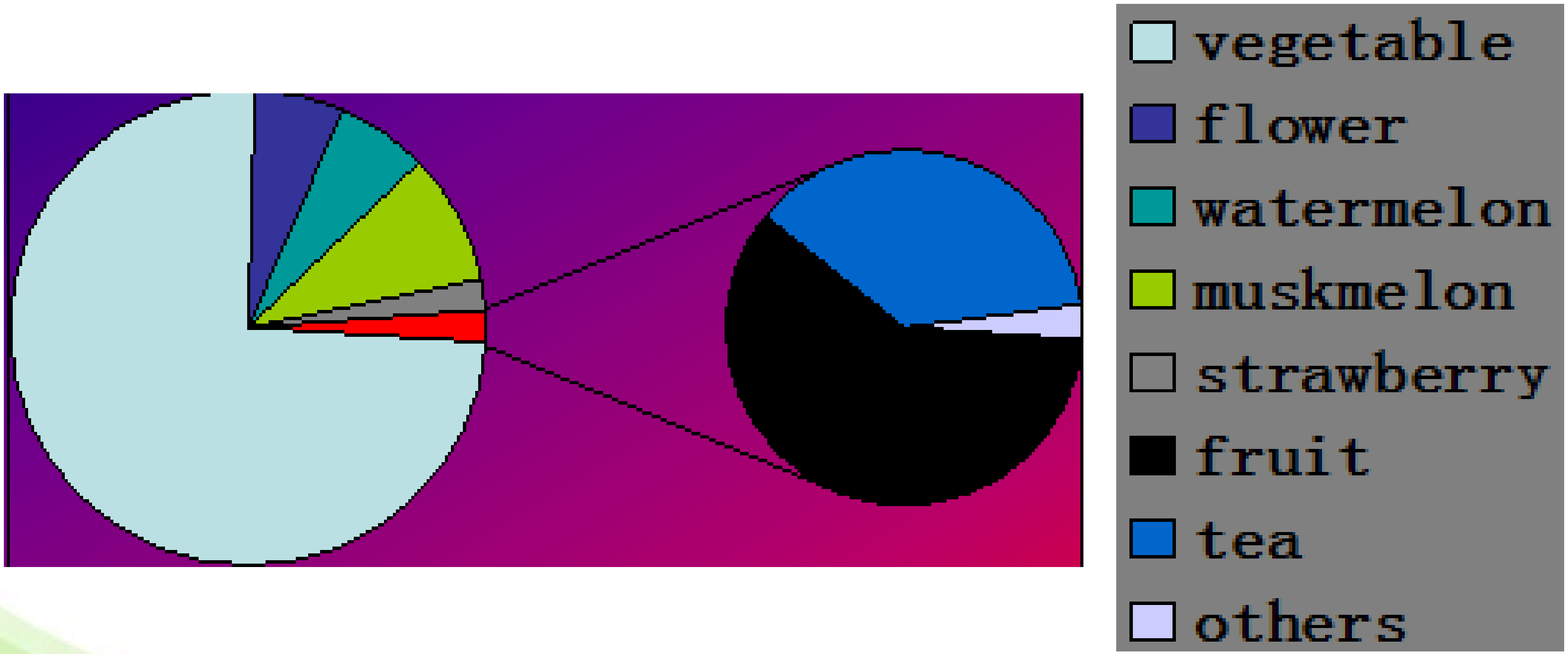
Development of Protected Horticulture in China

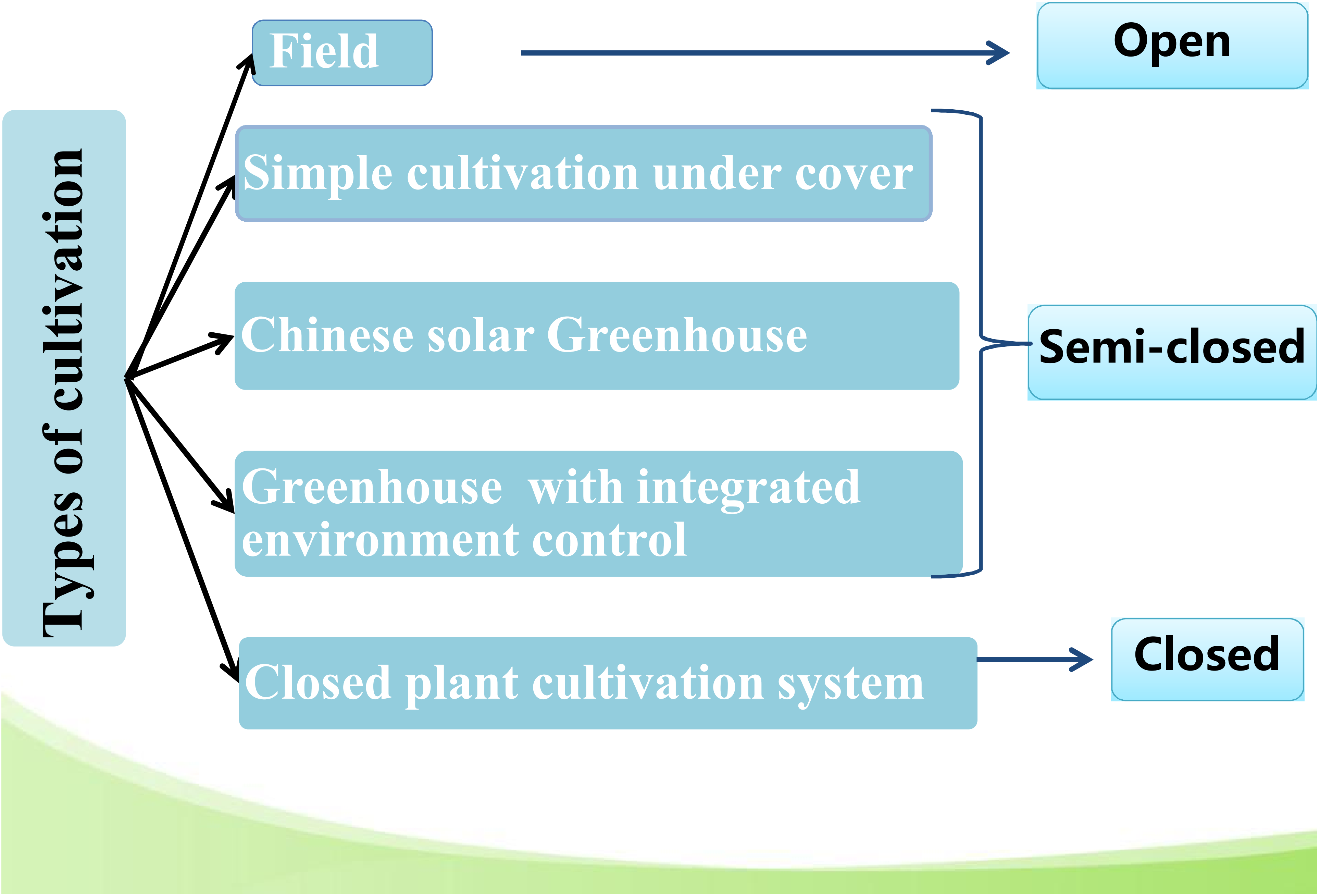


(Data from China Agriculture Yearbook ,2015,MOA)

Crops for protected cultivation in China

Vegetable 74.4%, Flower 6.1%, Watermelon 6.1%, Muskmelon 9.3%, Strawberry 1.9%, Fruit 1.3%, Tea 0.7%, and others 0.2%.




Types of cultivation
Field
Simple cultivation under cover
Chinese solar Greenhouse
Greenhouse with integrated environment control
Closed plant cultivation system
Open
Semi-closed
Closed

Simple cultivation under cover

Chinese solar greenhouse

Greenhouse with integrated environment control

Cooling/heating, CO_2 enrichment, hydroponic, Shading/Thermal screen, computer control , etc.

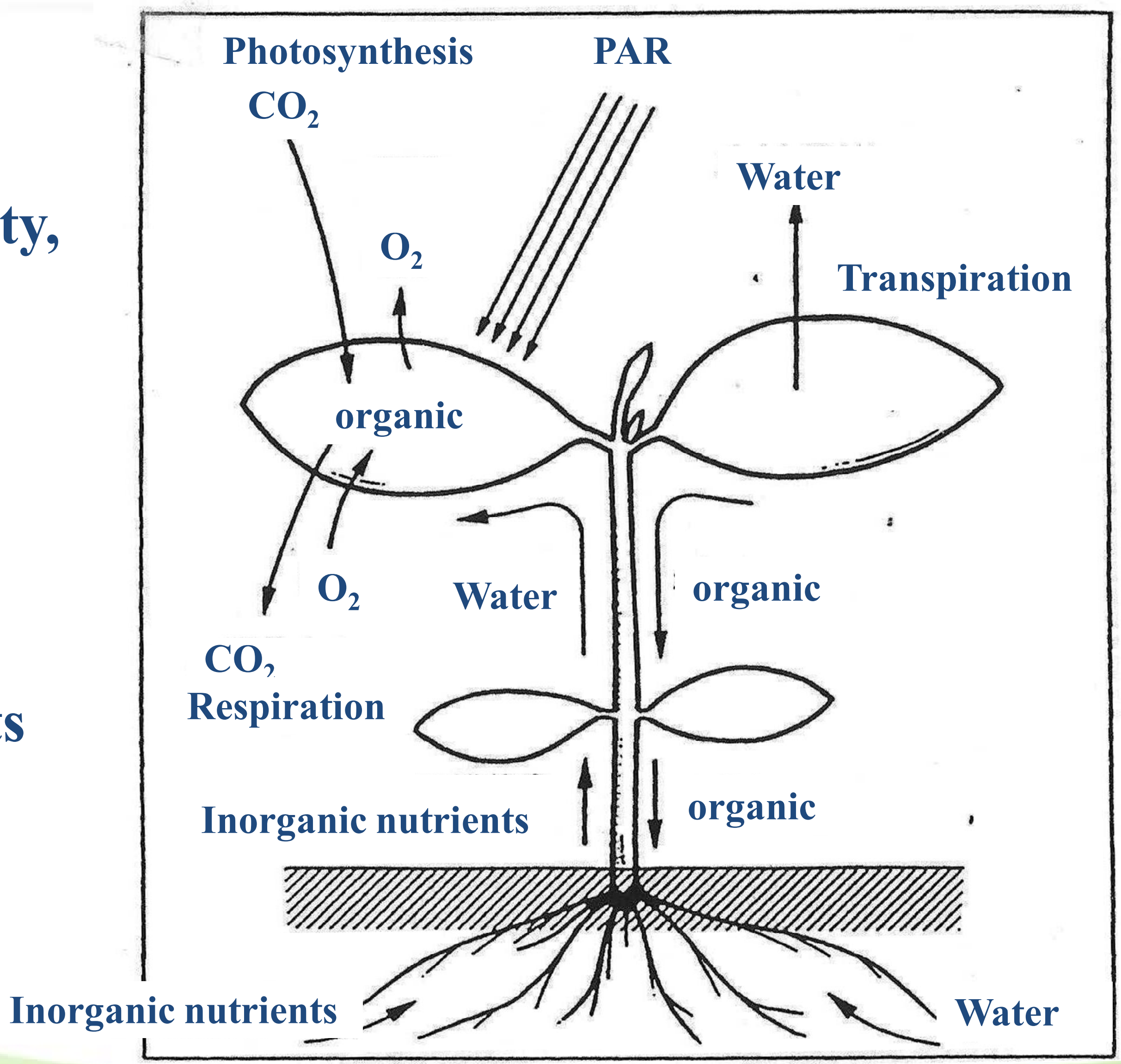
Closed plant cultivation system

Environment factors can be controlled as designed

2 Environmental factors in protected horticulture

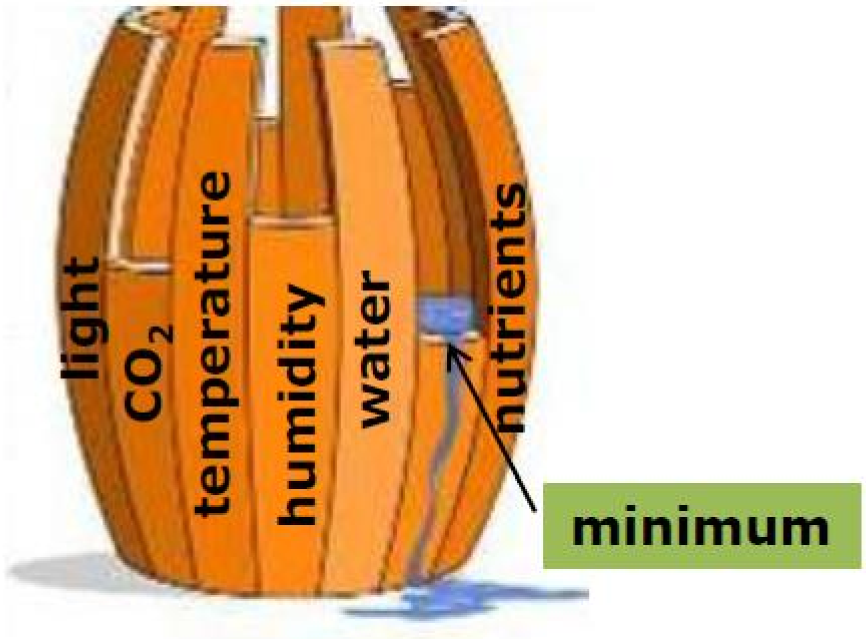
Essential resources for plant growth

Light
(intensity, quality, photoperiod)
CO_2
Temperature
Relative humidity
Air current speed
Water
Inorganic nutrients

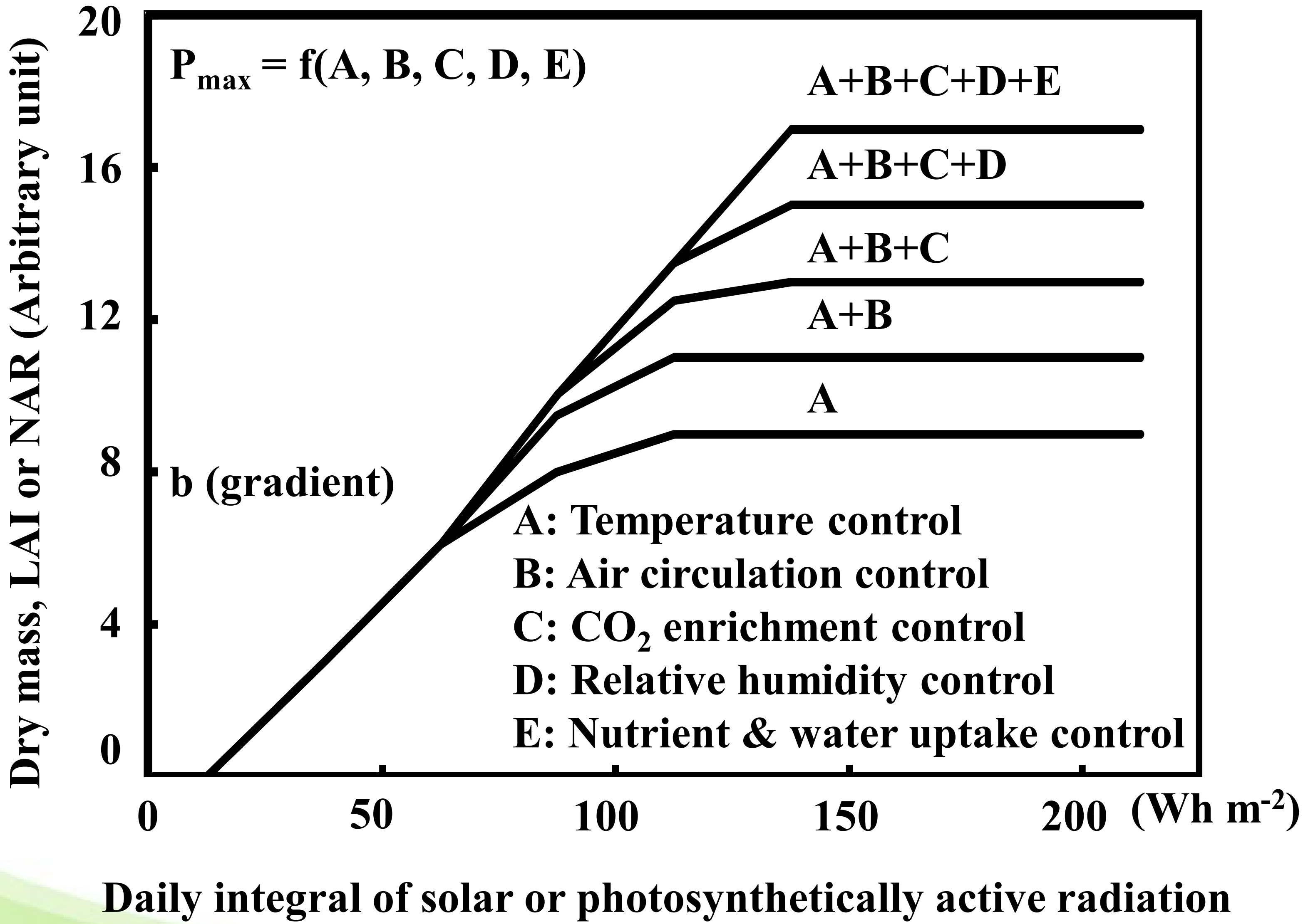


Interrelationship of the environmental factors

- All environmental factors need to be optimum at the same time for maximum vegetable yield and quality;
- It does not help to improve one factor, if another factor is limiting production



