Current situation & prophase exploration on vertical farming and urban agriculture in China

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- Short introduction to CAAS & IEDA
- Why do we need to develop Vertical farming and urban agriculture in China
- Prophase exploration on technologies of vertical farming and plant factory
- Facing Challenges of vertical farming (plant factory)
- Projects on vertical farming and plant factory in China

1. Introduction of CAAS & IEDA

Chinese Academy of Agricultural Sciences (CAAS)

CAAS, located in Beijing, was established in 1957 and is affiliated to the Ministry of Agriculture of China. At present, CAAS has 40 research institutes, and 1 graduate school. About 11，000 technical professionals and over 4000 graduate students (M.S. and Ph.D.) working or studying in the CAAS.

Institute of Environment and Sustainable Development in Agriculture (IEDA) , one of the 40 institutes in CAAS,173 researchers and 250 MSc&PhD students.

Center for Protected Agriculture & Environmental Engineering (CPAEE) in IEDA

Group 1: Greenhouse Engineering

Group 2: Plant factory & Hydroponics

Group 3: Energy-saving Engineering

Group 4: Greenhouse Climate control

2. Why do we need to develop Vertical farming(plant factory) and urban agriculture in China ?

Challenges 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)

……

Population explosion

Increasing trend of population in China

Ratios of Chinese urban population

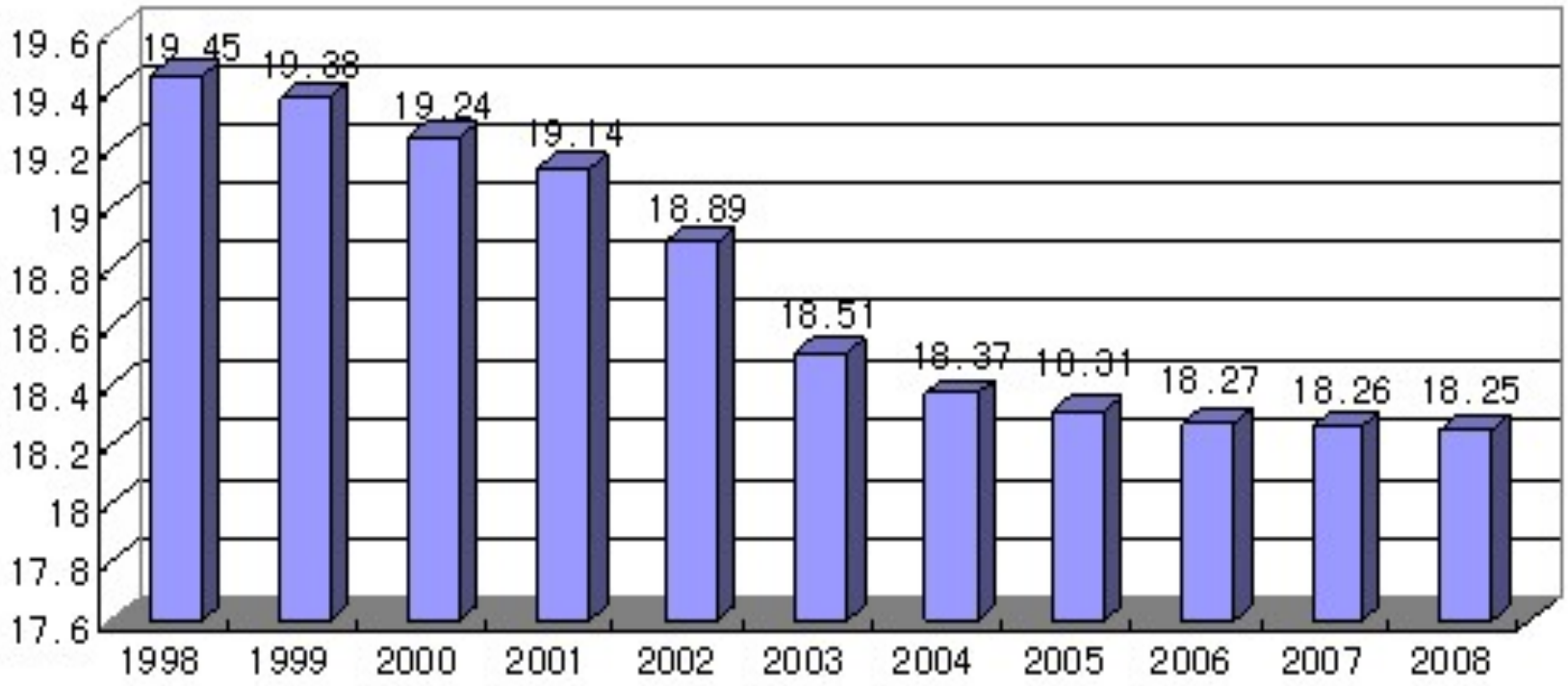
注：2012-2015年为测算值，未对外来人口及新增城市人口做区分

资料来源：《中国统计年鉴2011》，2011年统计公报，第六次全国人口普查

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

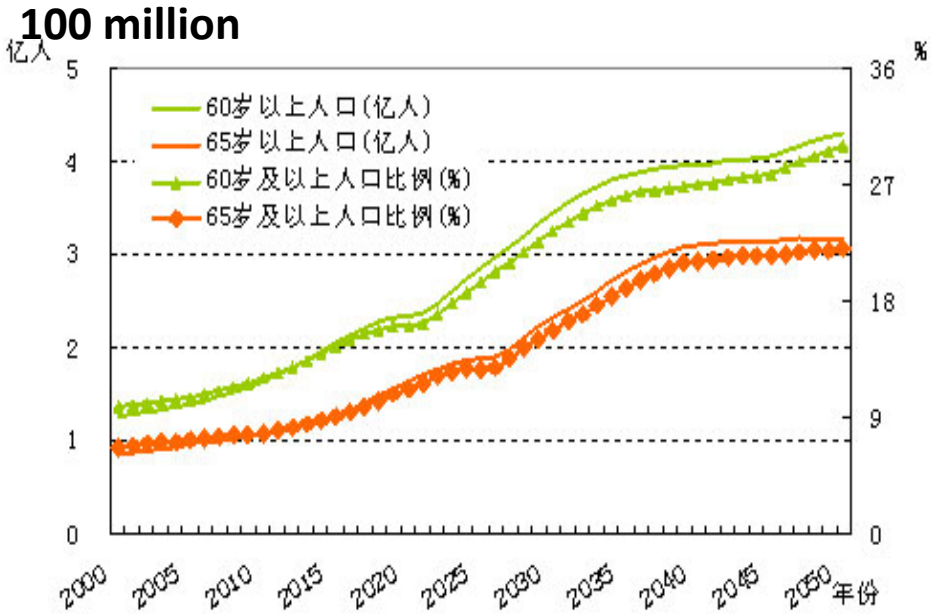
Land resources reducing & Agricultural pollution, desertification **(reducing cultivated land 300,000hm^2 each year)**

Natural disasters (drought, flood , etc.)



