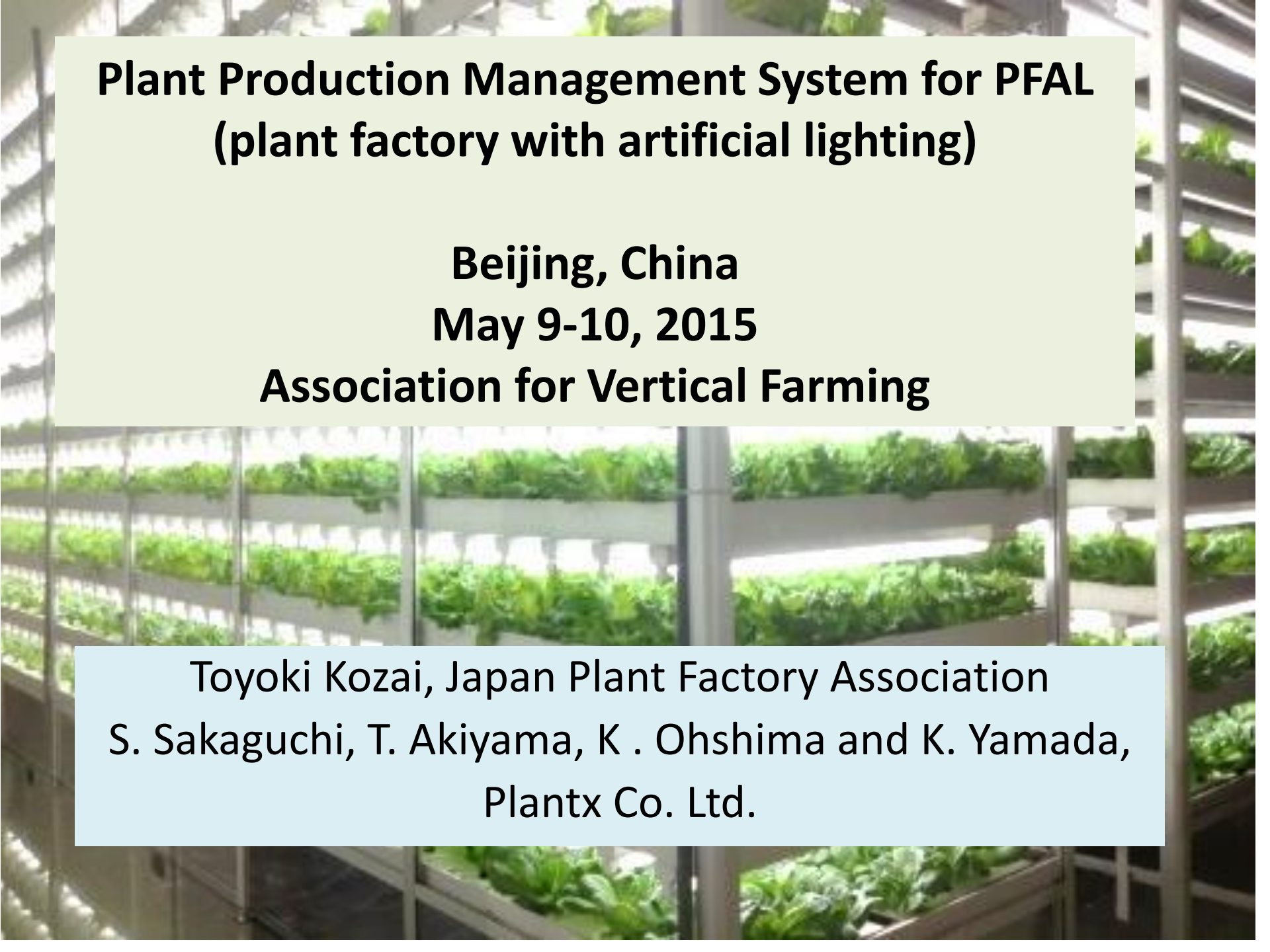


Plant Production Management System for PFAL (plant factory with artificial lighting)