Benefit of the integrated environment control



Kozai, 2009

2.1 Light

- Rule of thumb: 1% less light means 1% lower yield
- Data from literature and growers:

Crop	Yield reduction at 1% less light
Lettuce	0.8%
Radish	1%
Cucumber	0.7-1%
Tomato	0.7-1%
Rose	0.8-1%
Chrysanthemum	0.6%
Pointsettia	0.5-0.7%
Ficus benjamina	0.6%

More light by…

- Advanced covering material
  - *White glass (+1-2%)*
  - *Modern coatings on glass (+5-8%)*
  - *New plastic films ETFE (+3%)*
- Lighter greenhouse construction (5-10%)
- Change plastic film on time (5-10%)
- Cleaning (10-15%)




Necessity for supplemental lighting

Low light on cloudy and other extreme weather （raining 、snow、fog）；

Shorter and weak sunlight in high latitude (Netherlands)

Long-day plants production

Plant factory with artificial light

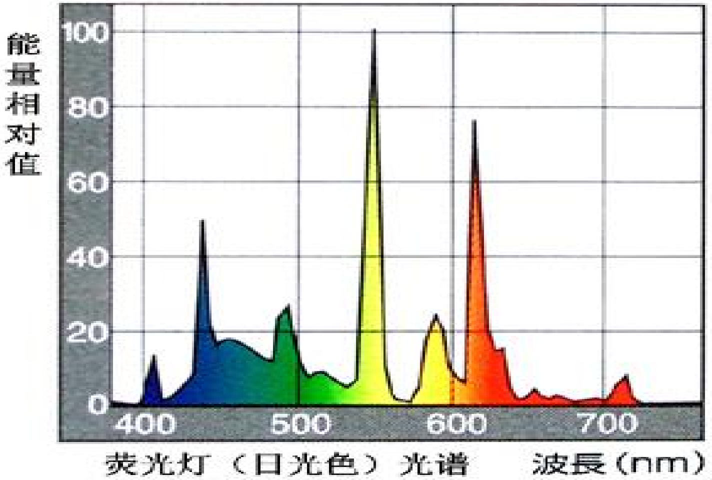
Dealing with haze

Haze reduces light intensity over 50%, and photoperiod, affecting negatively growth, flowering and fruiting of vegetables and fruits in greenhouses

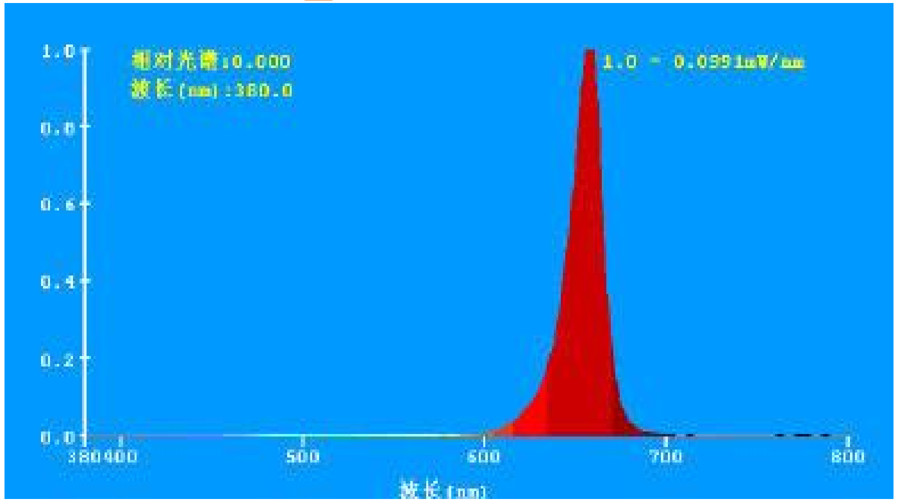
Main Light sources

- Light-emitting diodes (LED) lamps
- Fluorescent (FL) lamps
- High-press sodium (HPS) lamps

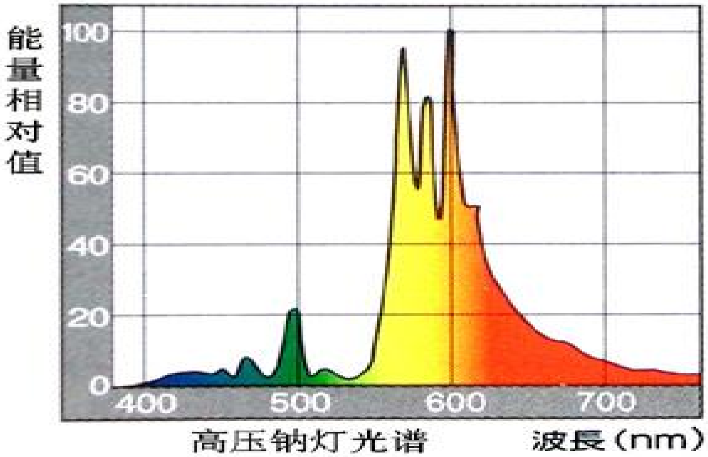

Light spectral distribution of FL, HPS and LED lamps



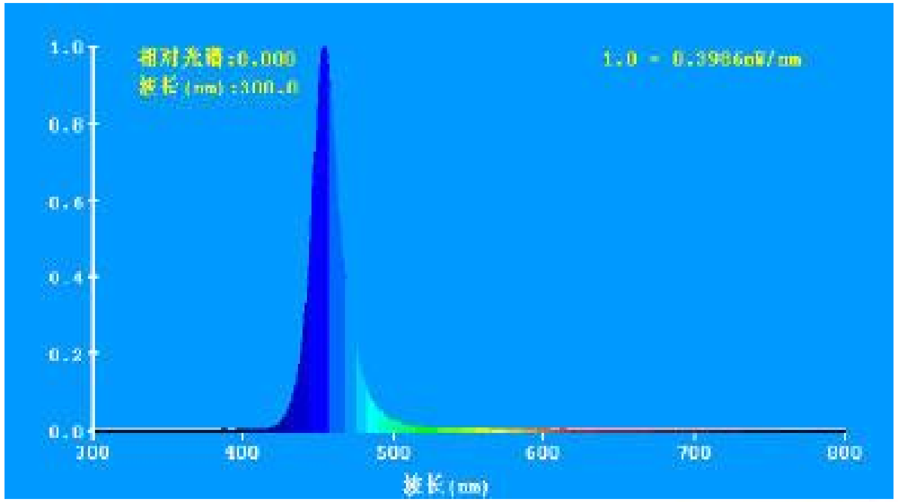
FL: Deficient in red light, rich in thermal radiation



Red LED spectrum: narrow wave width of 660nm, no heat radiation



HPS: Deficient in blue light, abundant in red and orange light, rich in thermal radiation



Blue LED spectrum: narrow wave width of 450nm, no heat radiation

Advantages of LED as light source

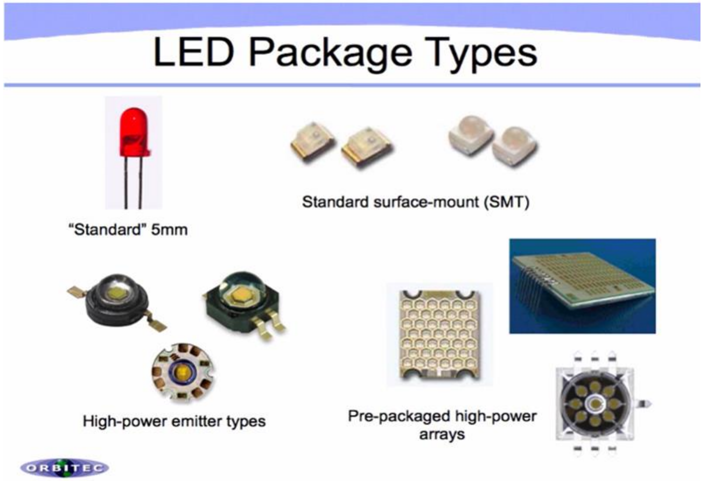
◆**Emitting specific color according to photosynthetic requirements of plant;**

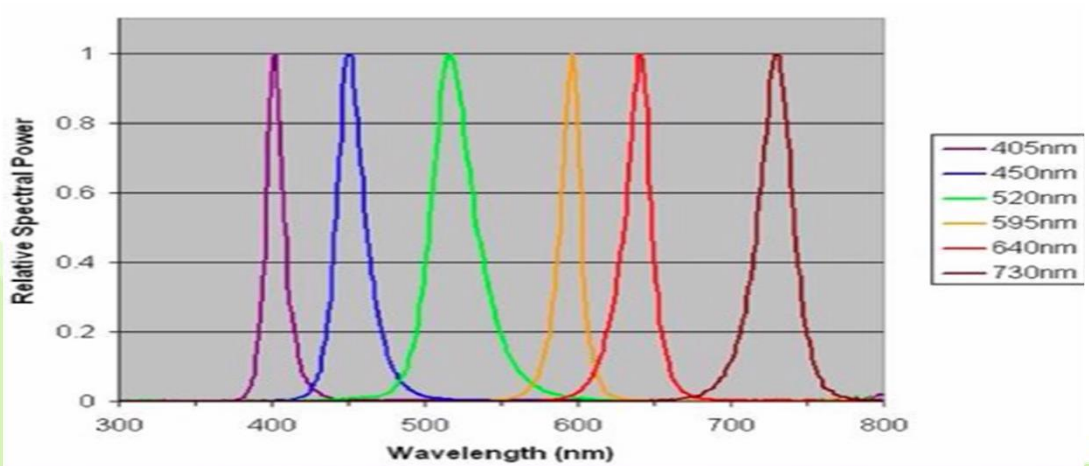
◆**Light adjustable (R/B, R/FR);**

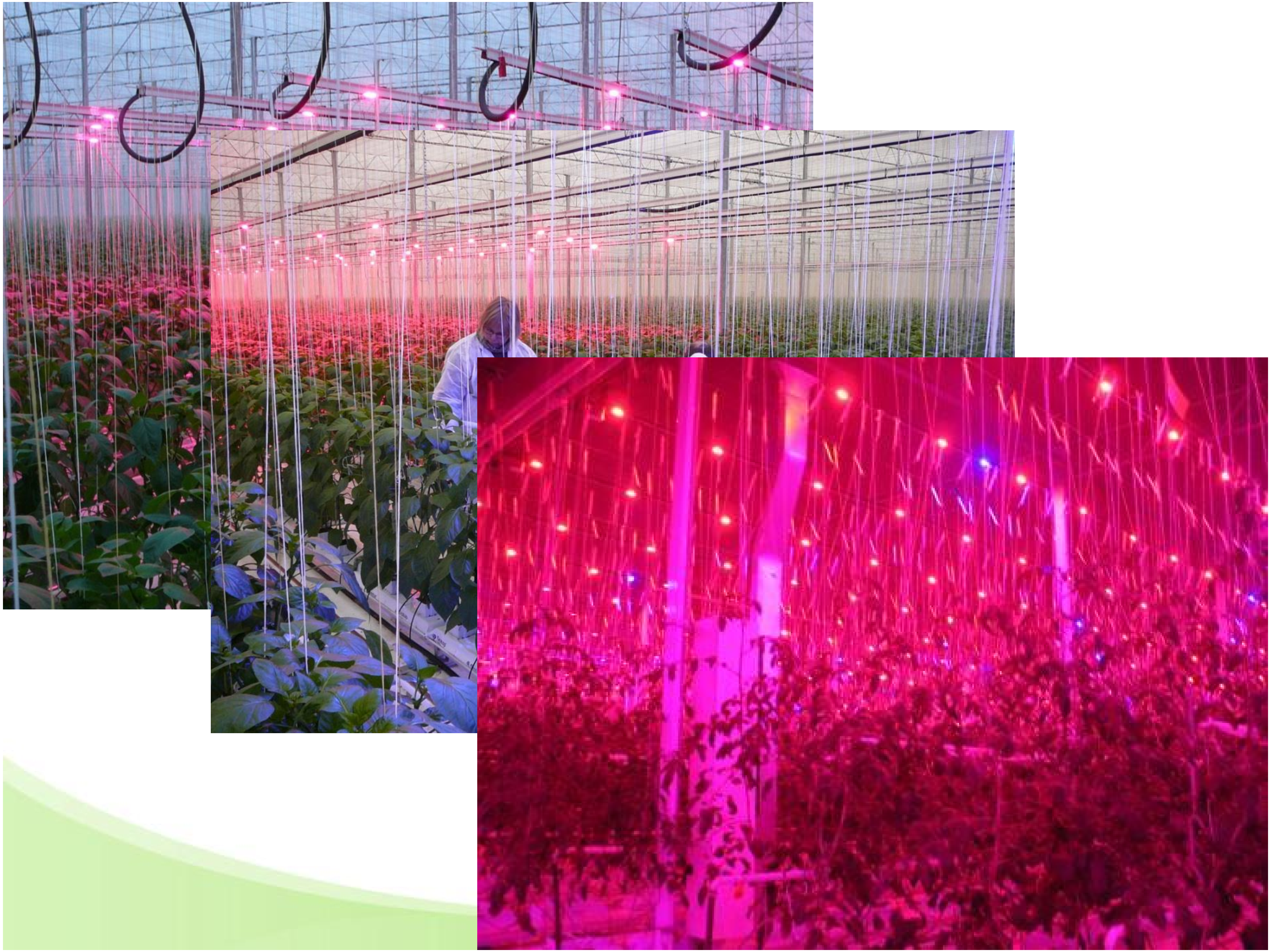
◆**Energy-saving without heat generation;**

◆**Long life;**

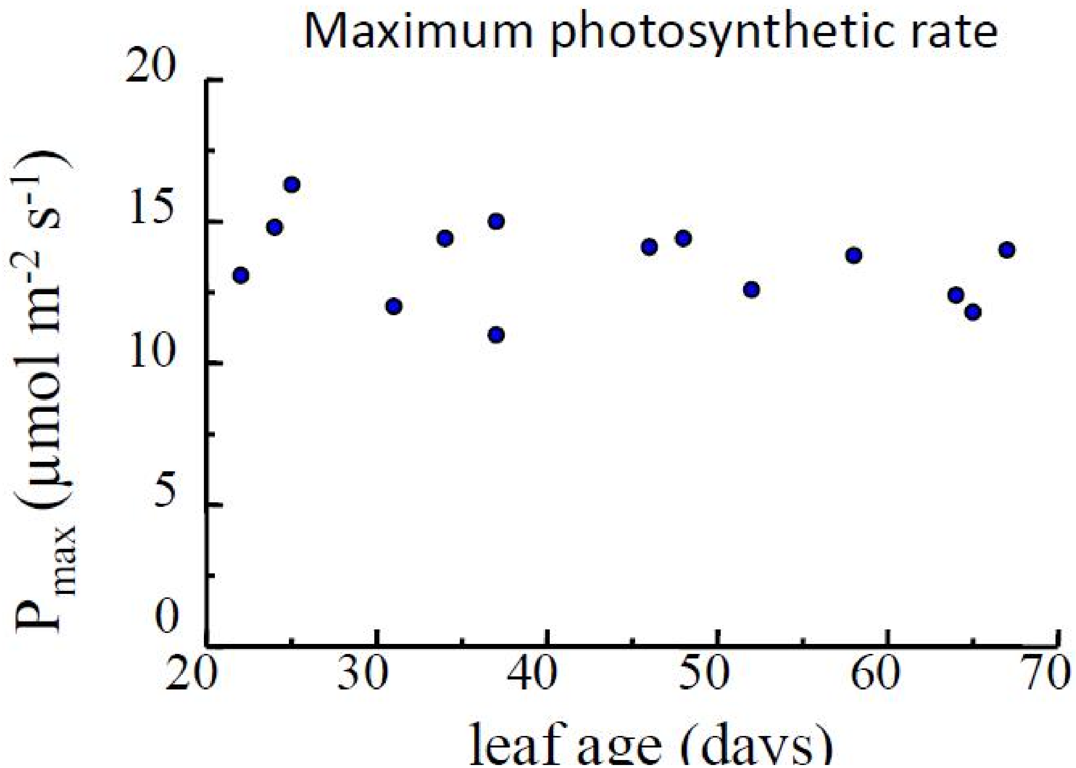
◆ **environmentally-friendly** without mercury (Hg) when it is broken.