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

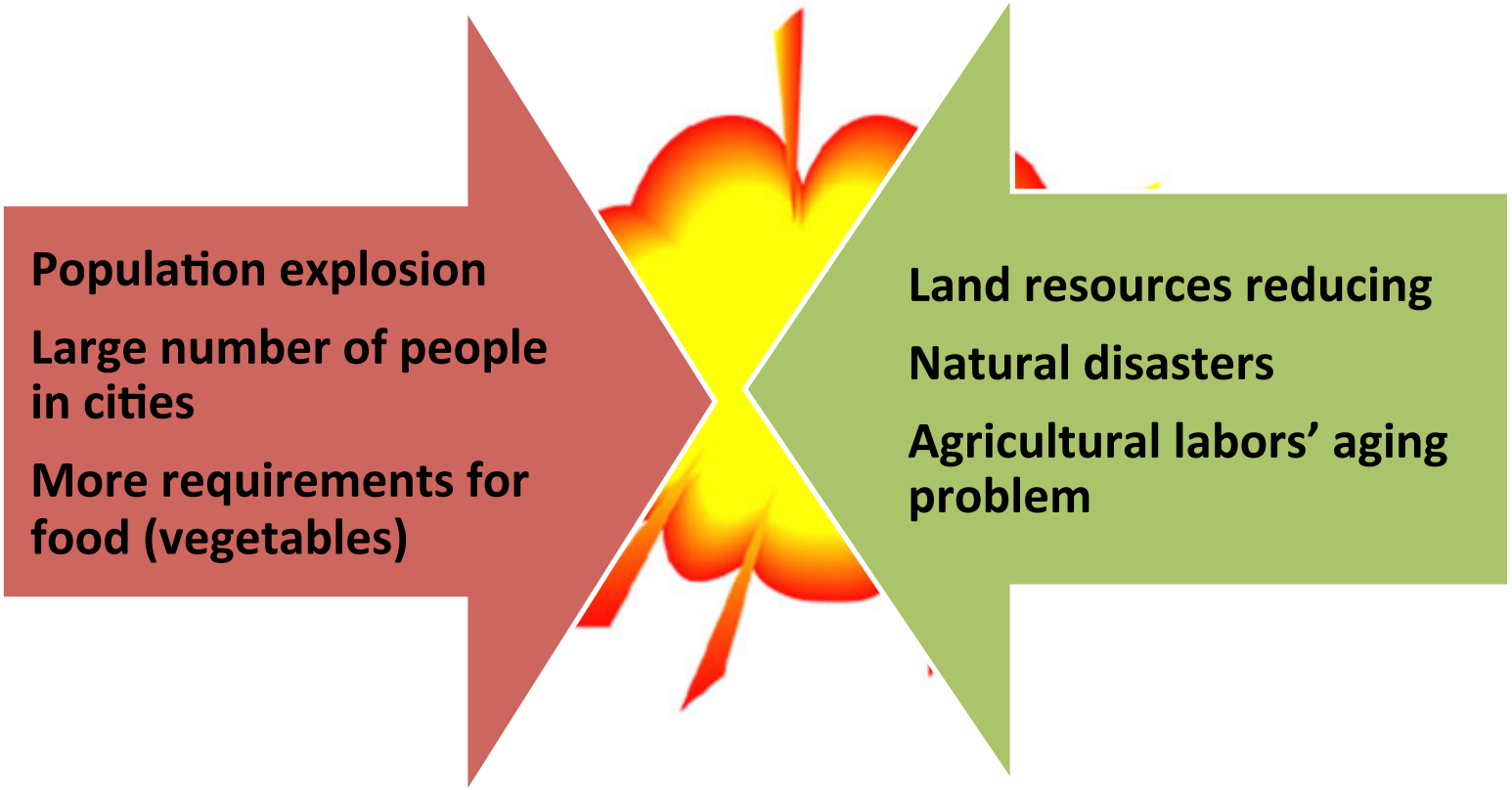
Agricultural labors' aging problem



The rapid increase of aged people in China

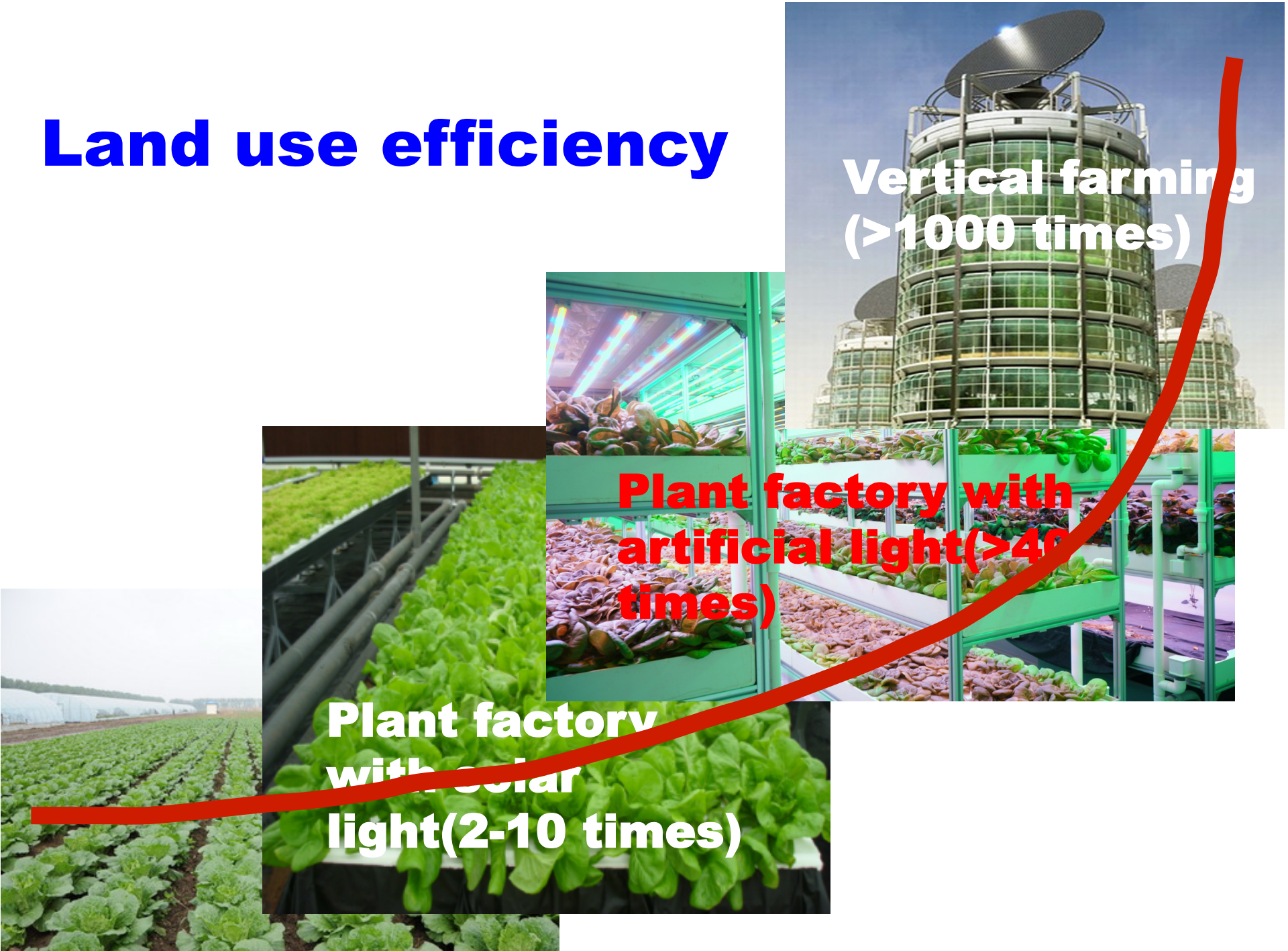
Food demands increasing (470 million tones of vegetables each year (330 million tones of vegetables for the residents in cities) in China)

How to solve the above problems?

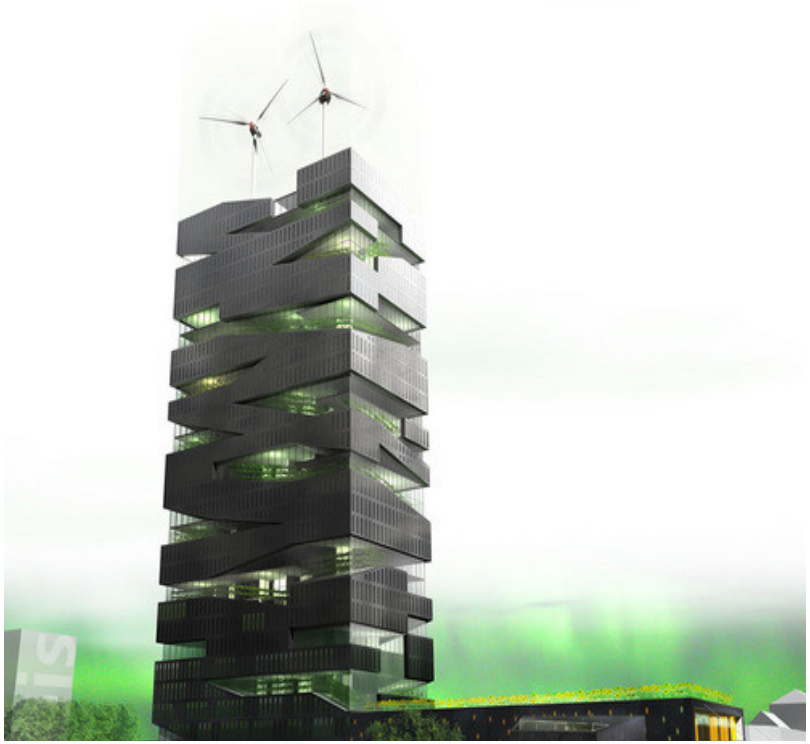


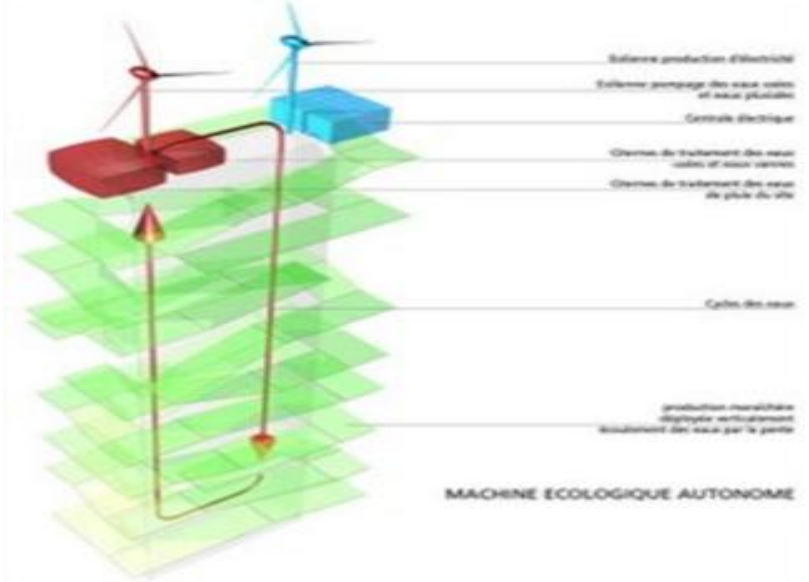
Vertical farming (plant factory) could be a possible way to solve the problems

Land use efficiency



3. Prophase exploration on technologies of vertical farming and plant factory



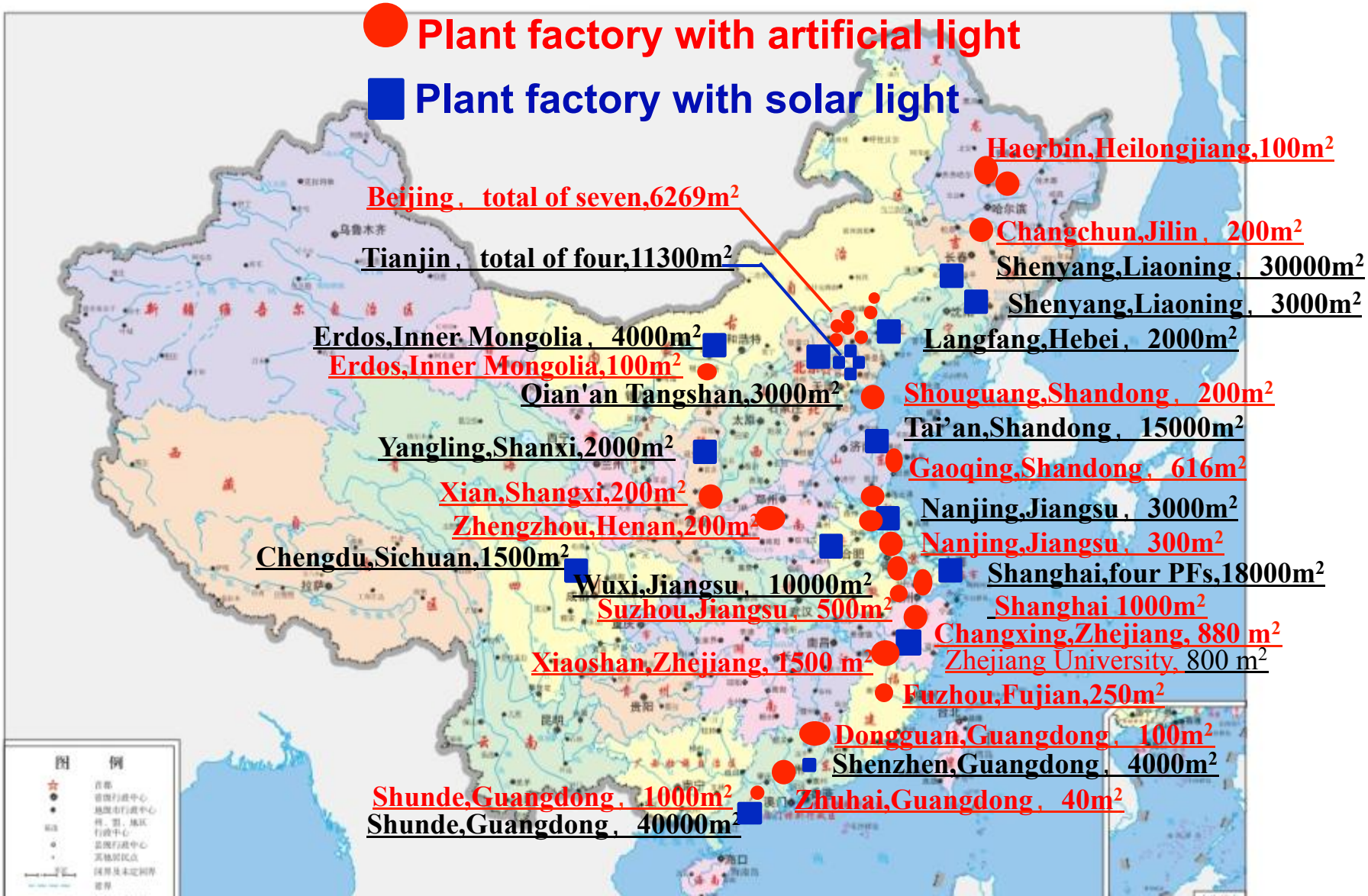


- Having not real vertical farming case In China now (2-3 ongoing projects)
- Plant factory developed very quickly
- Urban agriculture and vertical cultivation developed rapidly