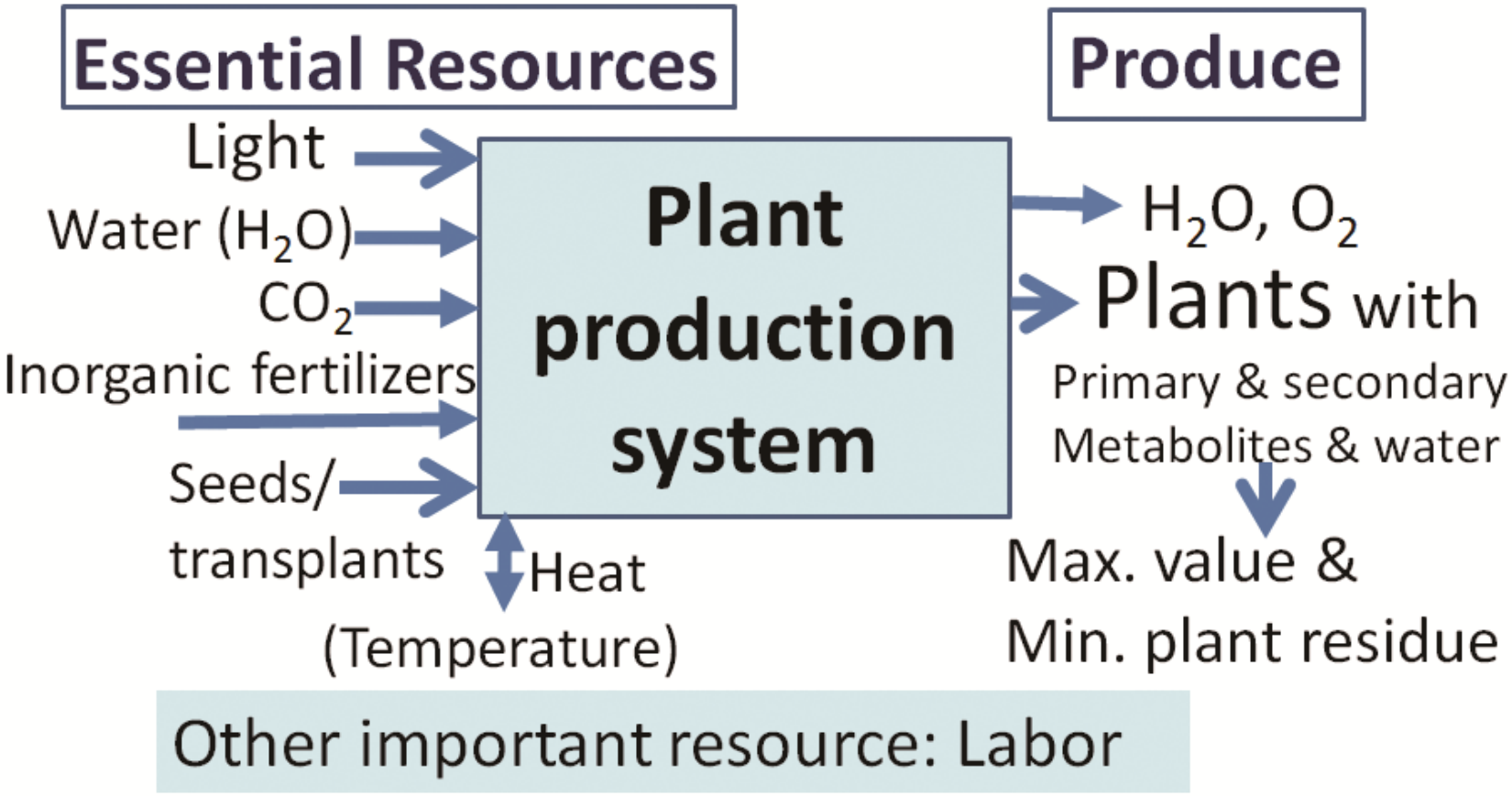
Beijing, China
May 9-10, 2015
Association for Vertical Farming

Toyoki Kozai, Japan Plant Factory Association
S. Sakaguchi, T. Akiyama, K . Ohshima and K. Yamada,
Plantx Co. Ltd.