No ageing effect during life time of tomato leaf

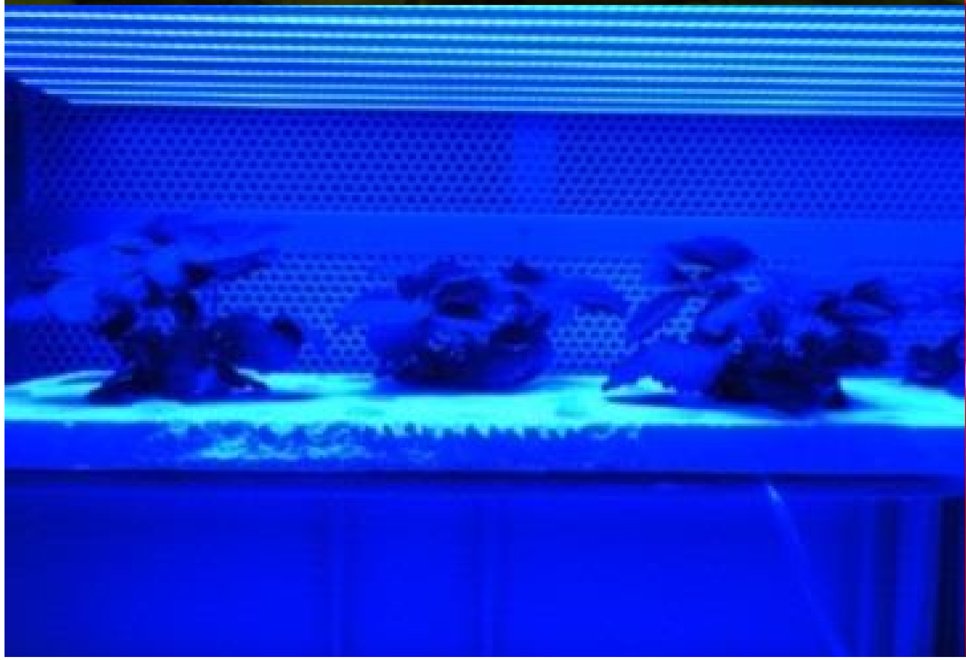


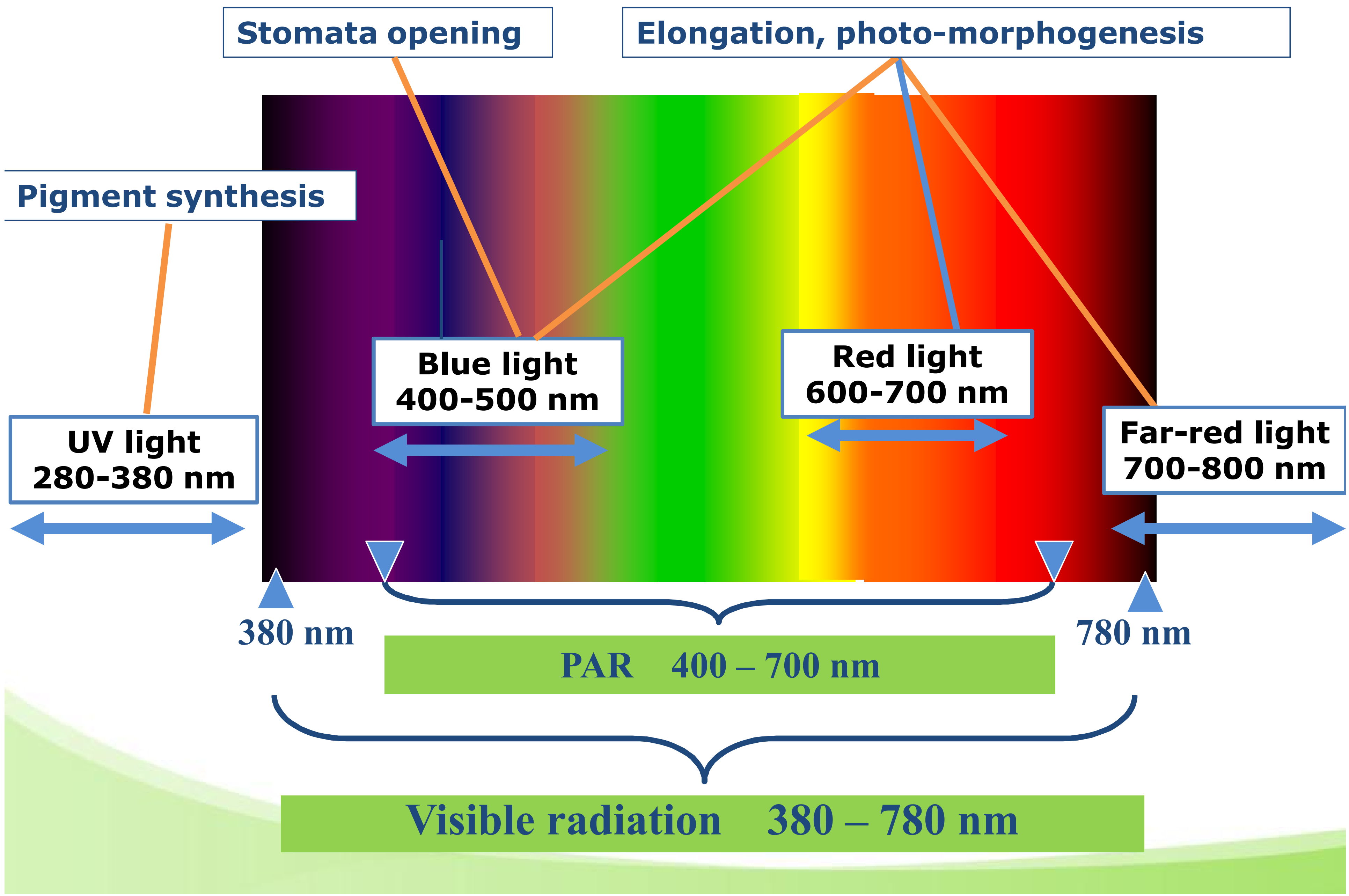
Photosynthetic ability of tomato leaf will not affect by its growth days (Trouwborst et al., 2011)c

Interlighting can result in yield increase

6-8% annual increase is observed for cucumber and tomato plant

Artificial light is the sole light source in Plant factory

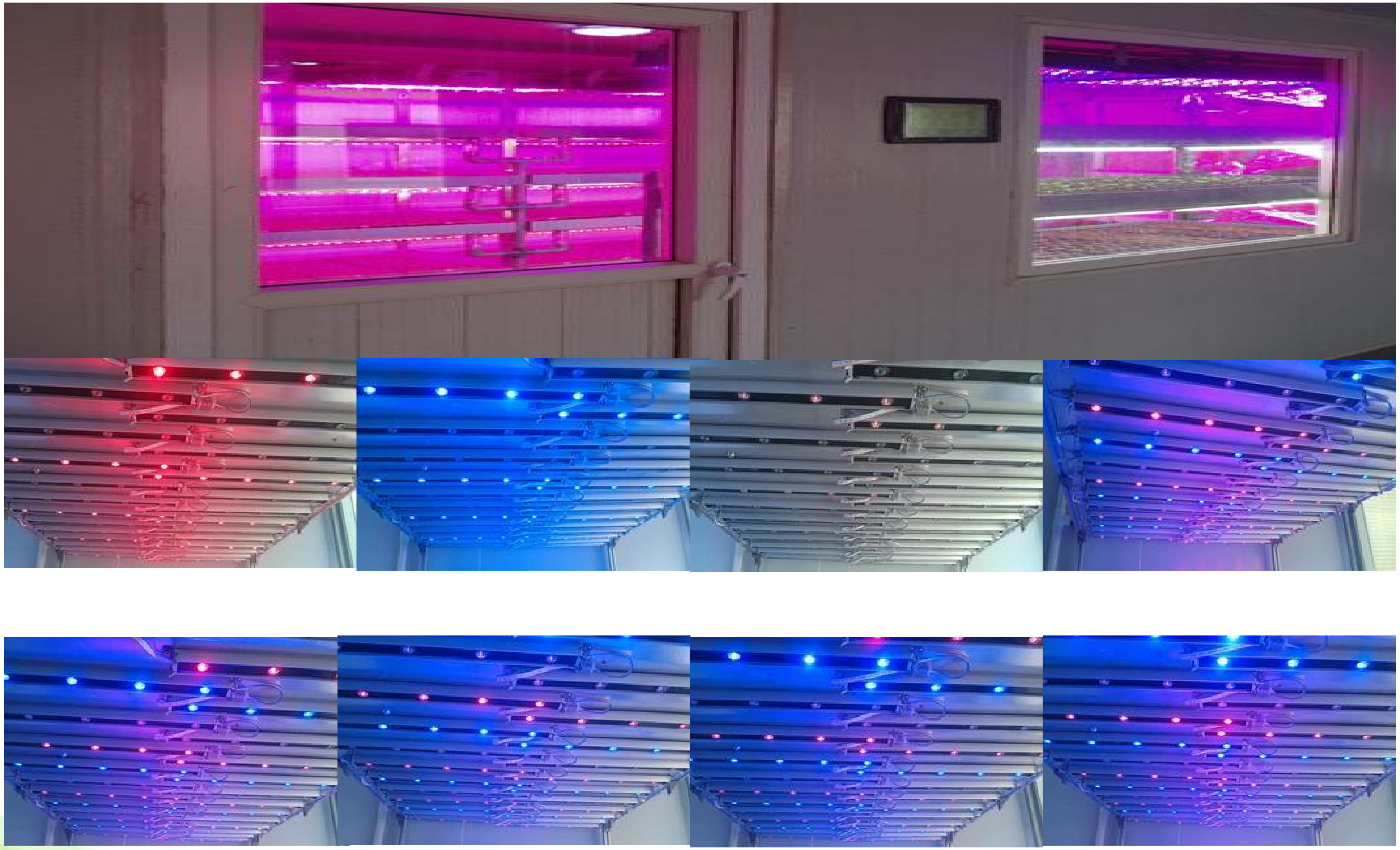



Stomata opening
Elongation, photo-morphogenesis
Pigment synthesis
Blue light
400-500 nm
Red light
600-700 nm
UV light
280-380 nm
Far-red light
700-800 nm
380 nm
780 nm
PAR 400 – 700 nm
Visible radiation 380 – 780 nm

Bioactive light quality, their names and wavelength ranges

Spectral light	Chinese name	English name	Wavelength（nm）
Ultravoilet	UV-C	ultraviolet light	200-280
	UV-B		280-320
	UV-A		320-380
Visible light	紫光	Purple light	380-420
	蓝光	Blue light	420-450
	青光	Cyan	450-490
	蓝绿光	Blue-green light	490-500
	绿光	Green light	500-560
	黄绿光	Yellow-green light	560-580
	黄光	Yellow light	580-590
	橙光	Orange light	590-620
	红光	Red light	620-700
Far-red light	远红光	Far-red light	700-780

LED lighting experiment



R50%B50%F

Roles of light quality in regulating nutritional quality of vegetables

- **Light quality regulation is potential method to improve nutritional quality of vegetables, such as sprouts (pea seedling, soybean and radish sprouts) , leafy vegetable (Lettuce) and fruit vegetables (tomato).**

Chlorophyll a, b and nutritional quality of pea seedlings treated different LED light

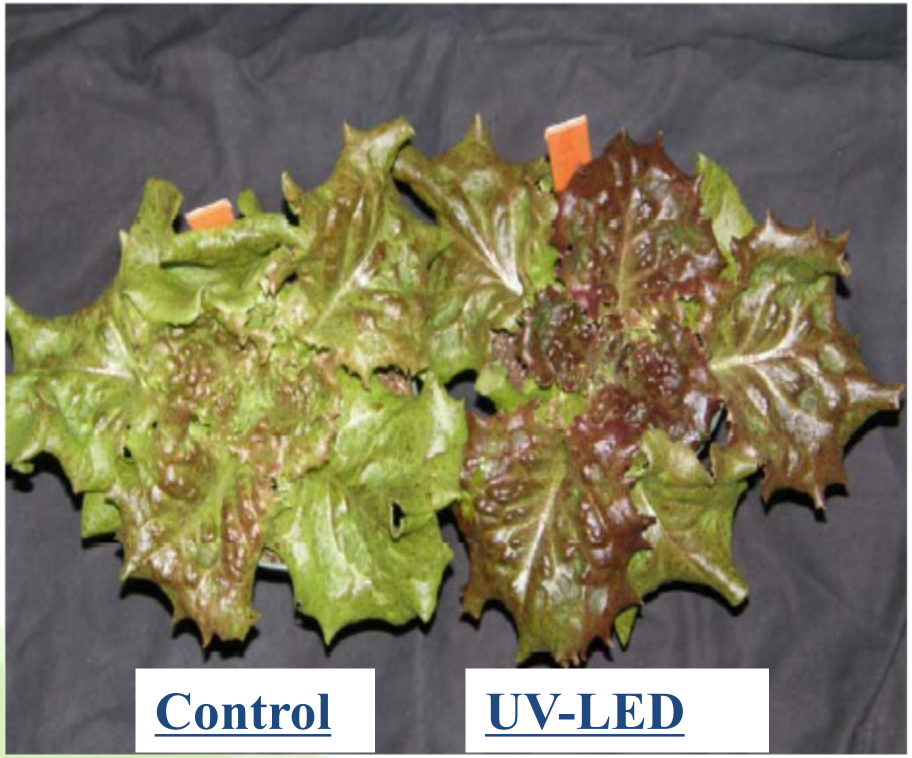
Treatments	Chrorophyll a content	Chrorophyll b content	Carotenoids content
White			0.28a
Red	1.20c	0.41ab	0.23b
Blue	1.28bc	0.37b	0.24b
Red+Blue	1.48a	0.45a	0.28a

Treatments	Vitamin C content (mg/g)	Nitrate content (mg/kg)	Anthocyanin content [（OD600-OD530）/g]	Flavonoid content [OD325/g]
White	0.55b	396.5a	0.047a	1.96a
Red	0.49b	526.1a	0.033ab	1.66a
Blue	0.56b	278.5a	0.014c	1.67a
Red+Blue	0.74a	708.4a	0.026bc	1.68a

Liu et al., 2012

UV (Ultravoilet light) is bioactive light spectrum for plant cultivation

UV-C	**Coloring of leaves and fruits**
UV-B	**Induction of disease resistance**
UV-A	**Synthesis of secondary metabolites**



UV is used to regulate plant exterior quality and nutritional quality of plant factory via short-term treatment. The UV-treated plant presented dark coloration indicative of anthocyanin accumulation. (Britz et al., 2009)

Roles of light quality in regulating plant growth of vegetables

- ✓ LED red and blue light are necessary for plant normal growth. The optimal red/blue ratio depends on plant species or cultivars.
- ✓ Other light quality, such as green light is helpful but not necessary for general plant growth.
- ✓ Far-red light is useful for plant photomorphologenesis.
- ✓ UV is the potential light quality for quality improvement (color and secondary metabolites).
- ✓ Notes: Some light quality can be used through the growth period of plant in plant factory, but UV and far-red light may just be used short-term during a special time.

LDP(Long-day plants) SDP(Short-day plants)

Long day: P_{fr} left at end of short night.

P_{fr} promotes flowering for LDPs.

P_{fr} inhibits flowering for SDPs.

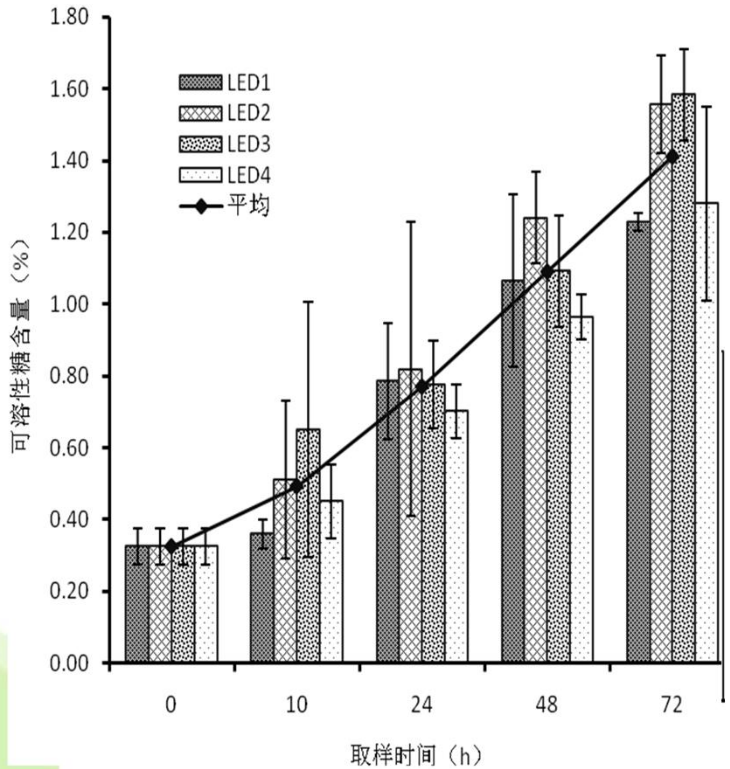
Short day: Pfr gone at end of long night.