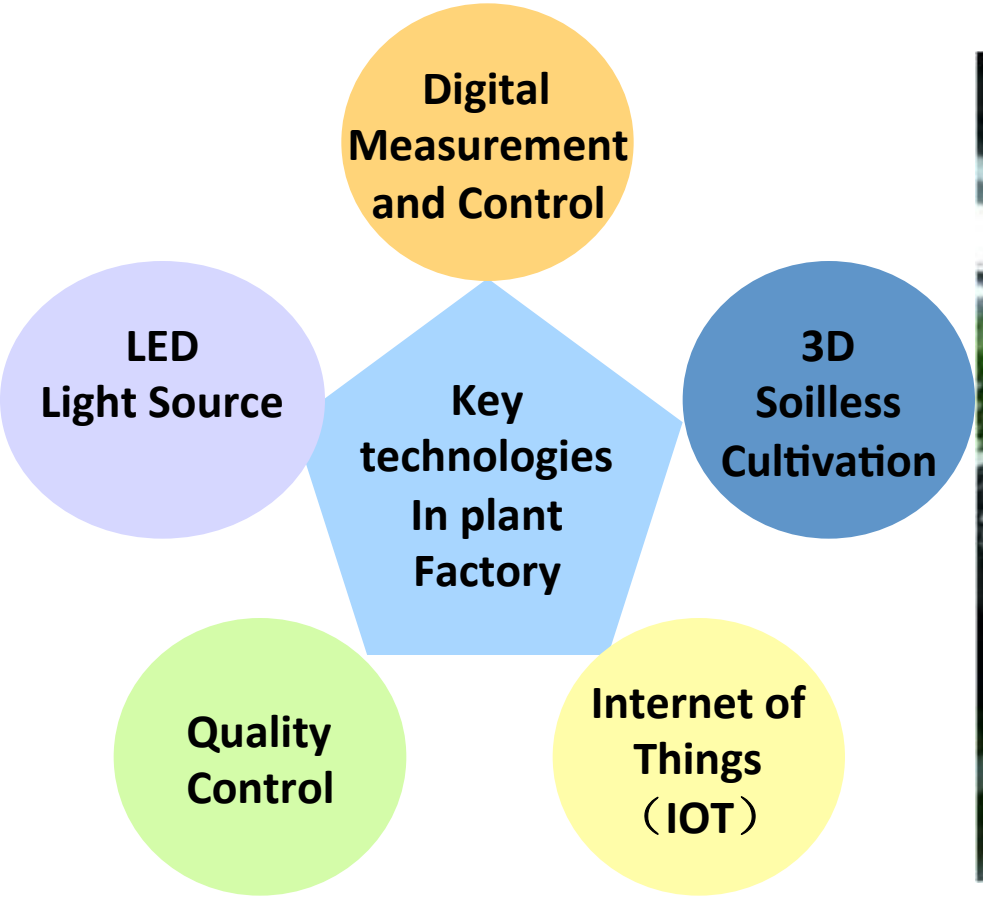
3.1 Development of plant factory in China

- Up to 2014, there are about 110 plant factories in China.
- PF with artificial light：about 43 plant factories, which are distributed in 13 cities or provinces (Another 10-12 PFs will be constructed recently).
- PF with solar light：about 67 plant factories(with hydroponic system for leaf or fruit vegetable production in controlled environmental greenhouses), which are distributed in 15 cities or provinces.

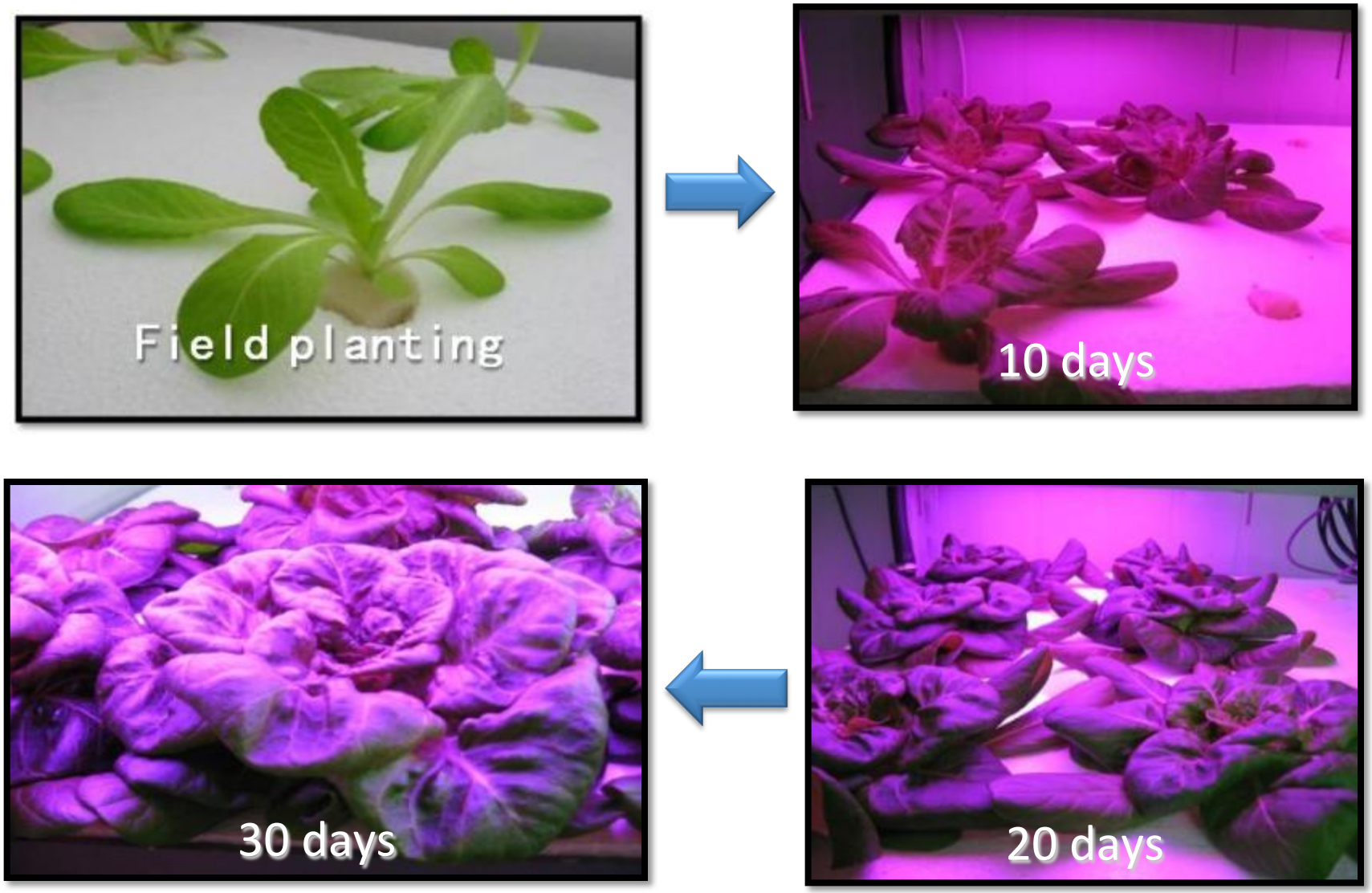
Regional Distribution of Plant Factory in China (2014)



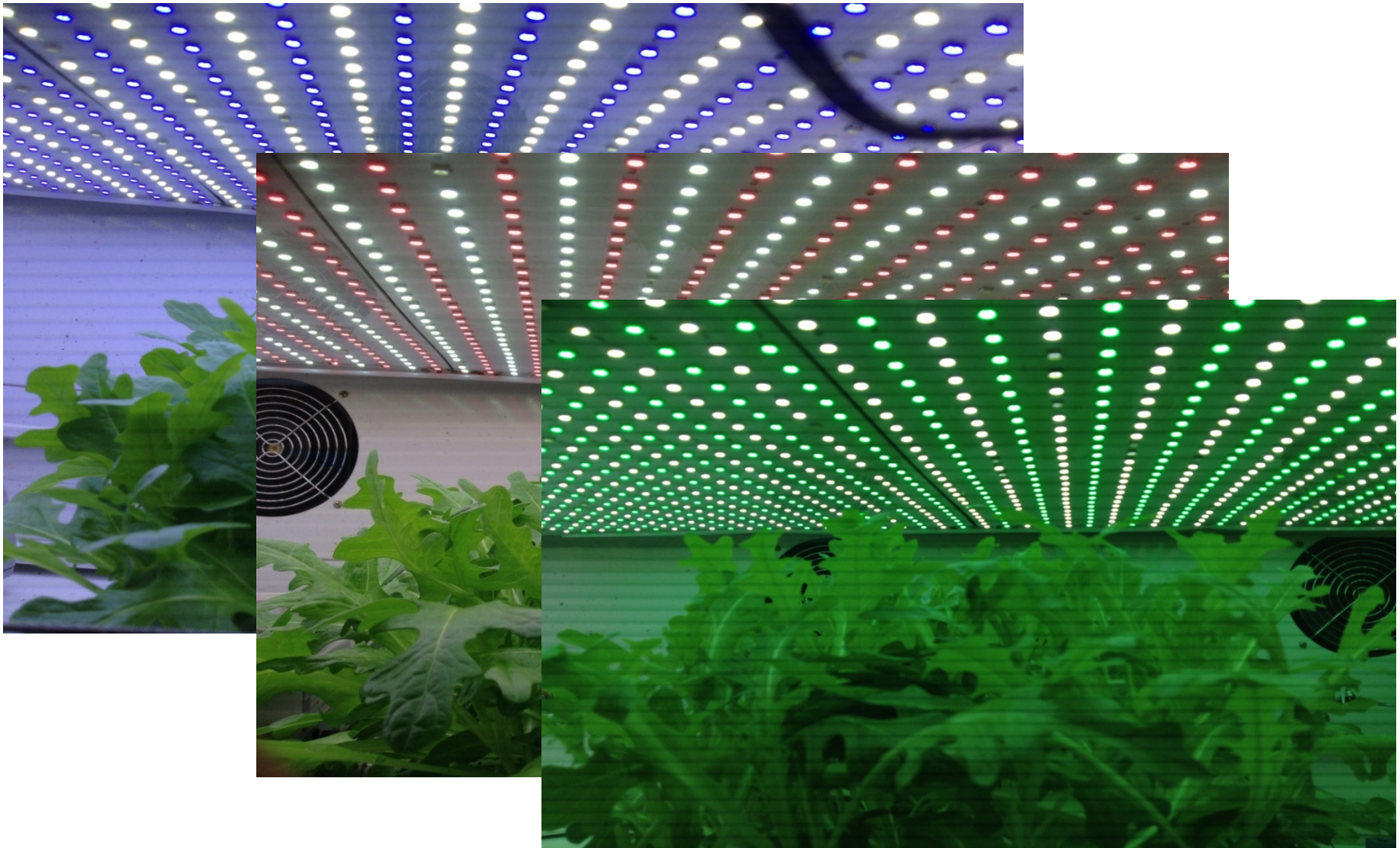
3.2 Researches on the key technologies in plant factory



1.Parameter Optimization of LED Light for Vegetable Cultivation



Controllable LED on light Parameters (light quality, light intensity and light period) has been developed in China



Parameters of Light source for Vegetable Cultivation

Parameter		LED Wave Length (nm)	number of beads（PCS/ cm^2）	photosynthetic photon flux density（μmol ·m^{-2}·s^{-1}）	Power conversion efficiency（%）	Light emitting surface size（cm）	Weight（kg）
LEDA	RED	660	1.82	288	6.7	L54×W28	15
	BLUE	450	0.20	29	13		
LEDB	RED	637	0.14	256	28	L54×W28	10
	BLUE	460	0.11	42	18		