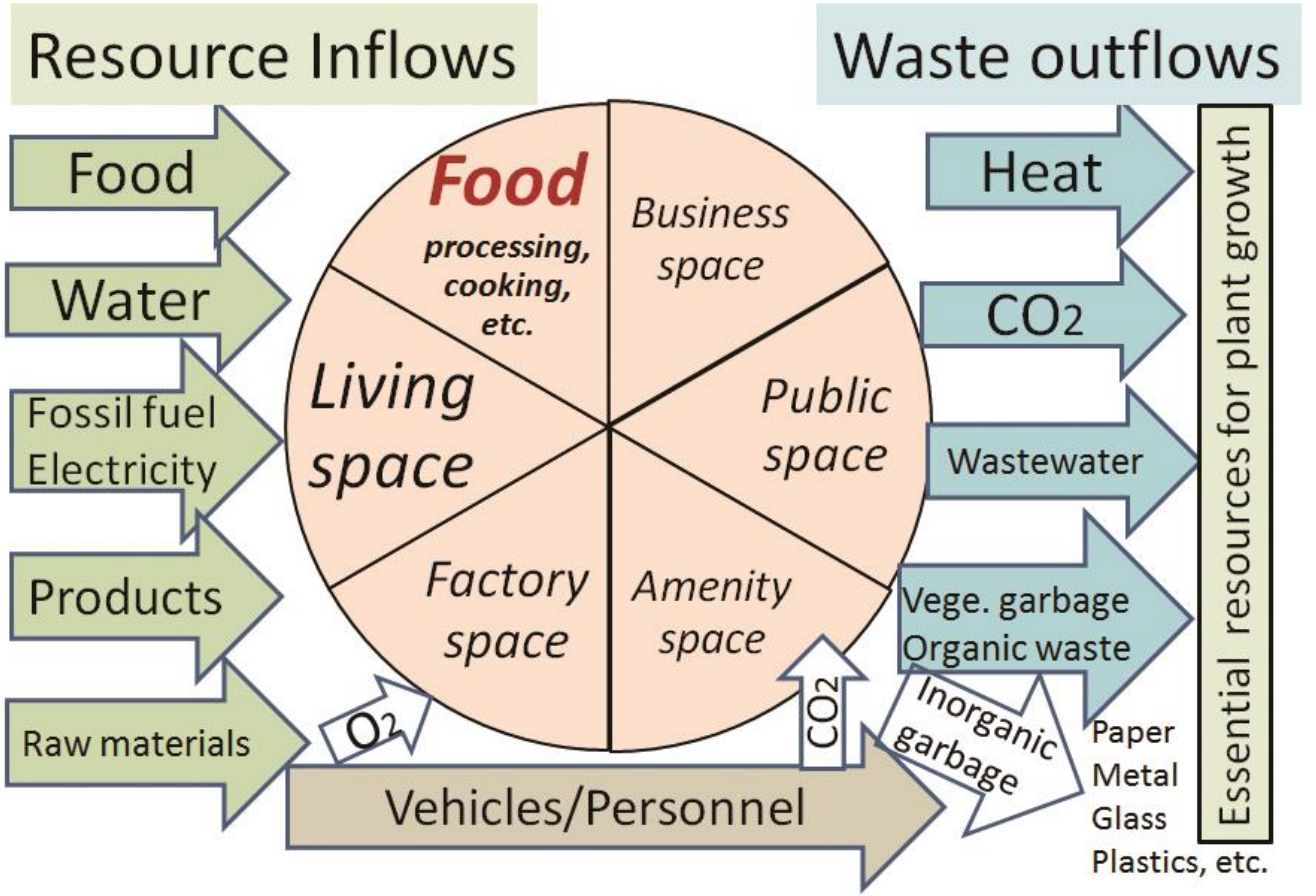
Contents

- **Introduction** –essential resources for plant production -
- **Current status of PFALs in Japan** and issues to be solves
- **Structure of PFAL (plant production system)**