No Pfr inhibited flowering for LDPs.

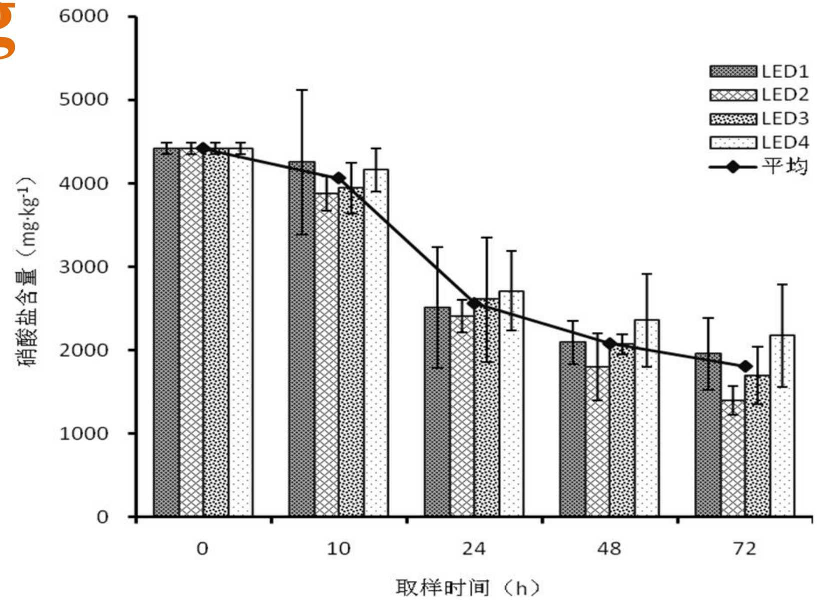
No Pfr promote flowering for SDPs.

48 hours continuous lighting

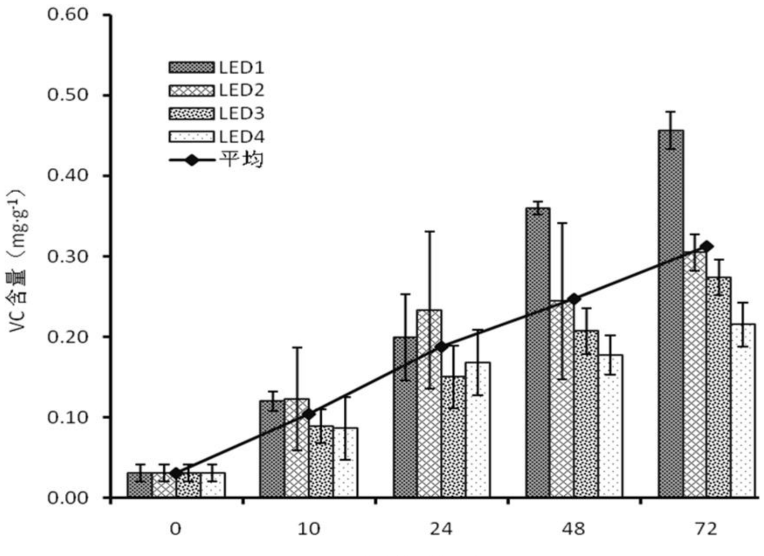
Treatments	Red light/Blue light	PPFD (μmol·m^{-2}·s^{-1})	
		Red light	Blue light
LED1	2	100	50
LED2	4	120	30
LED3	8	133	17
LED4	--	150	0



Soluble sugar content change in lettuce leaves during 72 hours continuous lighting



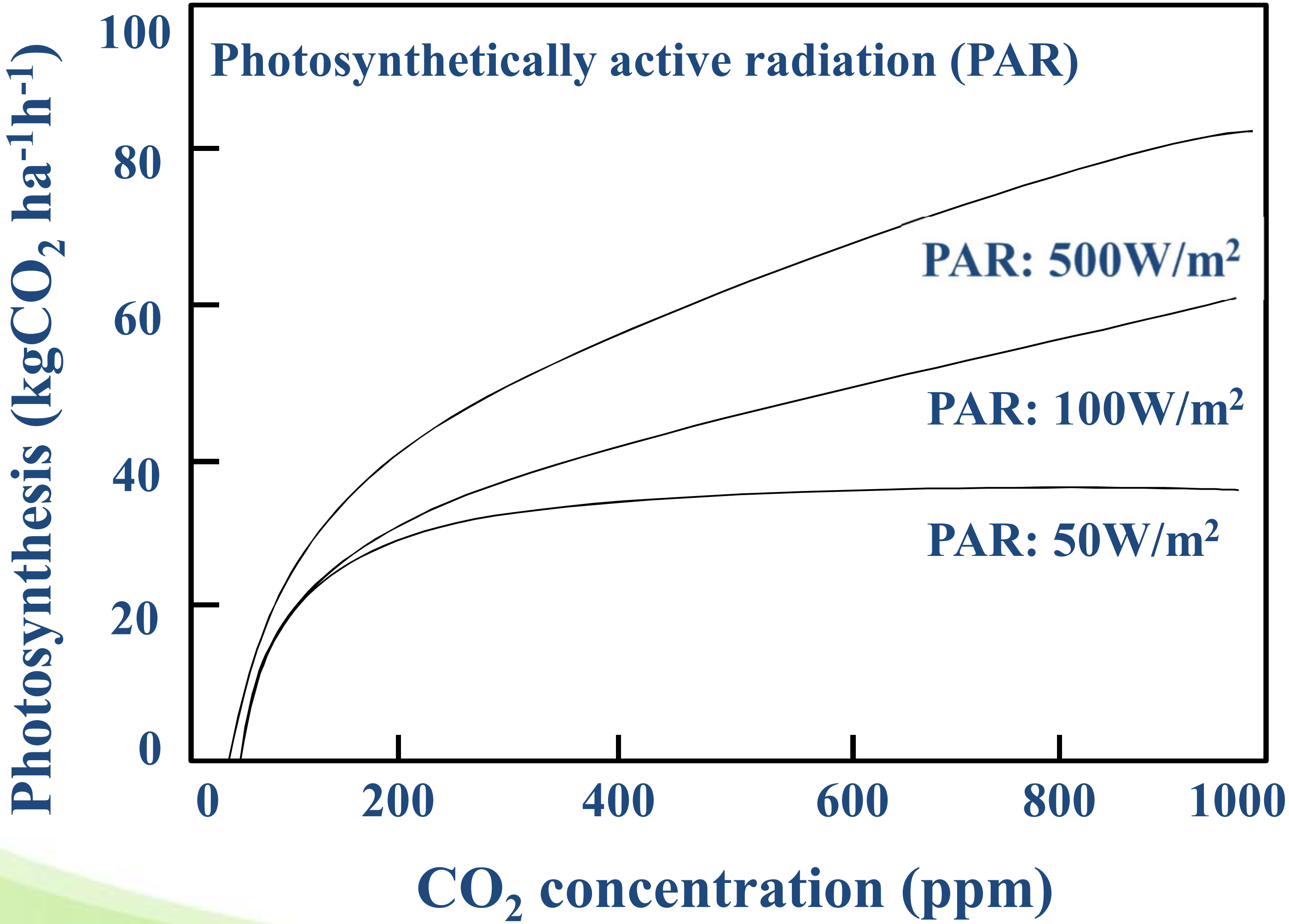
Nitrate content change in leaves during 72 hours continuous lighting



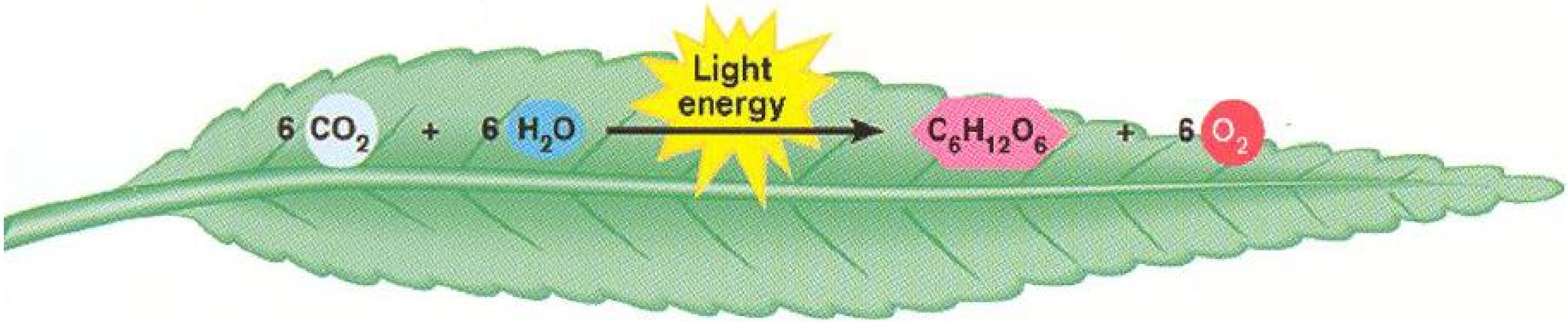
Vitamin C content change in lettuce leaves during 72 hours continuous lighting

2.2 CO_2 concentration

Photosynthesis in relation to CO_2 concentration

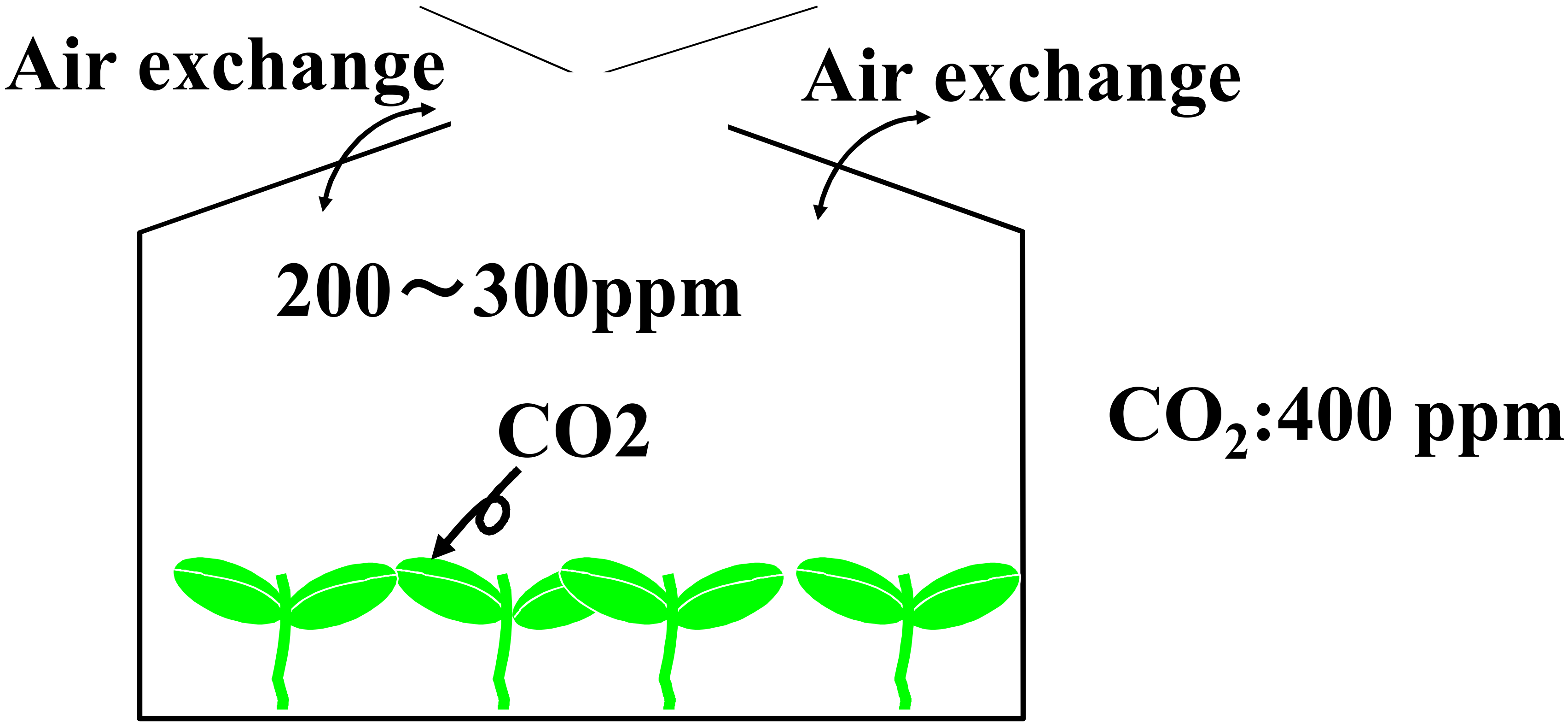


Takakura and Fang, 2002

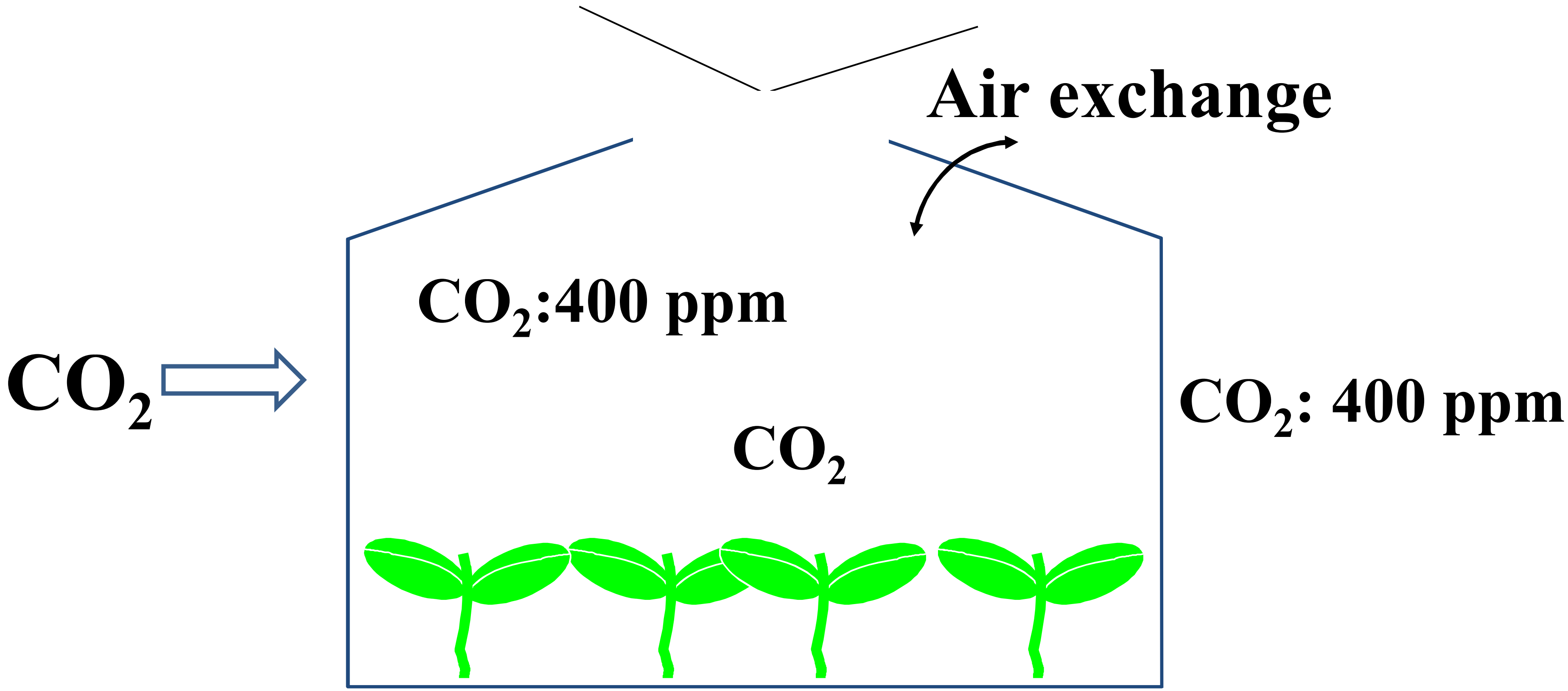


- Influence of CO_2 on crop growth and yield
- 15-30% higher photosynthesis (380 → 1000 ppm CO_2)
- Better fruit set
- More side shoots and flowers (pot plants)