Light Quality Treatments

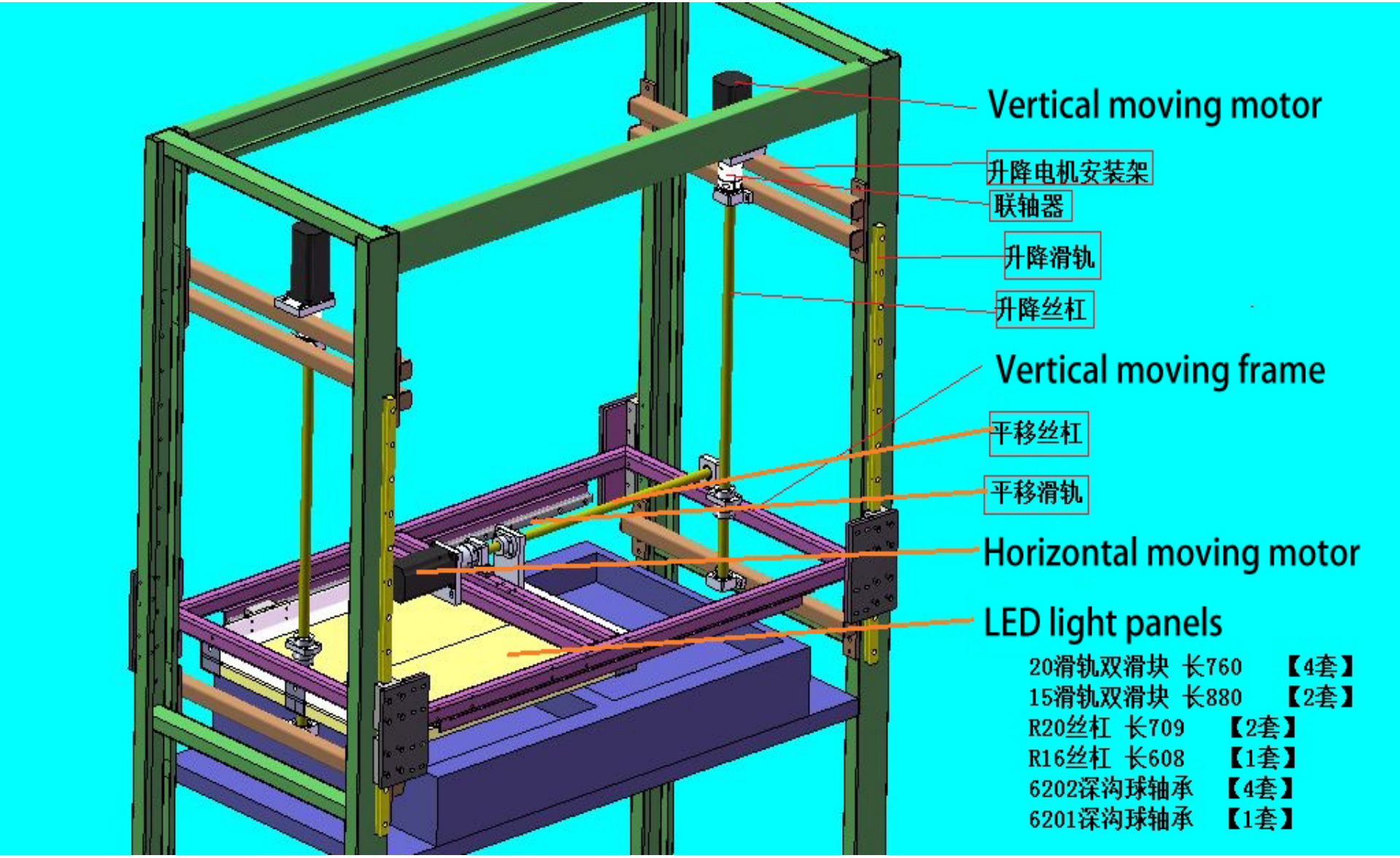
Treatment	photosynthetic photon flux density（RED）（μmol ·m^{-2}·s^{-1}）	photosynthetic photon flux density(Blue)（μmol ·m^{-2}·s^{-1}）	Total photosynthetic photon flux density（∑PPFD）（μmol ·m^{-2}·s^{-1}）	photosynthetic photon flux density ratio（R/B）
LEDA1	132	22	154	6/1
LEDA2	136	17	153	8/1
LEDA3	140	14	154	10/1
LEDB1	131	23	154	6/1
LEDB2	136	17	153	8/1
LEDB3	139	14	153	10/1

Photosynthetic characteristics of lettuce in different treatments

Treatment	Photosynthesis rate (μ mol • m^{-2} • s^{-1})	Transpiration rate (mol • m^{-2} • s^{-1})	Stomatal conductance (mol • m^{-2} • s^{-1})	Intercellular CO_2 concentration (μ mol • mol^{-1})
LEDA1	7.63bc	2.11cd	0.078d	247.8d
LEDA2	7.88b	3.863a	0.165b	332.8a
LEDA3	7.30c	2.42bc	0.098d	294.8b
LEDB1	7.57bc	1.88d	0.053e	275.9c
LEDB2	8.44a	3.62a	0.188a	270.2c
LEDB3	6.45d	2.58b	0.137c	295.2b
CK	5.70e	2.52b	0.086d	306.8b

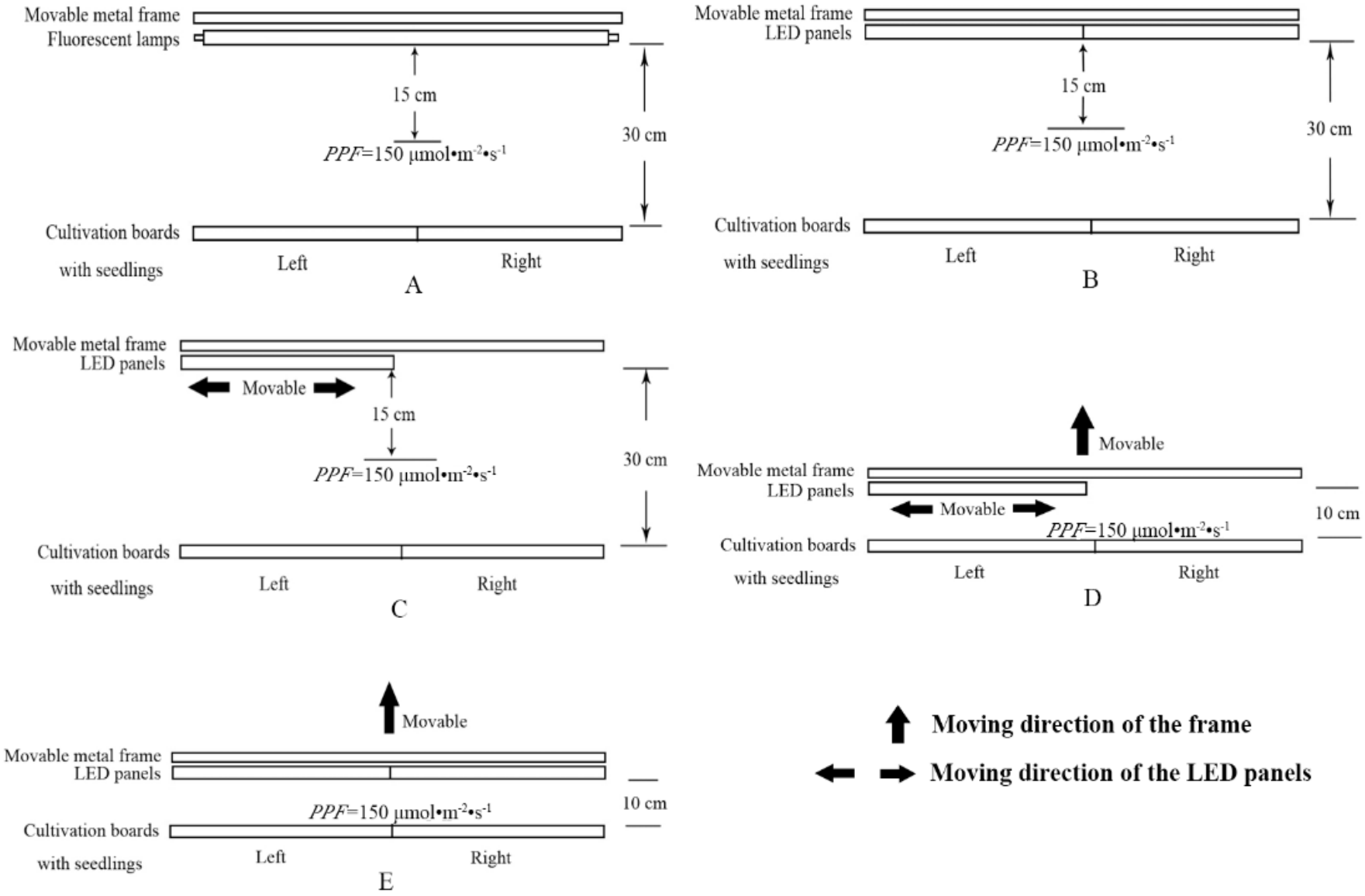
（Wenjing etc, 2007）

2. Energy saving for light by using movable LED system



Treatments

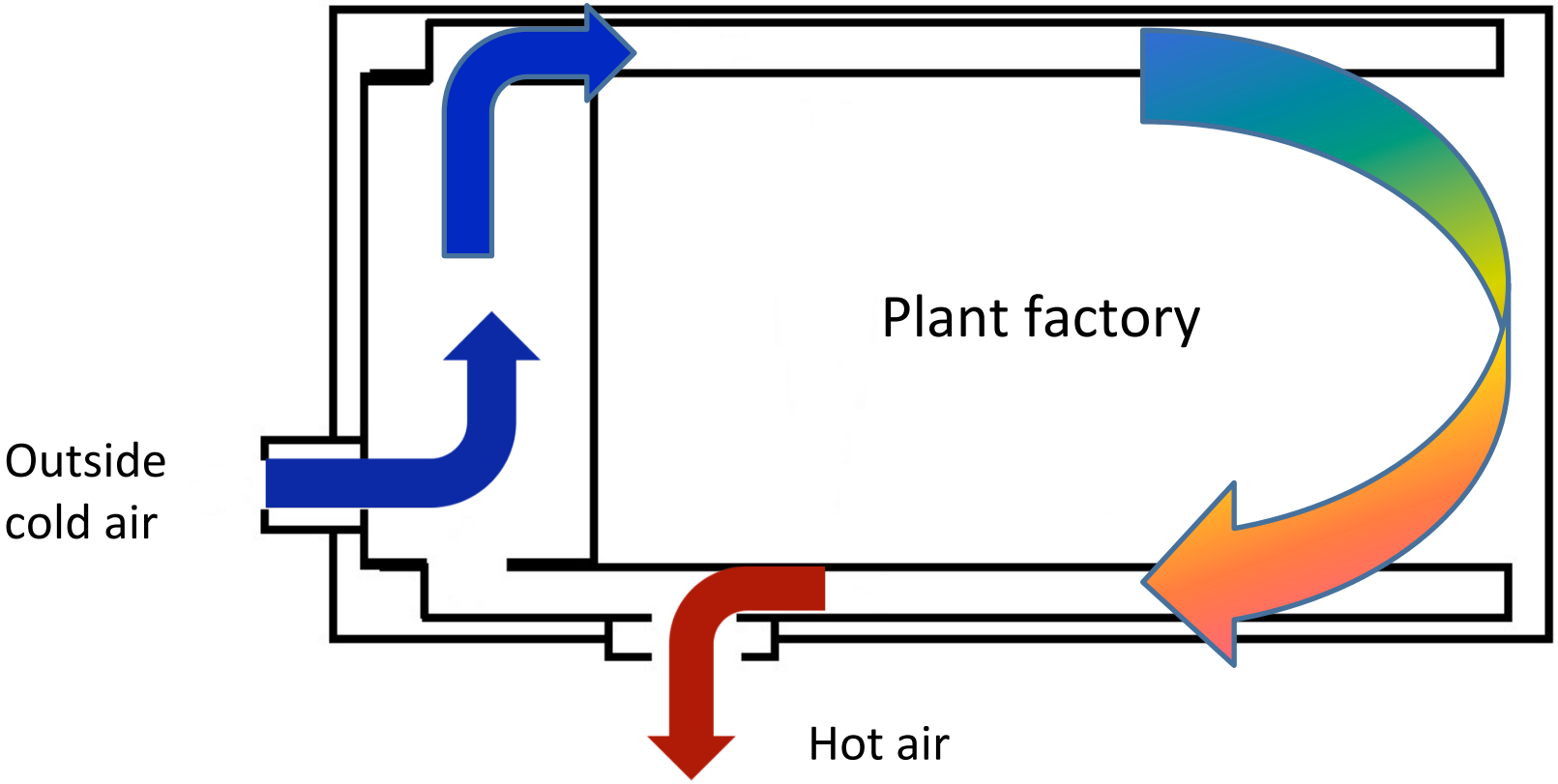
A：CK；B：F-LED30；C：M-LED30；D：M-LED10；E：F-LED10