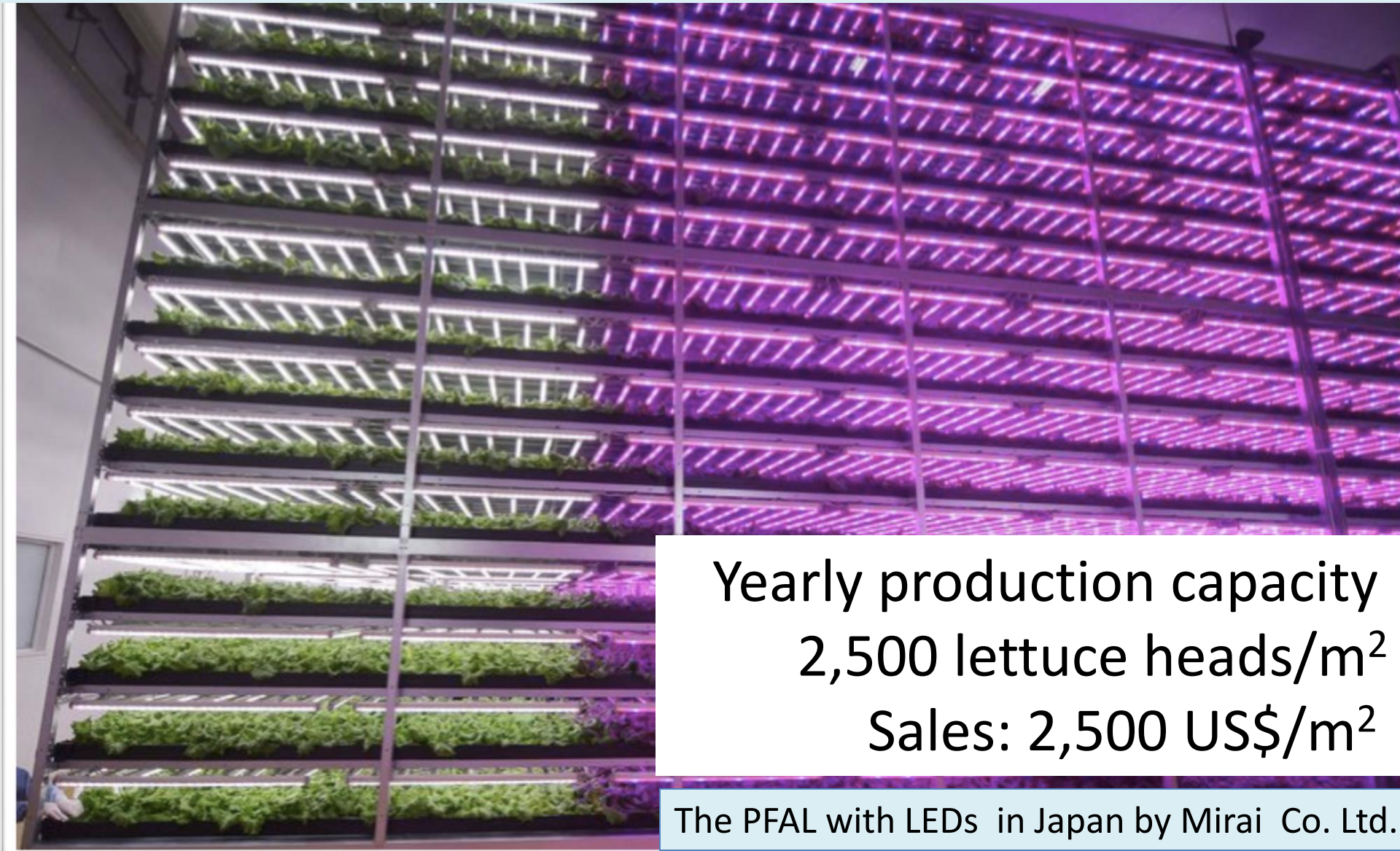
Essential resources (left) in plant production system & produce obtained form the system (right)



Most fresh garbage in the city can be converted into essential resources for plant production