During the sunny daytime, CO_2 concentration inside a greenhouse is lower than that outside

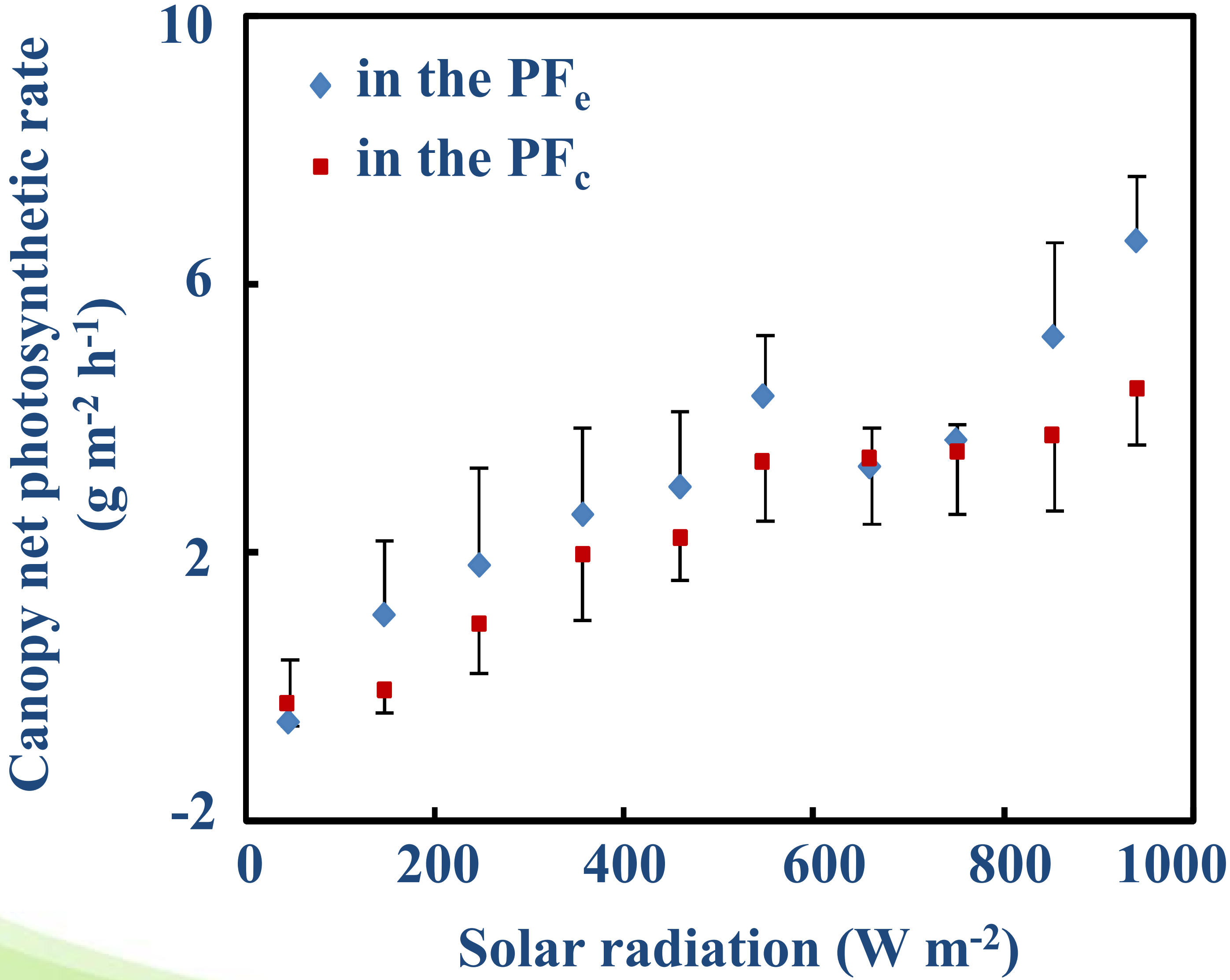


Zero CO_2 concentration difference enrichment



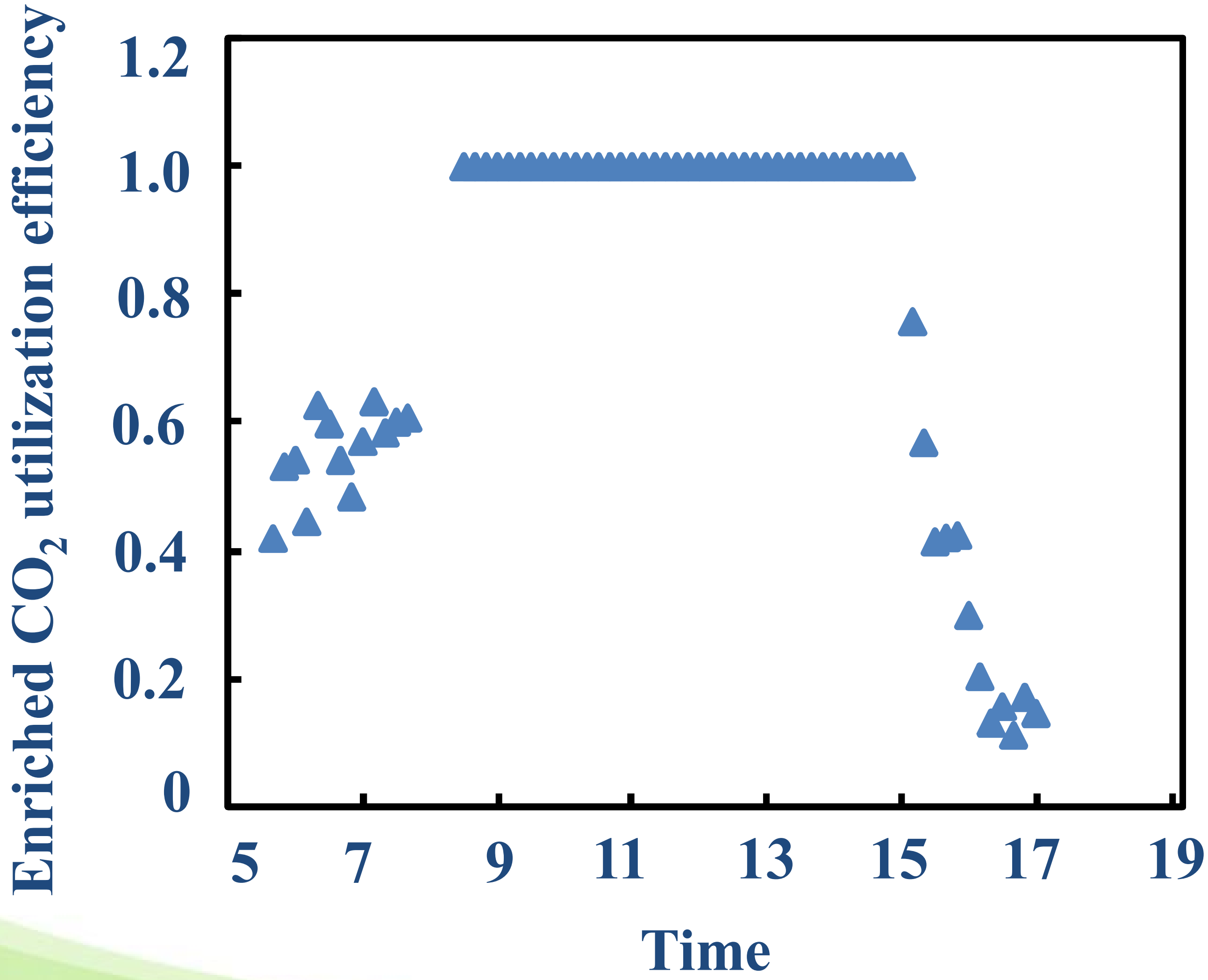
Keeping the CO_2 concentration inside and outside at the same level, CO_2 supplied was 100% absorbed by the plant

The canopy net photosynthetic rates in the experimental PF (PFe) and control PF (PFc) as affected by the solar radiation



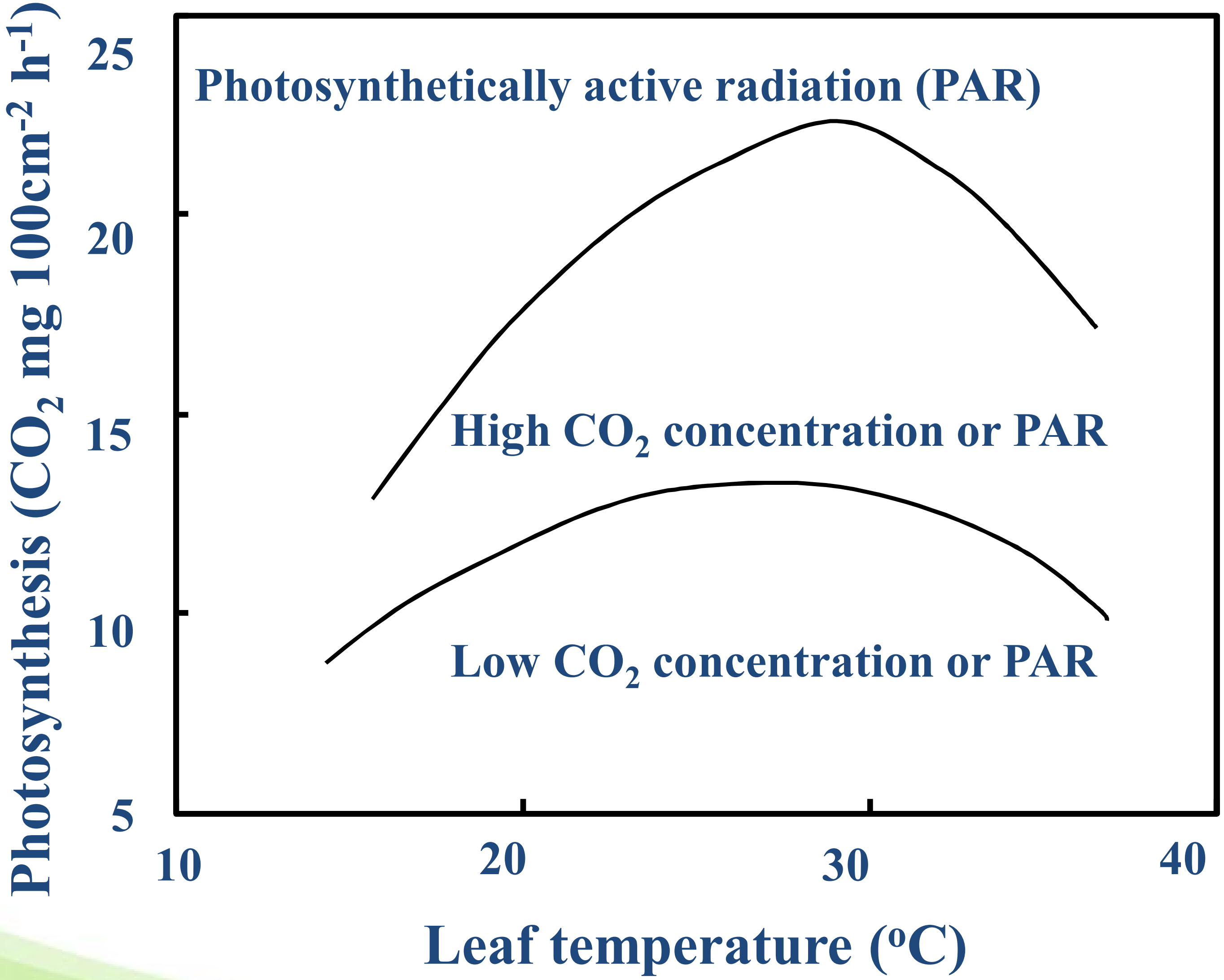
Each value represents an average of each 100 w m^{-2} solar radiation

Time course of enriched CO_2 utilization efficiency in the experimental PF



2.3 Temperature

Photosynthesis in relation to leaf temperature and CO_2 concentration



Mihara, 1980

Which plant processes are influenced by temperature ?

- Many enzymatic processes
- Developmental processes: appearance of new organs, flowering
- Photosynthesis
- Respiration
- Fruit set
- Fruit size

Relation with other climate factors

Cultivar differences

Conventional methods for greenhouse environment control

NO.	Purpose	Methods
1	Heating	Using fossil-fuel based heater, etc.
2	Cooling	Ventilation, shading, evaporative cooling, etc.

To integrate greenhouse environment control using the conventional methods, several equipments have to be installed

Functions and the related benefits of using heat pump (or air conditioner)

NO.	Function	Benefits
1	Heating	Reductions in the primary energy consumption and CO_2 emission
2	Cooling	Reduction in the leaf temperature and extension of the ventilators closed period for CO_2 concentration control
3	Dehumidifying in rainy season	Preventing the disease incidents and collecting water for recycling
4	Humidifying in dry season	Optimizing the vapour pressure deficit
5	Air circulation	Enhancement of photosynthesis, transpiration, nutrient/water uptake