Electricity consumption of lighting, plant yield and light use efficiencies (LUEs) of lighting (movable LED, fixed-LED and FL)

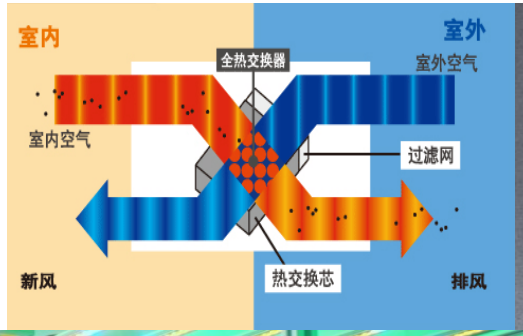
Treatment	Electricity consumption[z] ($kWh \cdot m^{-2}$)	Plant yields[y] ($g \cdot m^{-2}$)	LUEs[x] ($g \cdot kWh^{-1}$)
M-LED10	61.2	625.9±9.23a[w]	10.2±0.15a
F-LED10	60.5	620.1±35.76a	10.2±0.59a
M-LED30	74.1	629.8±13.17a	8.5±0.18b
F-LED30	72	621.9±6.37a	8.6±0.09b
FL	105	438.7±15.76b	4.2±0.15c

3. Energy saving for cooling by introducing outside cold air



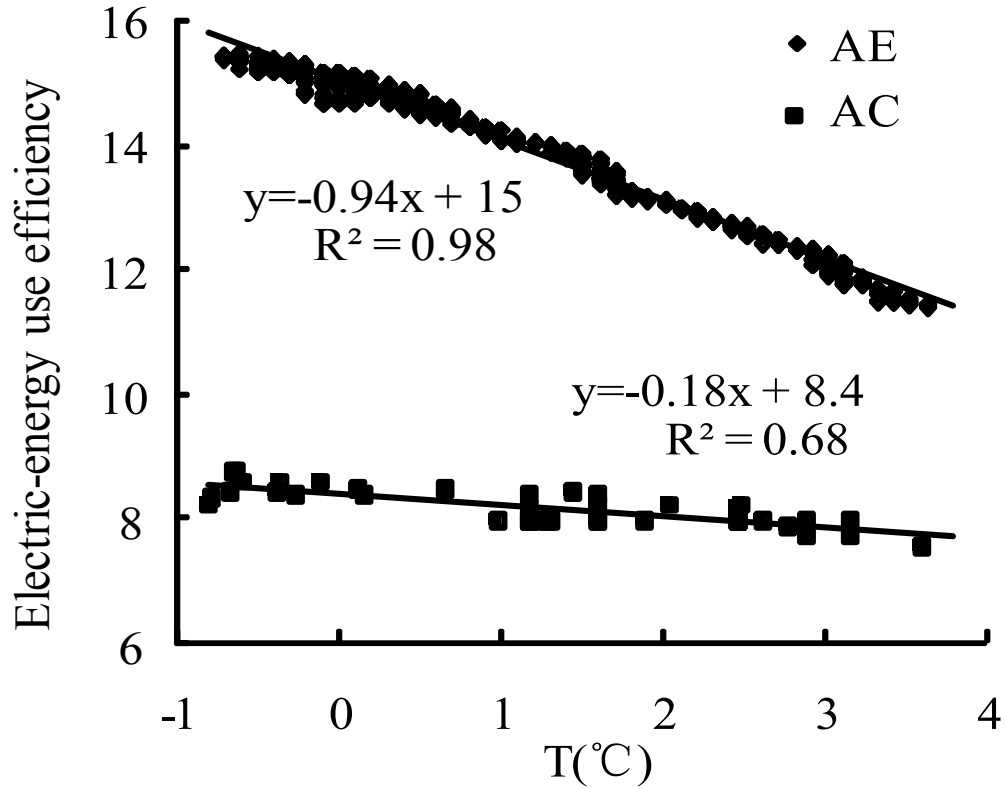
Outside cold air was introduced for cooling coordinated with air conditioner

Air exchanger(AE) system for introducing outside cold air to plant factory



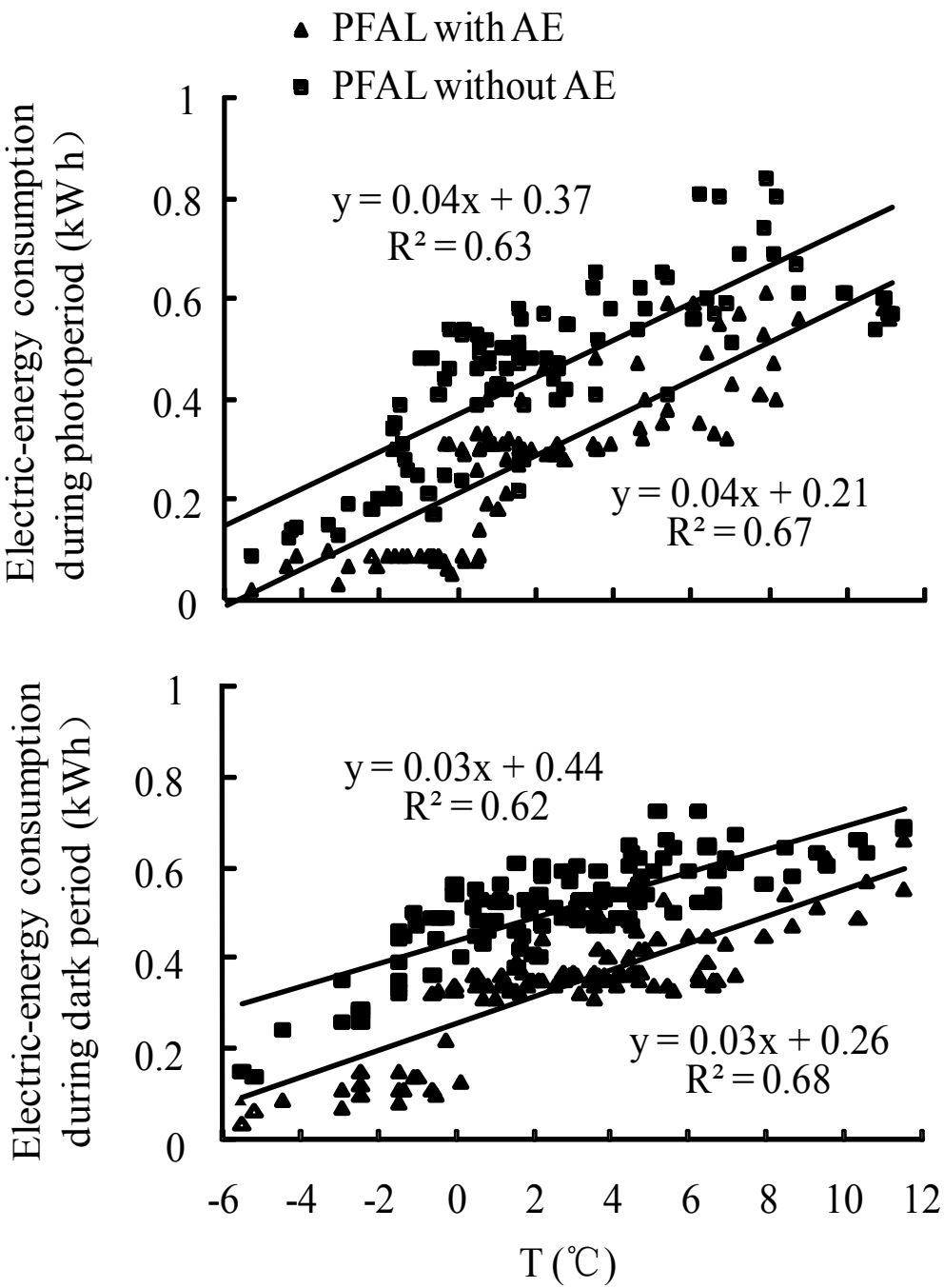
COP of air exchanger (AE) affected by outdoor air temperature is much higher than air conditioner (AC)

Indoor air temperature: 25℃



EUE	AE	AC
Highest	**15.5**	**8.8**
Average	**14.2**	**8.2**

Note: EUE-electric-energy use efficiency;

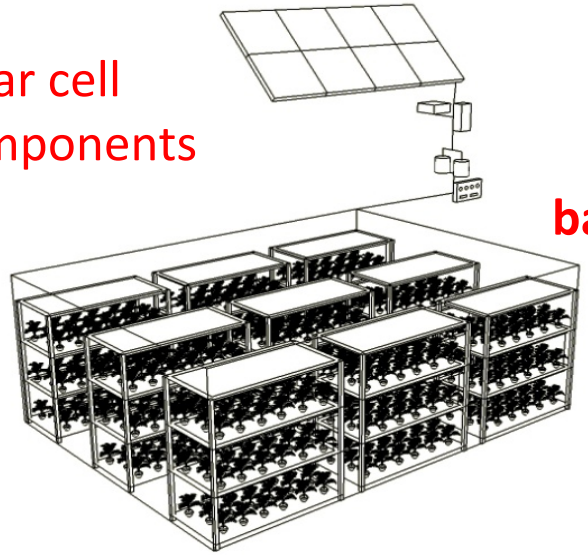


Hourly electric-energy consumption as affected by outdoor air temperature(T)

Stages	T_i	η_E
Photoperiod	25℃	24.6-63.0%
Dark period	15℃	2.3-33.6%

Note: T_i - indoor temperature;
η_E-electric-energy saving effect.

4. Energy-saving using Solar energy power and LED in Plant factory



5. Quality control of vegetables

Nitrate

75~80%

Nitrate

20~25%

High nitrate → Cancers and diseases

Hemoglobin —Nitrate→ methemoglobin

（carries oxygen） （stop carrying oxygen）

(Cassens, 1997)

Reducing nitrate concentration with pre-harvest short-term continuous lighting

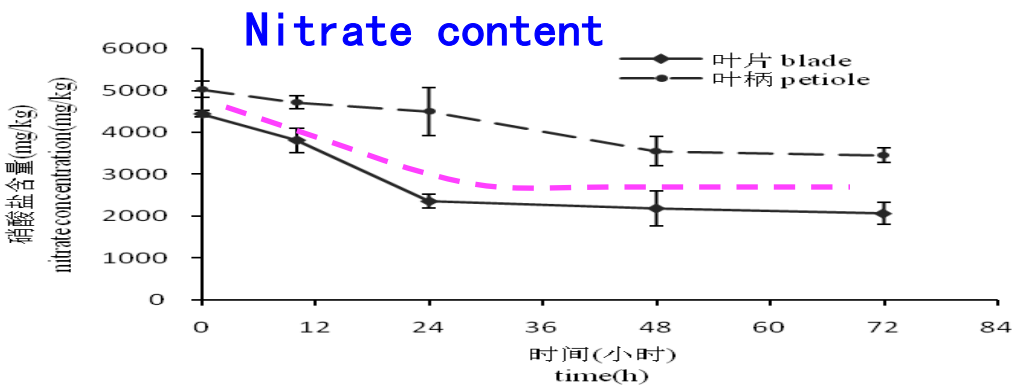
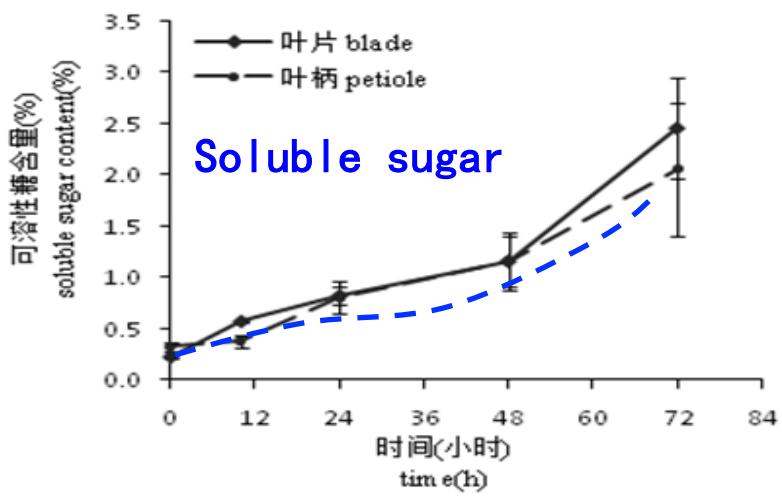


图2 连续72小时光照下生菜硝酸盐含量的变化
Fig. 2 Changes of nitrate concentration in lettuce under 72h continuous light



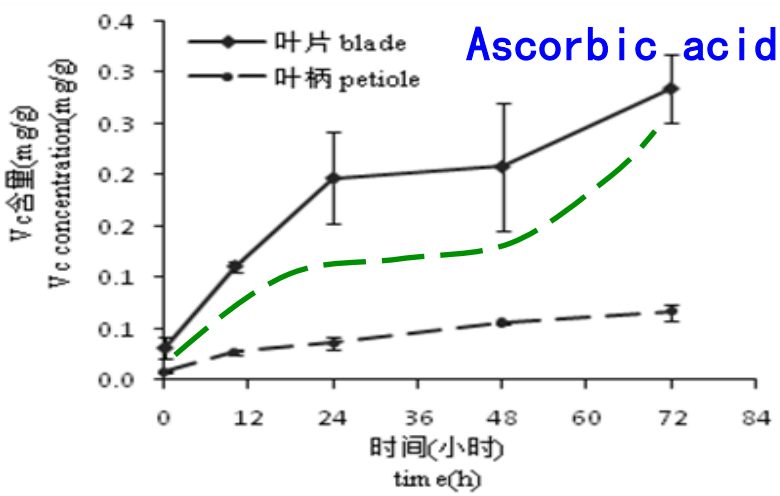
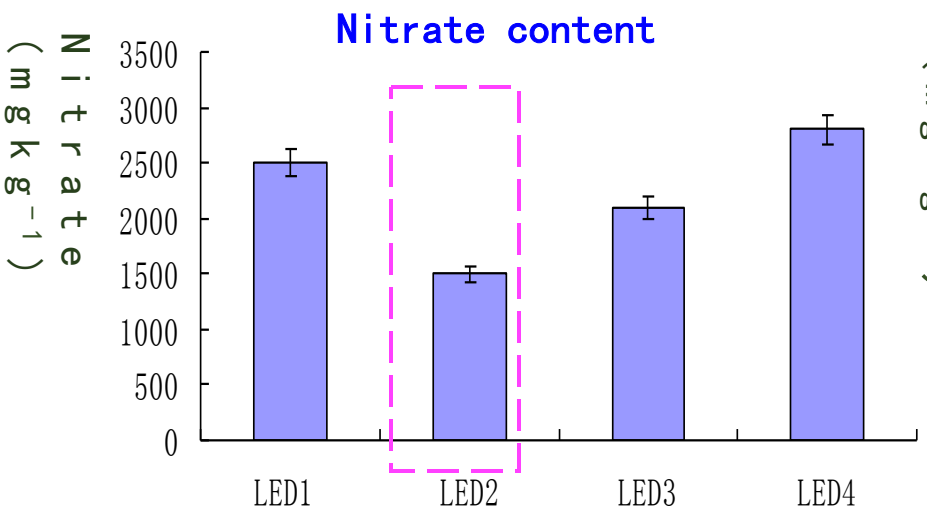
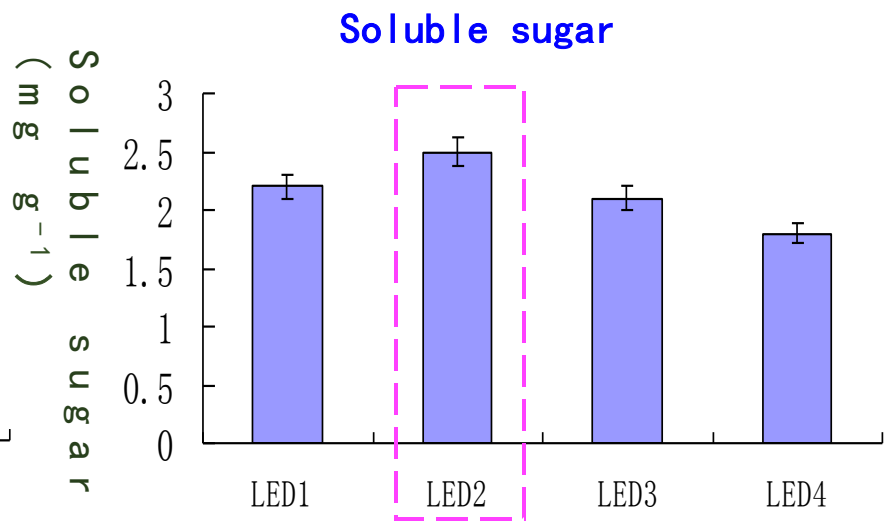


图3 连续72小时光照下生菜可溶性糖及Vc含量的变化
Fig. 3 Changes of soluble sugar content and Vc concentration in lettuce under 72h continuous light

R/B ratio during pre-harvest continuous lighting treatment

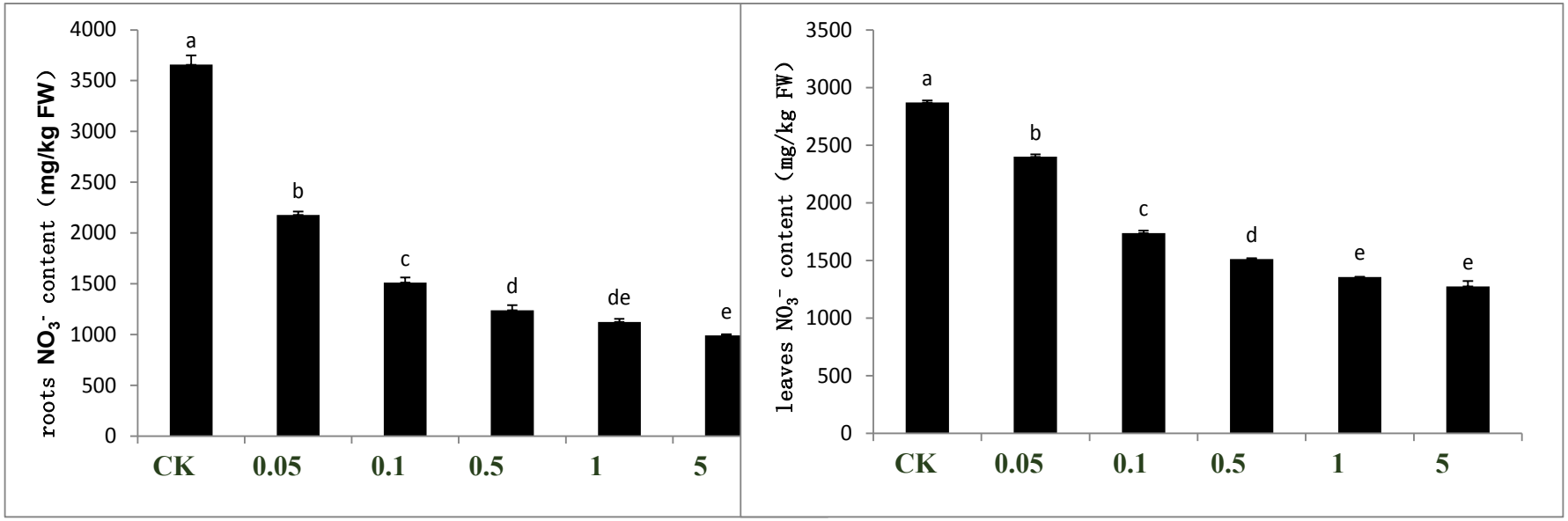




Treatments	R/B ratio	Photon flux density of red and blue component (μmol·m^{-2}·s^{-1})	
		Red	Blue
LED1	2	100	50
LED2	**4**	**120**	**30**
LED3	8	133	17
LED4	--	150	0

(Zhou *et el*, 2013)

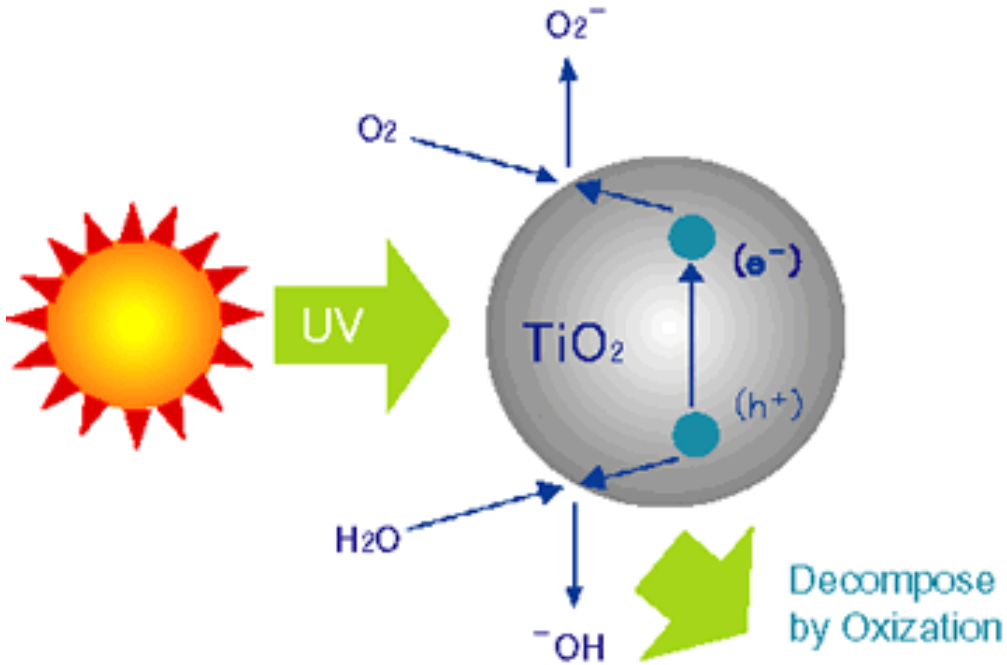
Reducing nitrate concentration by enriching selenium content in nutrient solution