Heat pumps used for greenhouse heating

a

Inner units

b

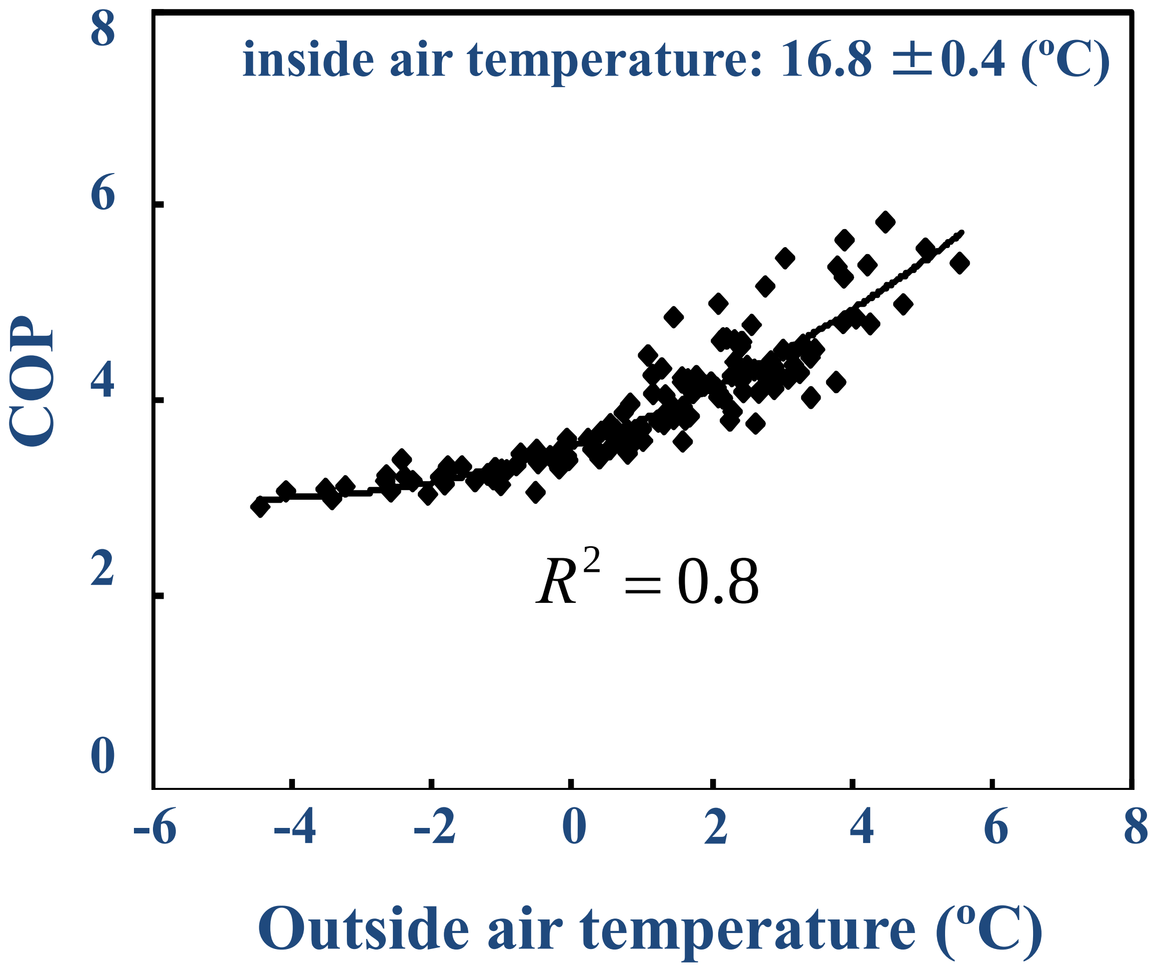
Outer units

Heating capacity: 2.8 kW
COP at 20ºC indoor and 7ºC outdoor: 5.4

Cooling capacity: 2.8 kW
COP at 27ºC indoor and 35ºC outdoor: 4.4

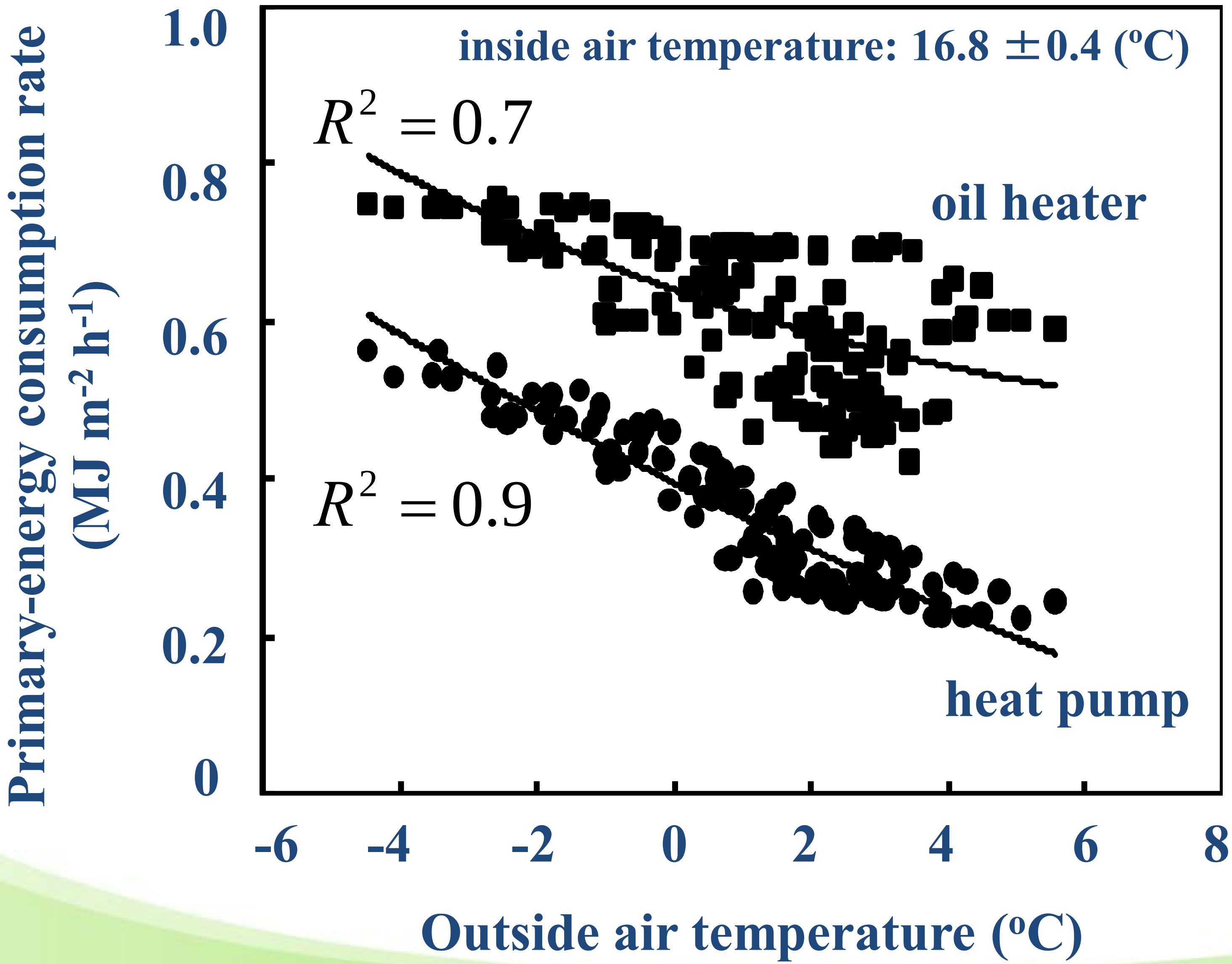
Heat pumps used for greenhouse cooling

The COP of heat pumps as affected by outside air temperature

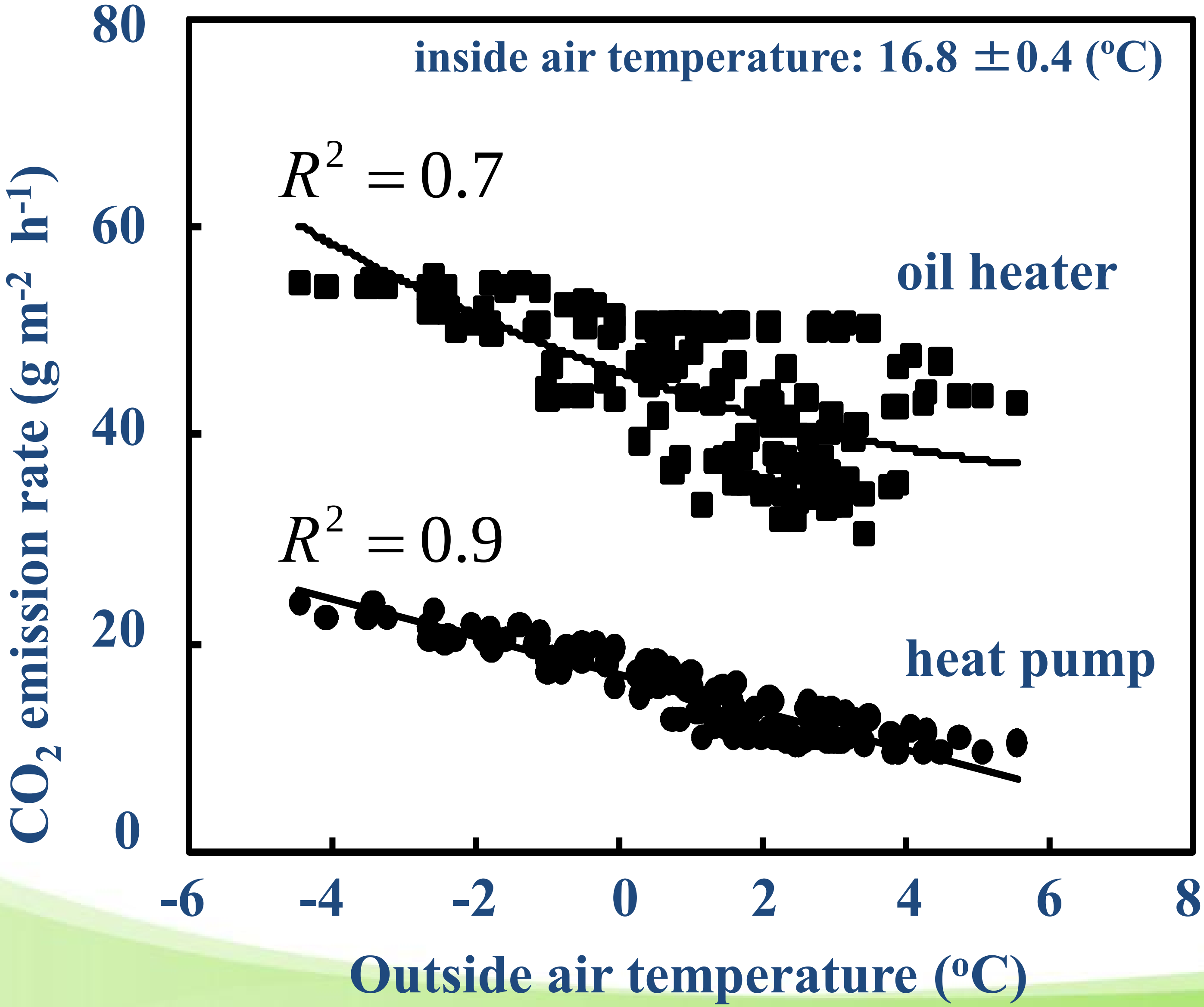


The average COP of 4.0 is almost 2 times higher than that of previous studies (Ozgener, 2010； Ozgener & Hepbasli, 2007)

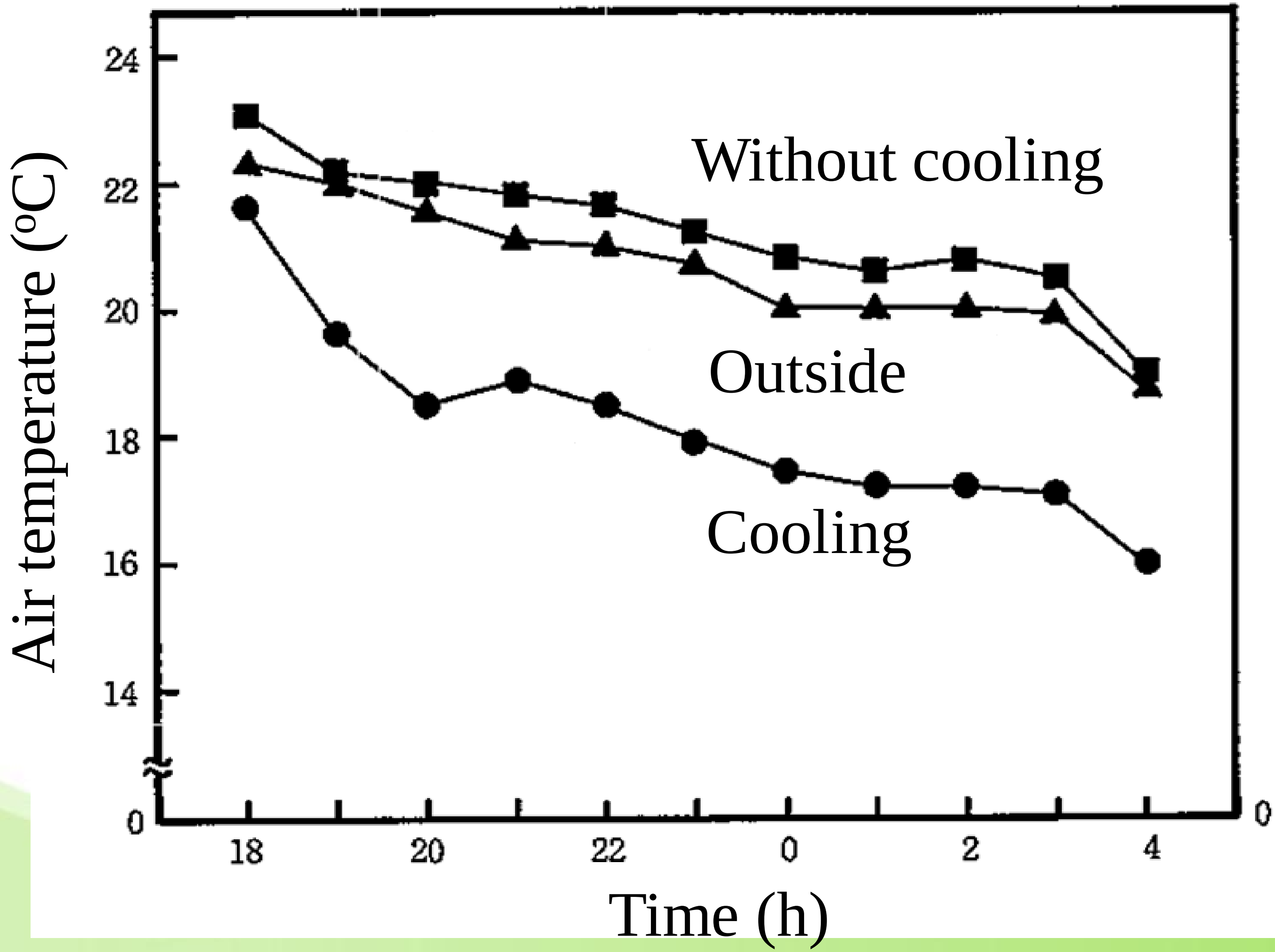
Primary-energy consumption as affected by the outside air temperature



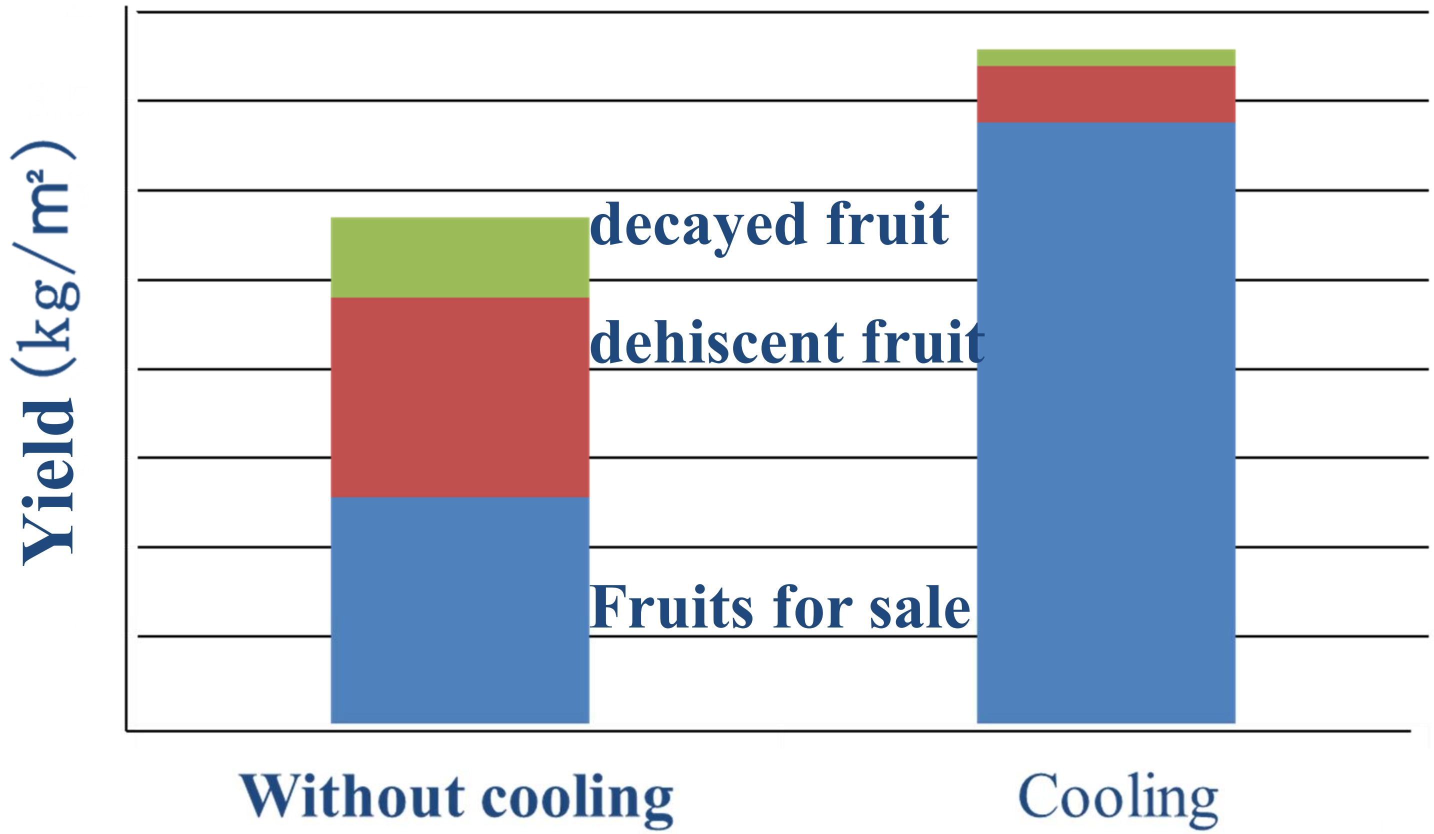
CO_2 emission as affected by the outside air temperature



Variation of the nighttime air temperature inside and outside the greenhouse with and without heat pumps for cooling