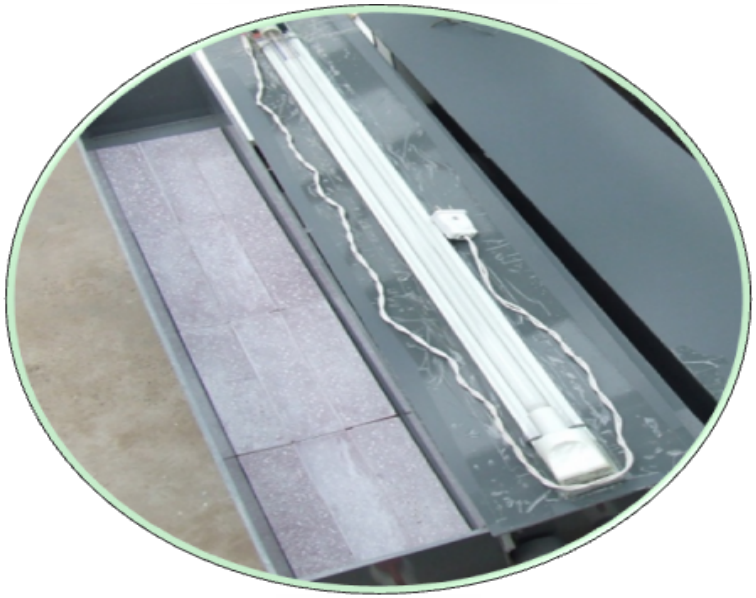


Enrichment of selenite significantly decreased NO_3^- content in roots and leaves.

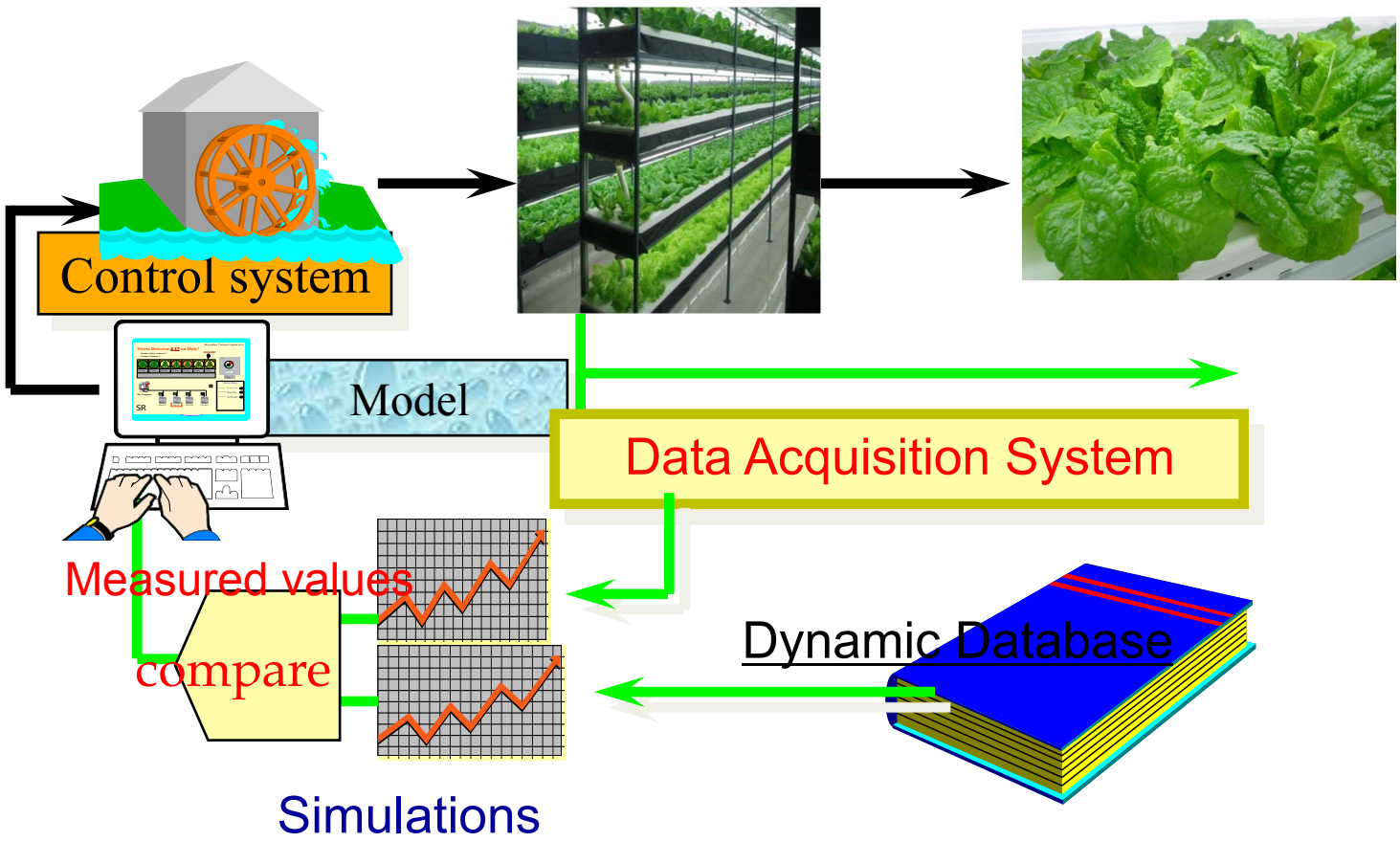
(Lei *et el,* 2014)

6. Photocatalytic Degradation of Phytotoxic Substances in Waste Nutrient Solution by Nano-TiO_2





7. Digital measurement and control



3.3 Researches on vertical cultivation and urban farming

Column cultivation

Column cultivation

Vertical Cultivation

Vertical Cultivation

Multi-layer cultivation (leaf vegetable)

Multi-layer cultivation (fruit vegetable)

Sweet pepper

Tomato

Tree-type Cultivation






Interesting Cultivation

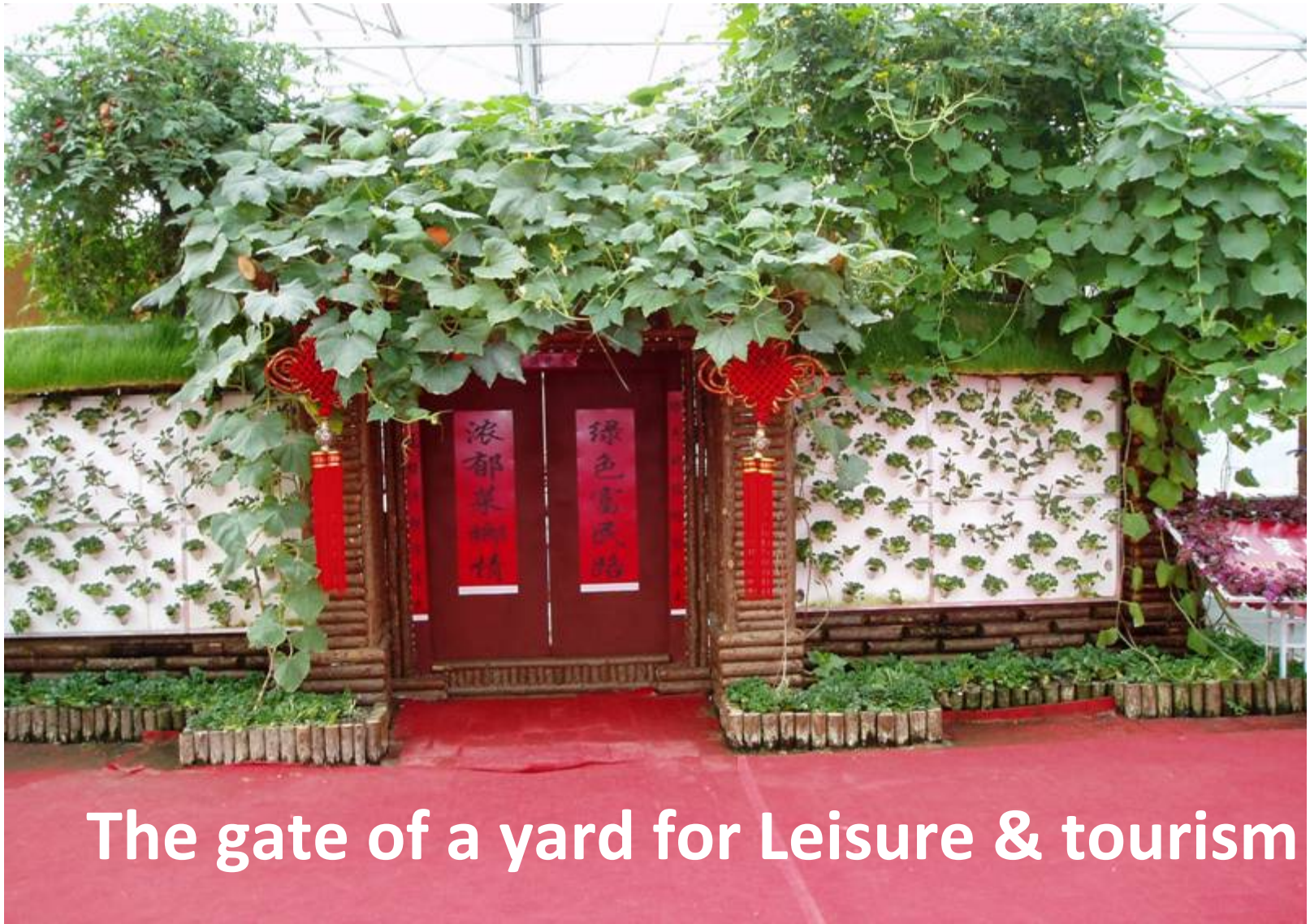
Giant Cultivation

Over-ground tuber production of sweet potato

(invented by IEDA in 2005)