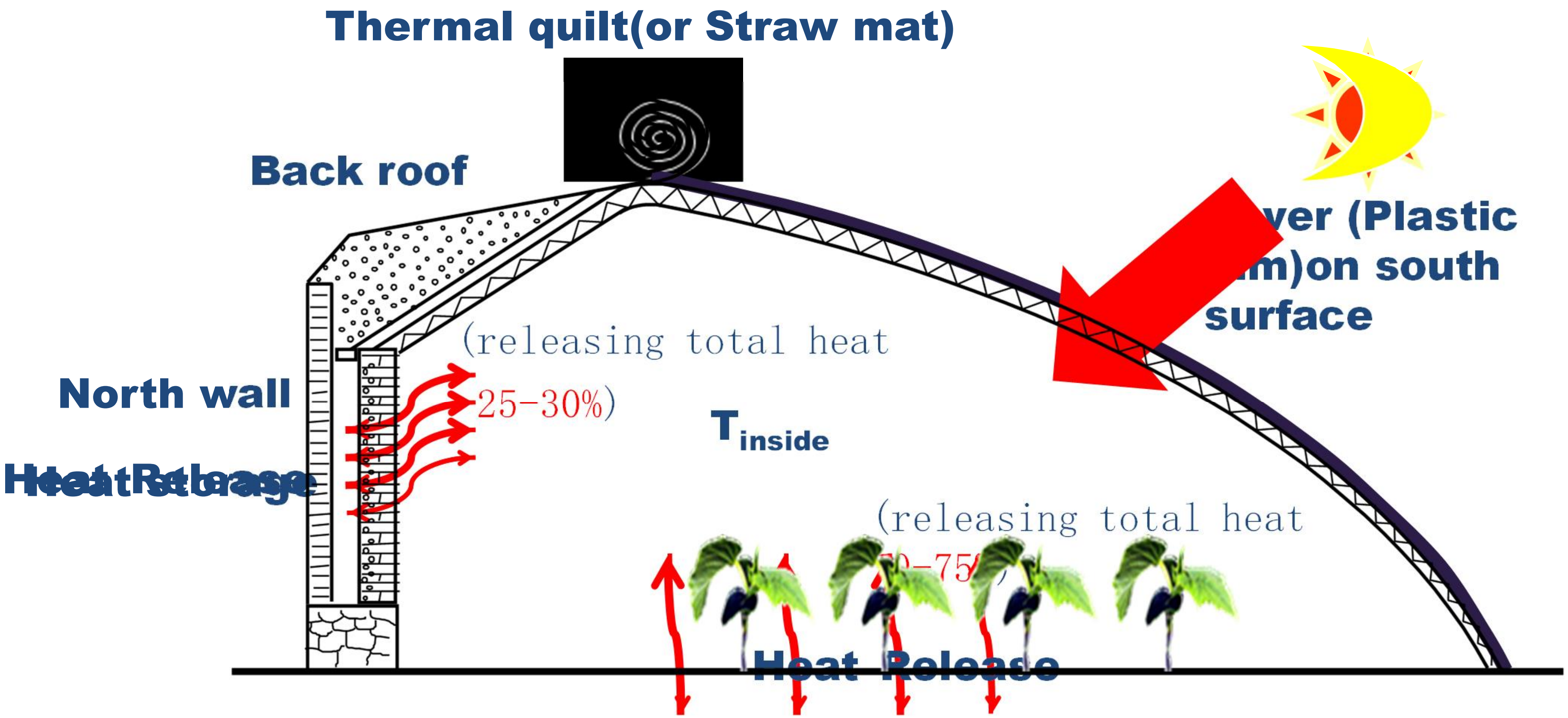


Tomato quality as affected by greenhouse cooling



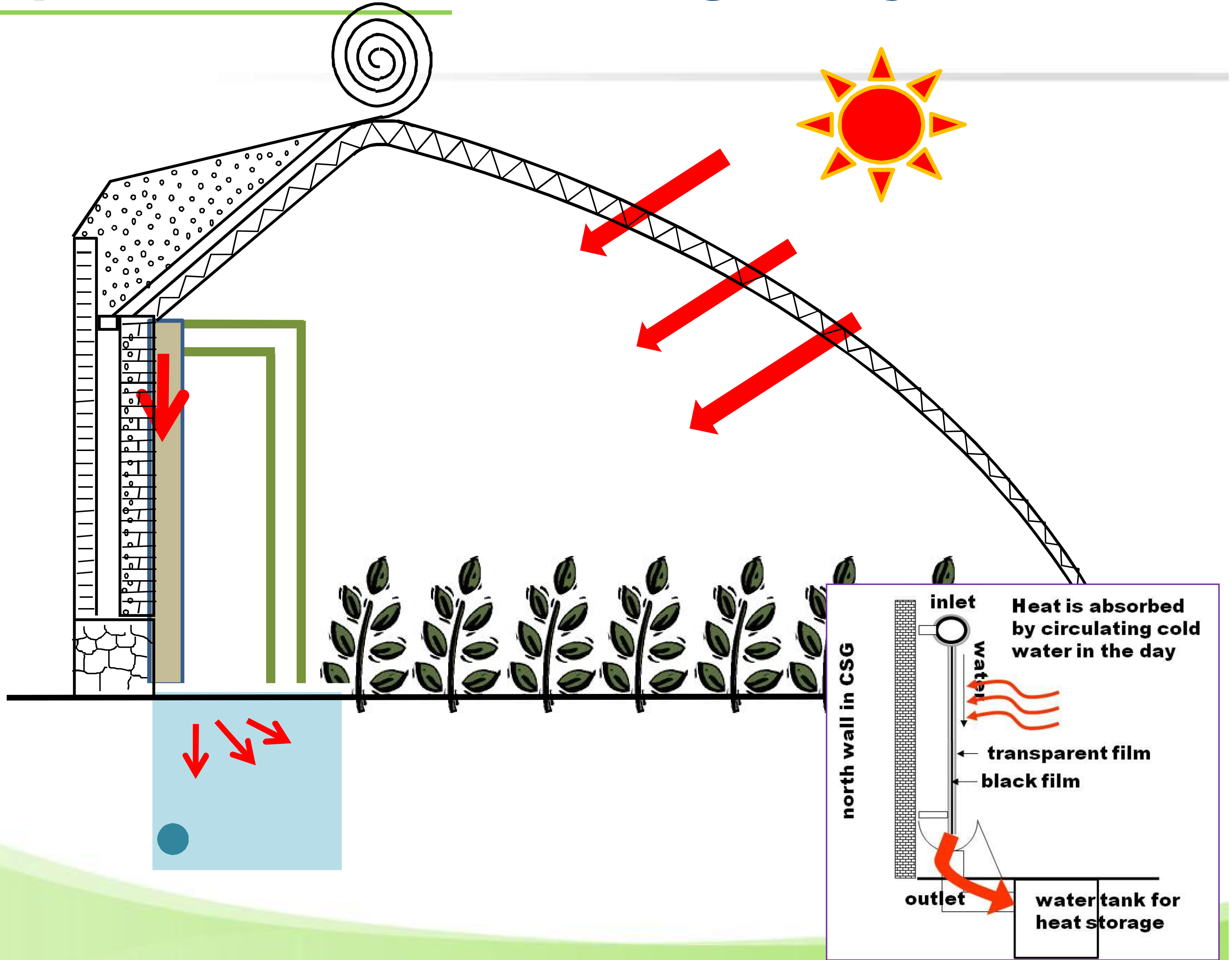
Temperature control in Chinese Solar Greenhouse

- **North Wall:** Storing heat in day time and releasing heat at night
- **Thermal quilt:** covering at night to keep more heat in CSG

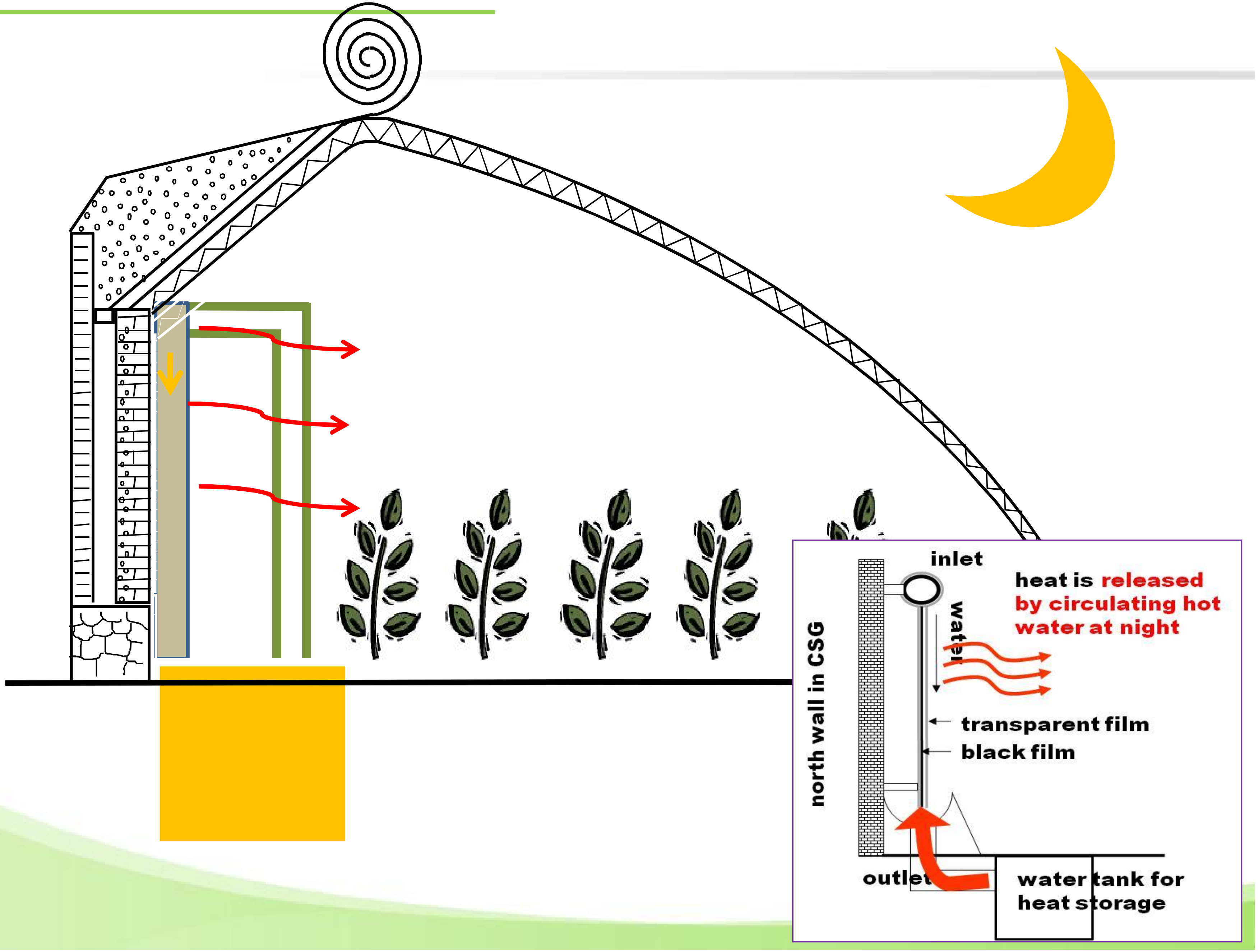


Structure of Chinese Solar Greenhouse (CSG)

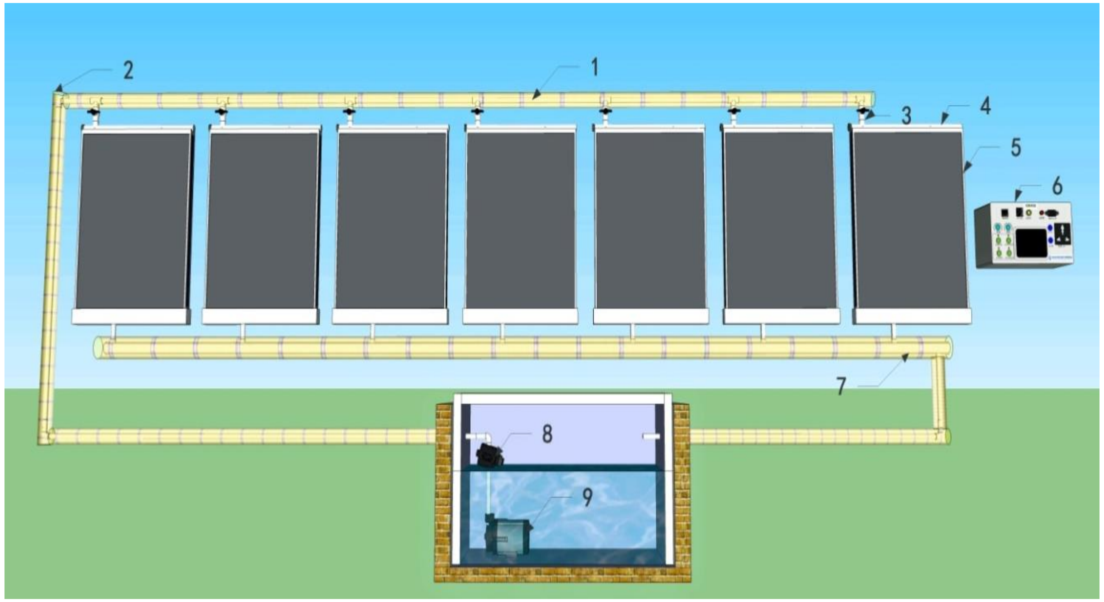
Principle of active heat storing in daytime



Principle of active heat Releasing at night



AHS System 1: Water curtain between black films on the surface of north wall



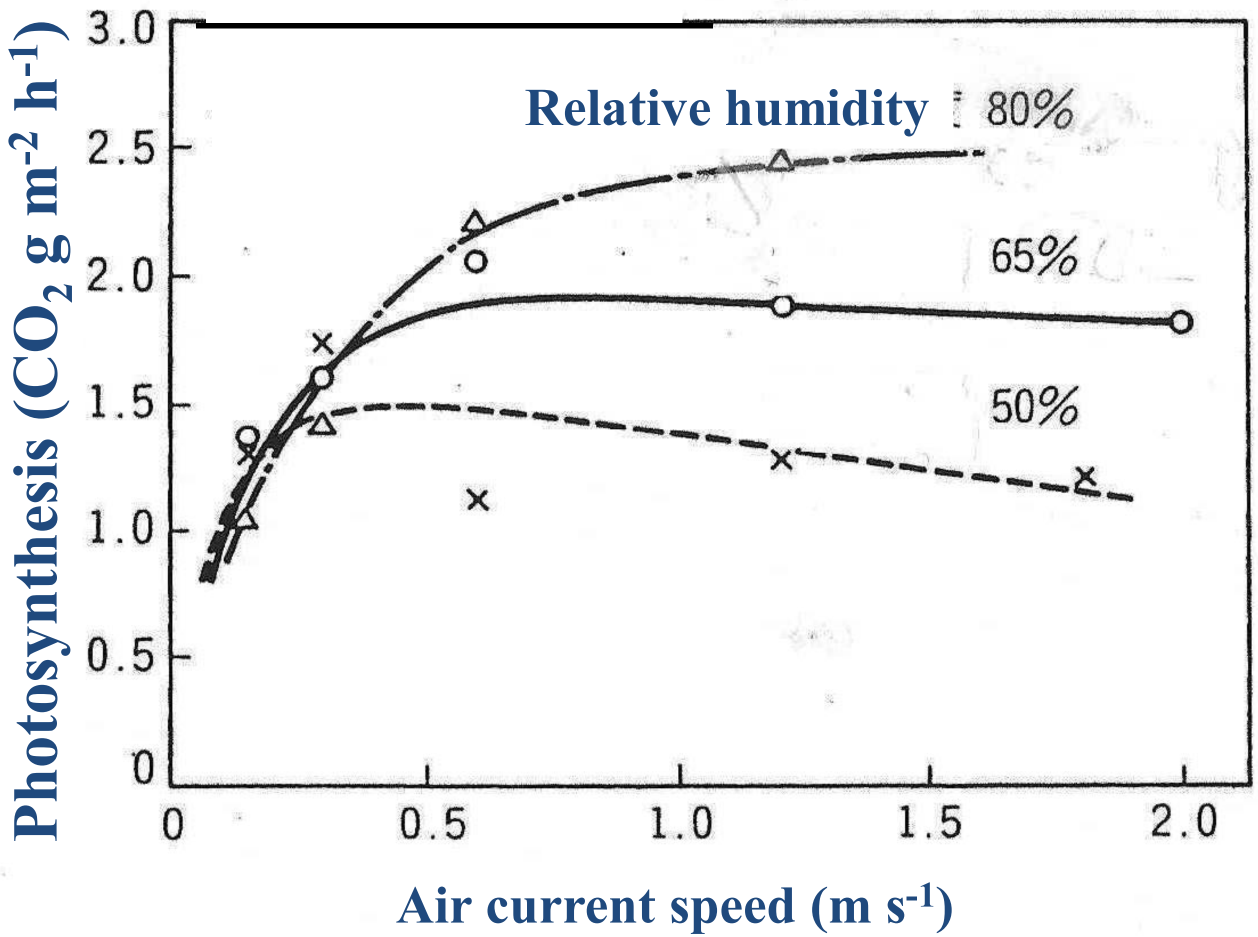
1.Water supply pipe 2.Lagging 3.Valve 4. Water inlet 5.Transparent and black film 6.Control cabinet 7.Water return pipe 8.filter 9. Water circulating pump

- ◆ Water curtain made of black films (water flows between two layers' film), for heat collection
- ◆ Water tank for heat storage

Crops in the CSG (Vegetable, flower, fruit,…)