Tuberous roots

Ecological house



The gate of a yard for Leisure & tourism

Ecological house

4. Facing Challenges of vertical farming (plant factory)

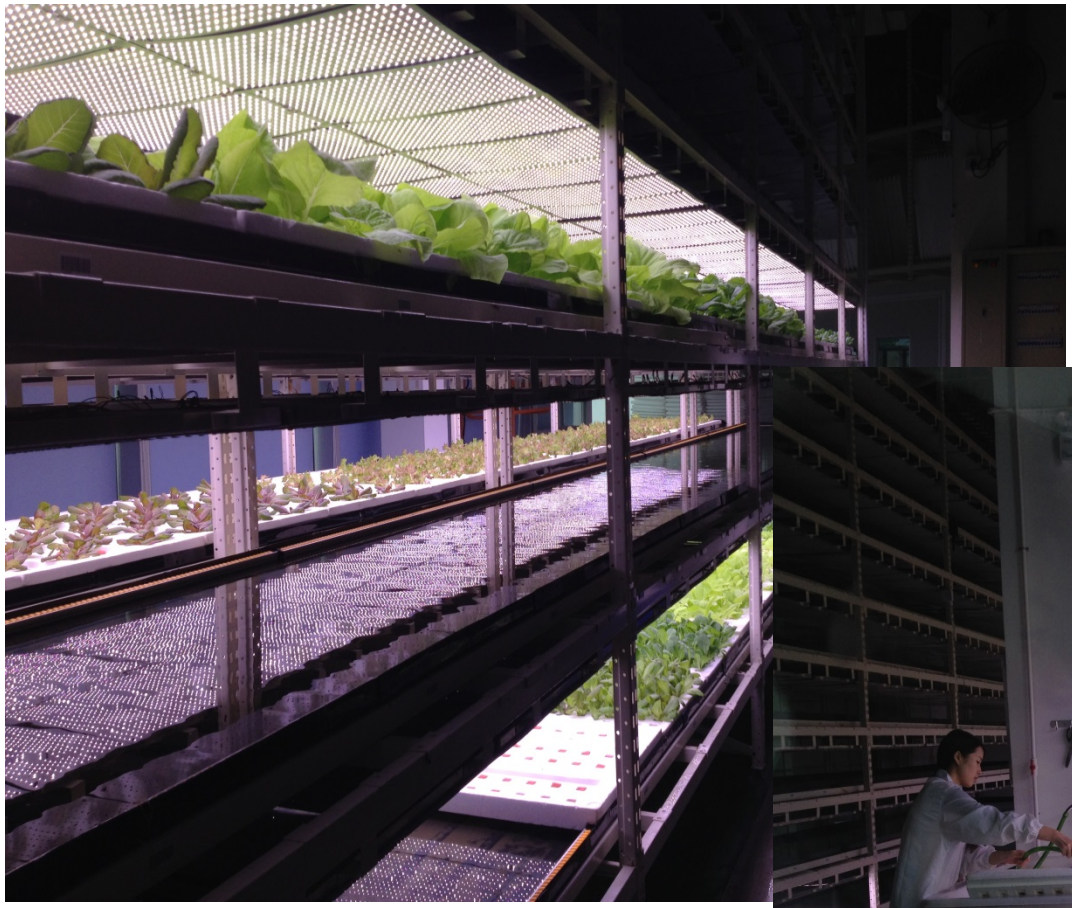
4.1 Facing Challenges of vertical farming (plant factory)

- 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)

Vegetable from greenhouse and field is very cheap,if the vegetable from VF or PF was put in the same market,it has lower competition,so it need to create special markets for high-end consumers.

One way—Old industry building (not used now)for plant factory(can decrease initial cost of construction)

Used for plant factory now



Dongguan city, Guangdong province, 2013)

4.2 Perspectives of vertical farming (plant factory) in China

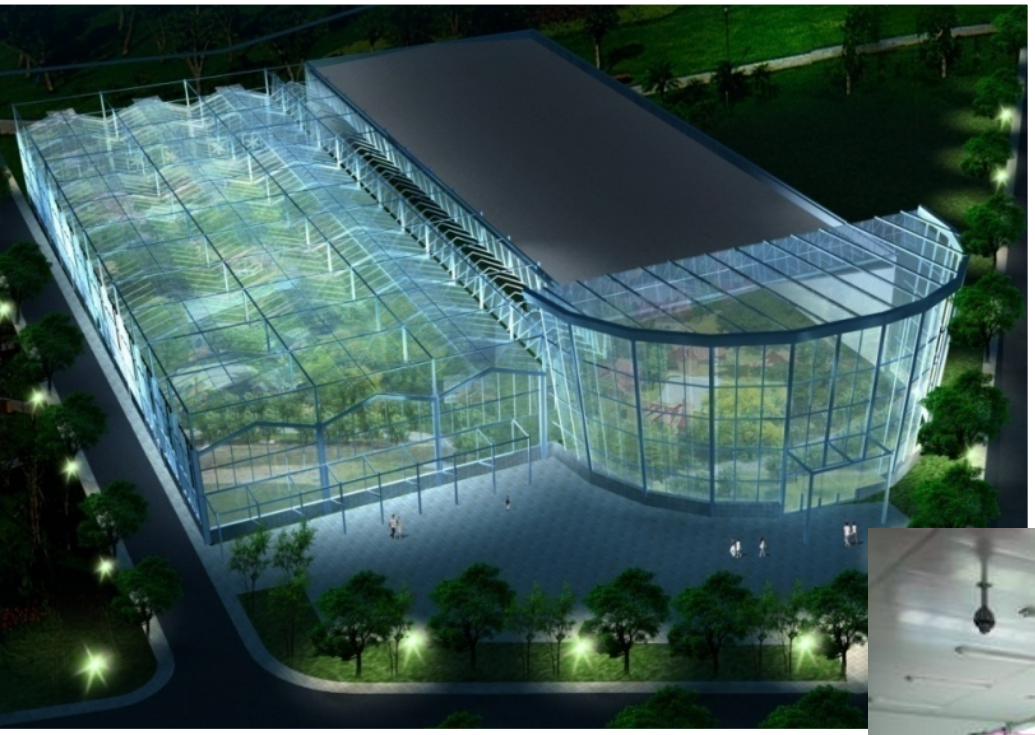
- Priority areas for developing: Agri.sci.& tech.park, for demonstrating PF.
- Producing healthy and safe vegetables(fresh, clean, pesticide-free,and multi-function) for high-end consumers or local consumers in large cities,like Beijing,Shanghai.
- Multi-function utilization in special areas: family, building, supermarket, school, restaurant (Ubiquitous plant factory).
- Vertical farming(2-3 ongoing projects now)

Priority areas for developing PF

◆**High-tech agricultural demonstrate park**（**over 6000 Agricultural Sci.& Tech. parks in China)**

Vegetable Expo (April 20-May 30) in Shouguang, Shandong. The number of visitors in 2014 is up to 2.2 million.

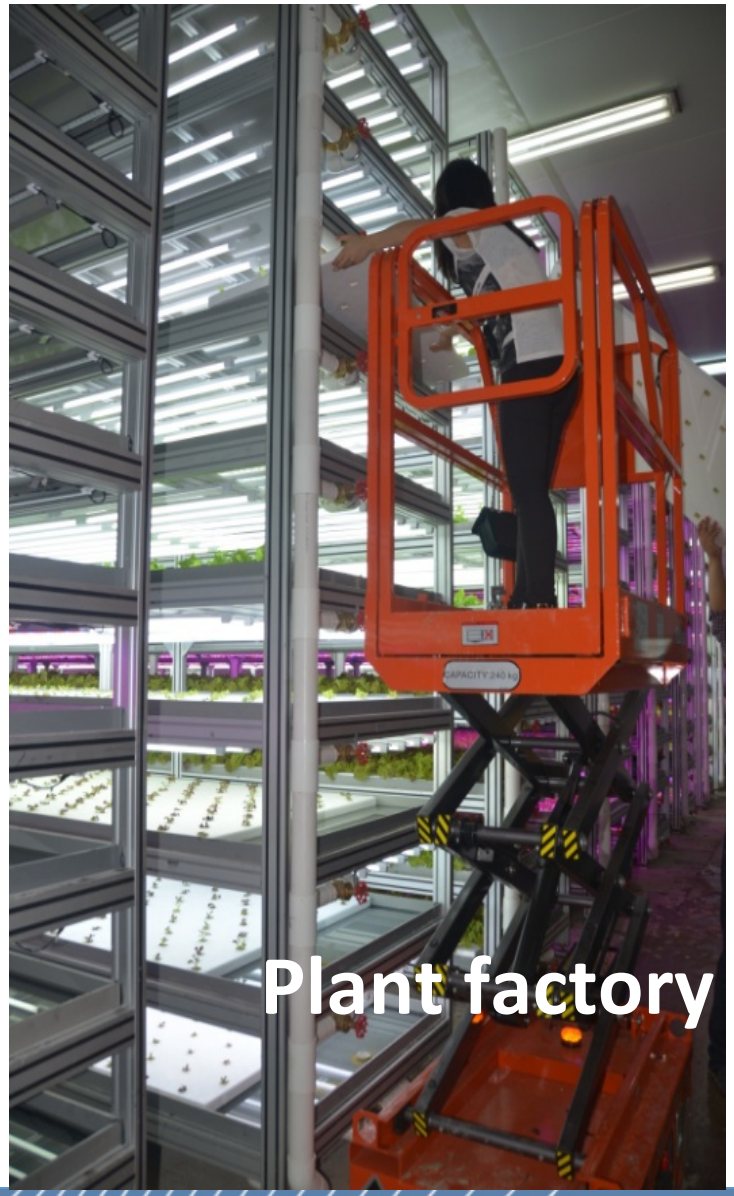
Plant Factory for demonstration in Zhejiang



Bird eye view of the plant factory, 1600 m^2 (include PF with artificial light 880 m^2)

Movable cultivation beds with LED light

Inside view of the plant factory



Plant factory with LED light(Zhejiang)

High quality vegetable production

High-end consumer groups increasing quickly in large cities (demands increasing for fresh, clean, pesticide-free vegetables）

Plant factory in Shenyang, Liaoning province

Plant factory in Beijing

PF for producing healthy and safe vegetables (800m^2,Beijing)

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

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

Agri.sci.& tech.park(Sunqiao,Shanghai)

The area is about 50,000 m^2 (PF with artificial light and solar light)

PF for producing healthy and safe vegetables (fuzhou,Fujian province)

The area is 250m^2,producing 260,000 heads of lettuce.

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.

Low-carbon, intelligent, Plant Factory for Family, Shanghai Expo 2010 (Concept of growing vegetables at your kitchen)

Mini-type plant factory for family

Mini-type plant factory for family

5. Projects on vertical farming and plant factory in China

Research projects of Plant Factory in China

Research on intelligent plant factory production technology, national high sci.& tech. project (2013-2017; 50,000,000 ￥RMB (8 million USD)) ,orgenized by Chinese Academy of Agricultural Sciences. 15 Uni.,Insti.,and Companies joined the project.

Chief scientist: Qichang Yang (CAAS)

1	Energy-saving LED light source and light environment intelligent control in plant factory	Institute of Environment and Sustainable Development in Agriculture, CAAS; IEDA Ltd
2	Research on key technology and equipment of multilayer cultivation system in plant factory	Beijing Agriculture Machinery Institute, China Agri. Uni.
3	Energy-saving environmental control technology based on light and temperature coupling in plant Factory	Tech. Top photoelectric technology company, Nanjing agricultural university

4	Nutrient solution management and vegetable quality control technology research in plant Factory	Northwest A&F University , CAAS
5	Key technologies research of intelligent system control based on the network management in plant factory	The National Engineering Research Center for Information Technology in Agriculture,
6	Integrated demonstration of solar light plant factory	Dushi Green Engineering Company, Shanghai, Tongji Uni., SAAS
7	Integrated demonstration technology of artificial light plant factory	Zhejiang University , CAAS

China-Europe cooperation project on vertical farming &urban agriculture

- **Structure and cultivation systems** in vertical farming will be optimally designed for using vertical space efficiently.
- **Integrated environment control technologies** for producing high quality vegetables in vertical farming with zero fossil-fuel energy consuming
- **Innovations on resource** (wastewater, excess energy etc.) recovery and productive reuse
- **Energy-saving artificial light** in closed plant production systems for vegetable production
- **Hydroponic cultivation systems, nutrient solution's recycling and controlling**

Thanks for your attention

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