2.4 Humidity

Photosynthesis in relation to air current speed and relative humidity



（矢吹・宮川、1965 ）

Effects of high humidity on plant

High humidity =
Deficit <0.2 kPa (<1.5 g/m^3) or RH >94% at 25°C

- Too low Ca in leaves → smaller leaves → less light interception → less photosynthesis
- Pollination less optimal (without bumble bees)
- Higher disease risk (botrytis)
- Higher risk fruit "disorders" (cracking)

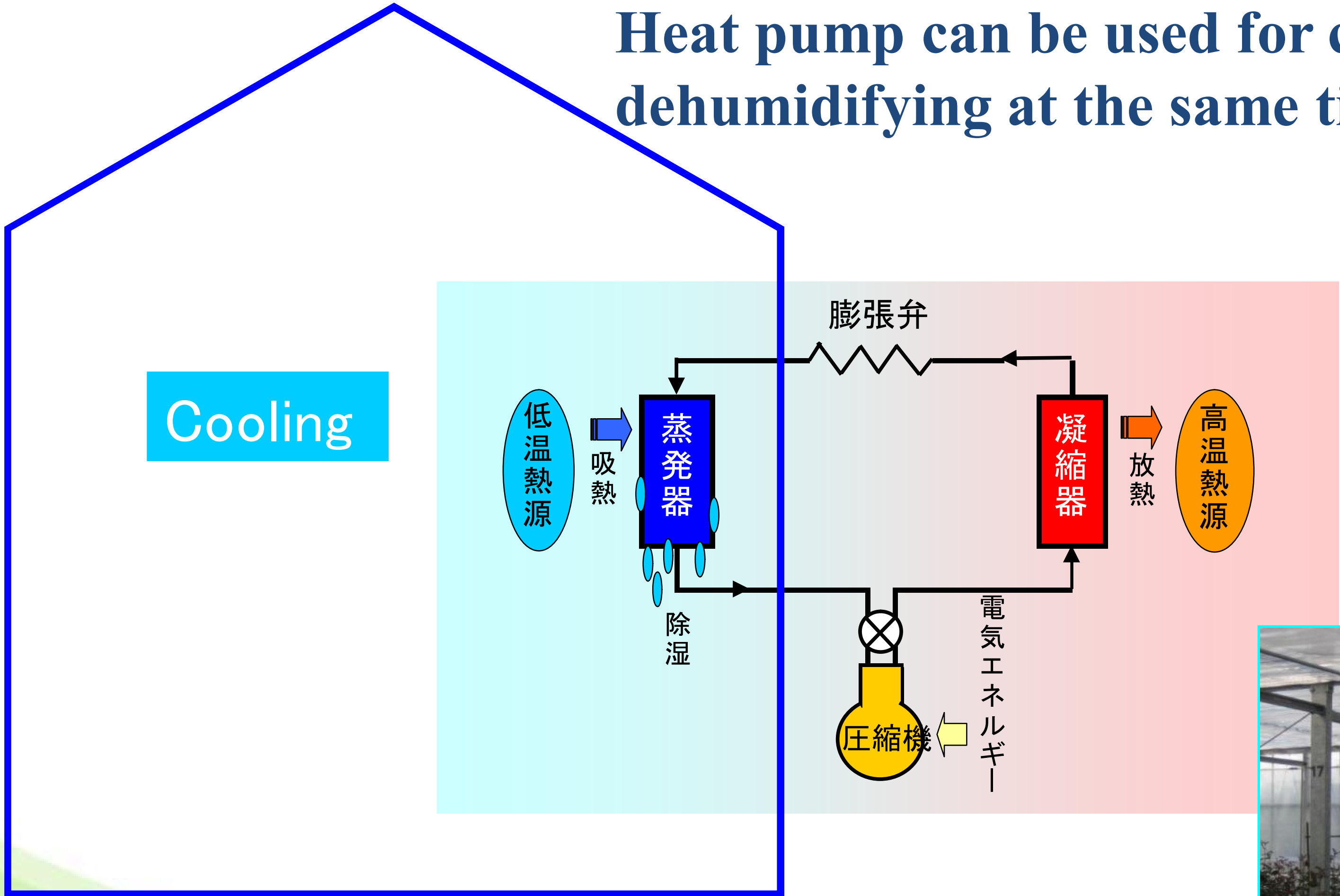
Effects of low humidity on plant

Low humidity =
Deficit >1 kPa (>7.5 g/m^3) or RH <70% at 25°C

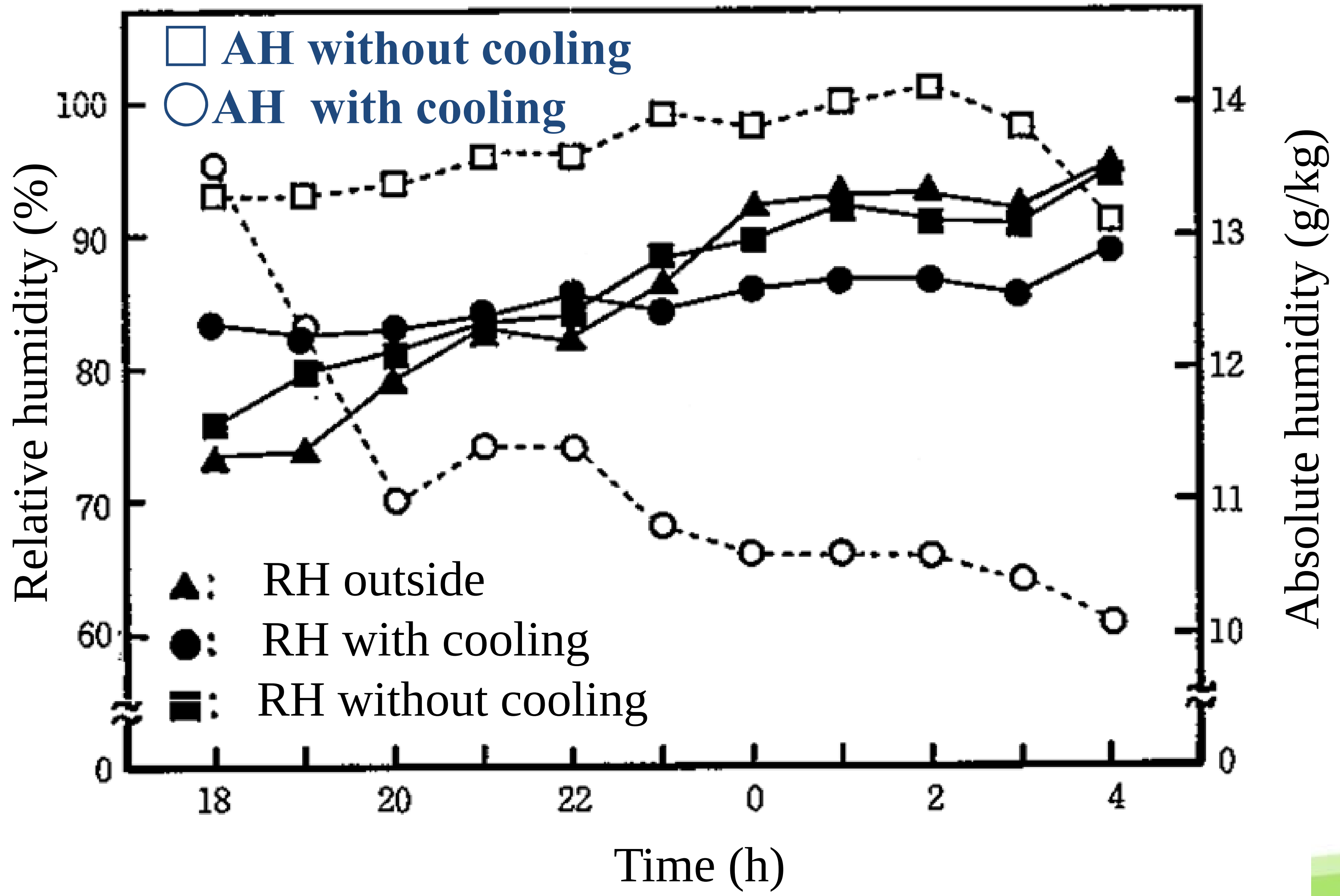
- Water stress in plant
- Stomata close
- Cell elongation reduced → smaller, thicker leaves
- Less photosynthesis
- Reduced water content fruit
- Blossom-end-rot (BER) →

Working principle of heat pumps for dehumidifying

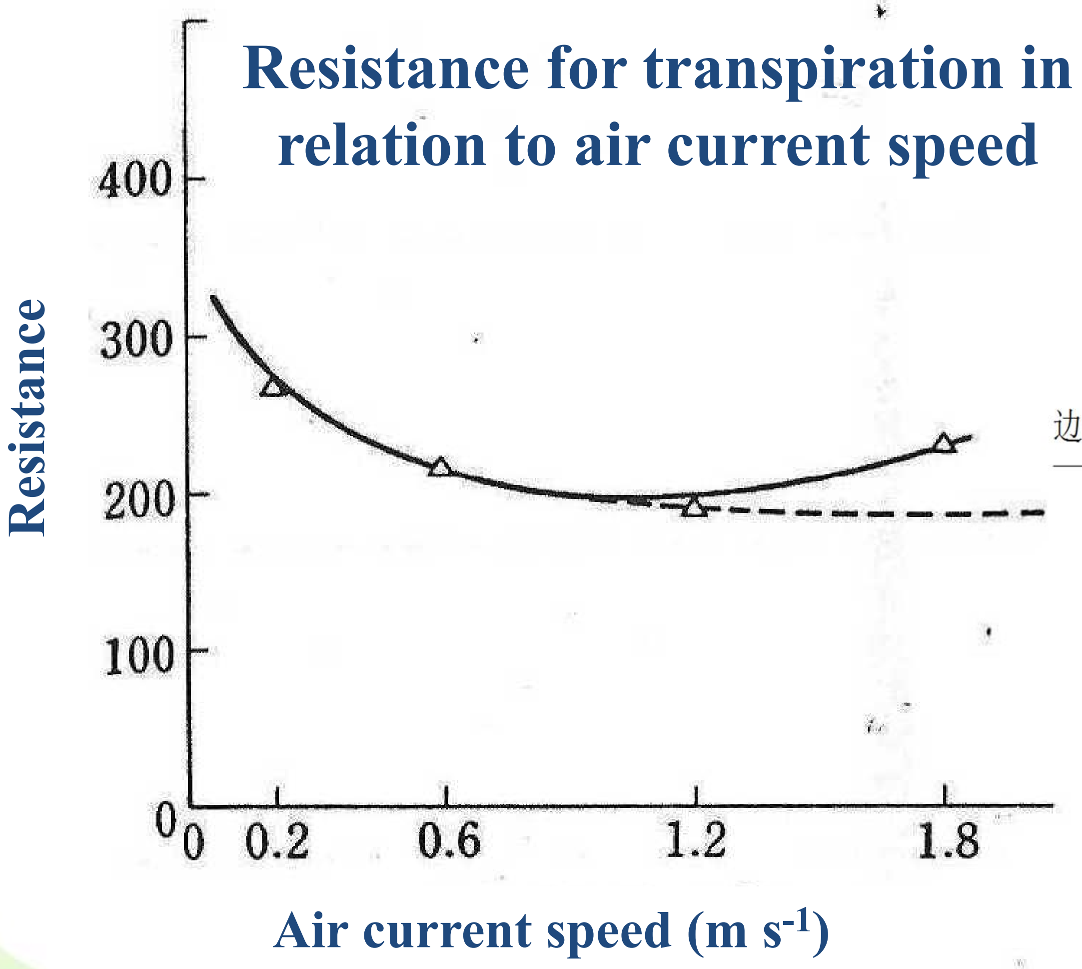
Heat pump can be used for cooling and dehumidifying at the same time

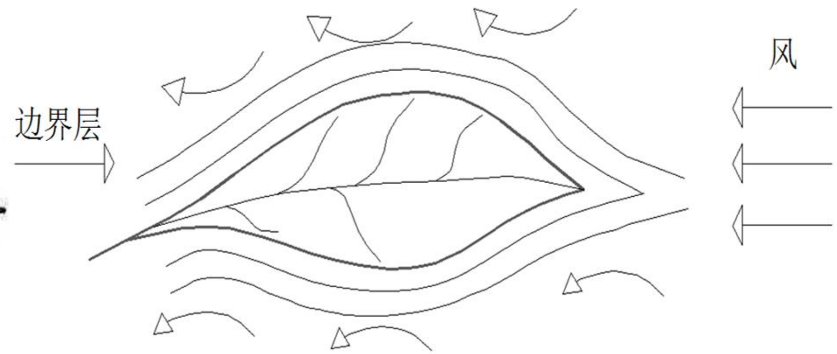


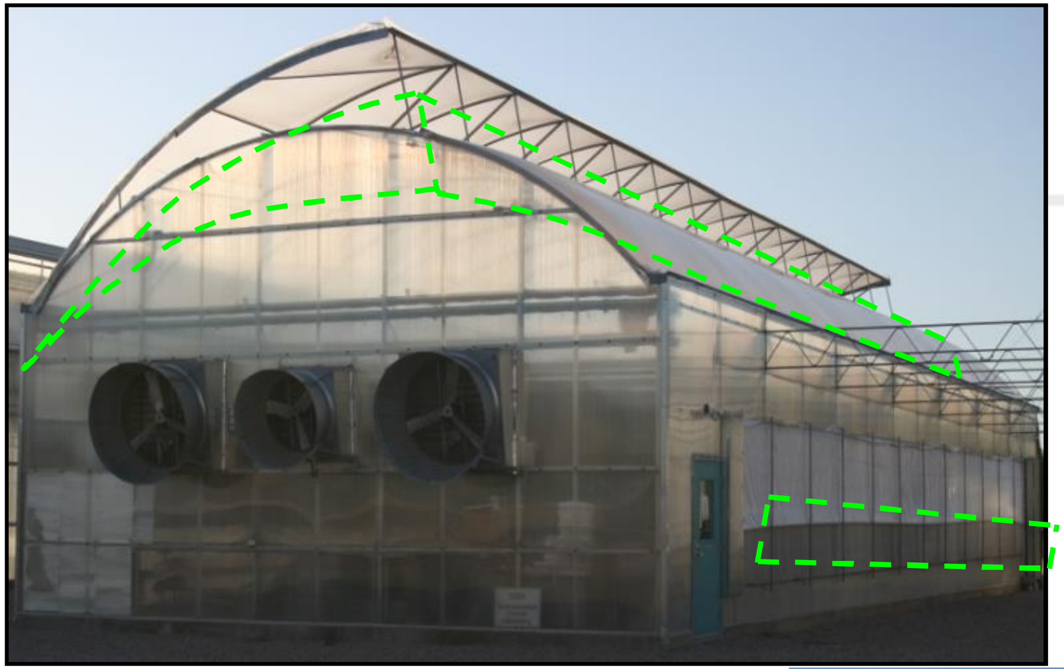
Variation of the nighttime RH and AH inside and outside the greenhouse with and without heat pumps for cooling



2.5 Air current speed







Mainly use natural ventilation, reduce energy consumption

Completely natural ventilation greenhouse

Forced ventilation in greenhouse

Forced ventilation in plant factory

3 Challenges and perspectives

Challenges of greenhouse

- **For the CSG:**
  - **Improving the land use efficiency(only 40%)**
  - **Enlarging single greenhouse area(400-600m2)**
  - **Increasing of greenhouse yield(10-30 kg/m2)**
  - **Enlarging soilless cultivation area (<1%)**
  - **Limitation in mechanization and automation**
- **For the multi-span greenhouse:**
  - **Decreasing in energy consumption**
  - **Shortage of suitable cultivation system**
  - **Increasing in economic benefit**
- **Shortage of qualified and specialized growers**

Challenges of plant factory

- High initial cost（construction & equipments)
- High energy consumption(light, air conditioning)
- Limited plant species(most of the plants is lettuce in PF with artificial light)
- Benefit (lower competition comparing with other vegetable production system, e.g. greenhouse and field)

Competition of vegetable value from protected horticulture and open field

Perspectives of protected horticulture

- Producing healthy and safe vegetables(fresh, clean, pesticide-free, and multi-function) for high-end consumers or local consumers in large cities, like Beijing, Shanghai;
- Priority developed areas: Agri.sci.& tech.park, for demonstrating Park;
- Multi-function utilization in special areas: family, building, supermarket, school, restaurant (Ubiquitous plant factory).
- Vertical farming (Ongoing project in CAAS)

Agri.sci.& tech. park (Xiaoshan,Zhejiang)

The area is about 40,000 m^2(PF with artificial light and solar light)

Expansion use of PF for producing healthy and safe vegetables (Shunde, Guangdong province)

The total area is 50000m^2(PF with artificial light and solar light), haven't finished now.

Development Mini-Plant Factory for Family