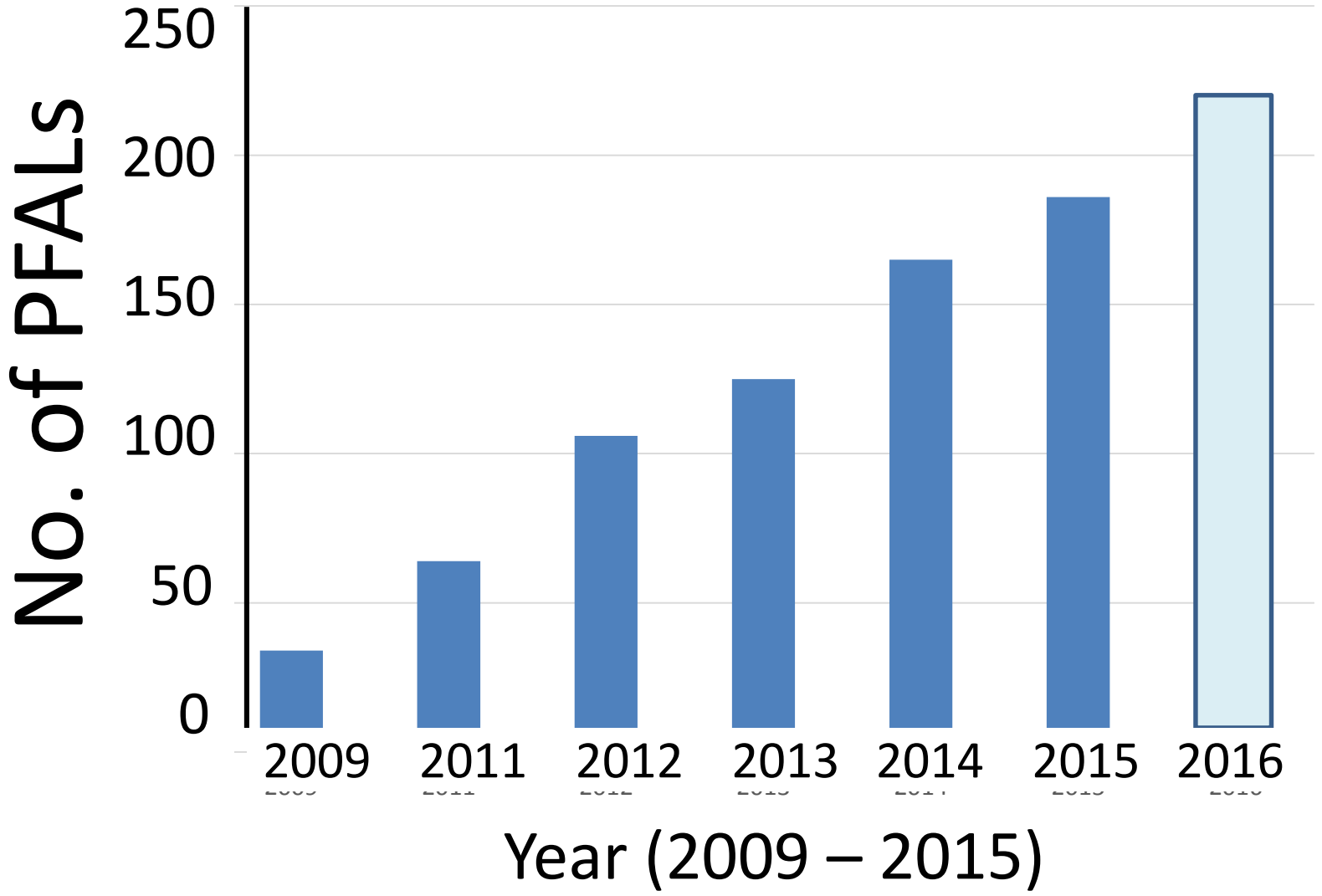
Annual production capacity is 100 -200 times higher in the PFAL than in the open-field



Yearly production capacity
2,500 lettuce heads/m^2
Sales: 2,500 US$/$m^2$

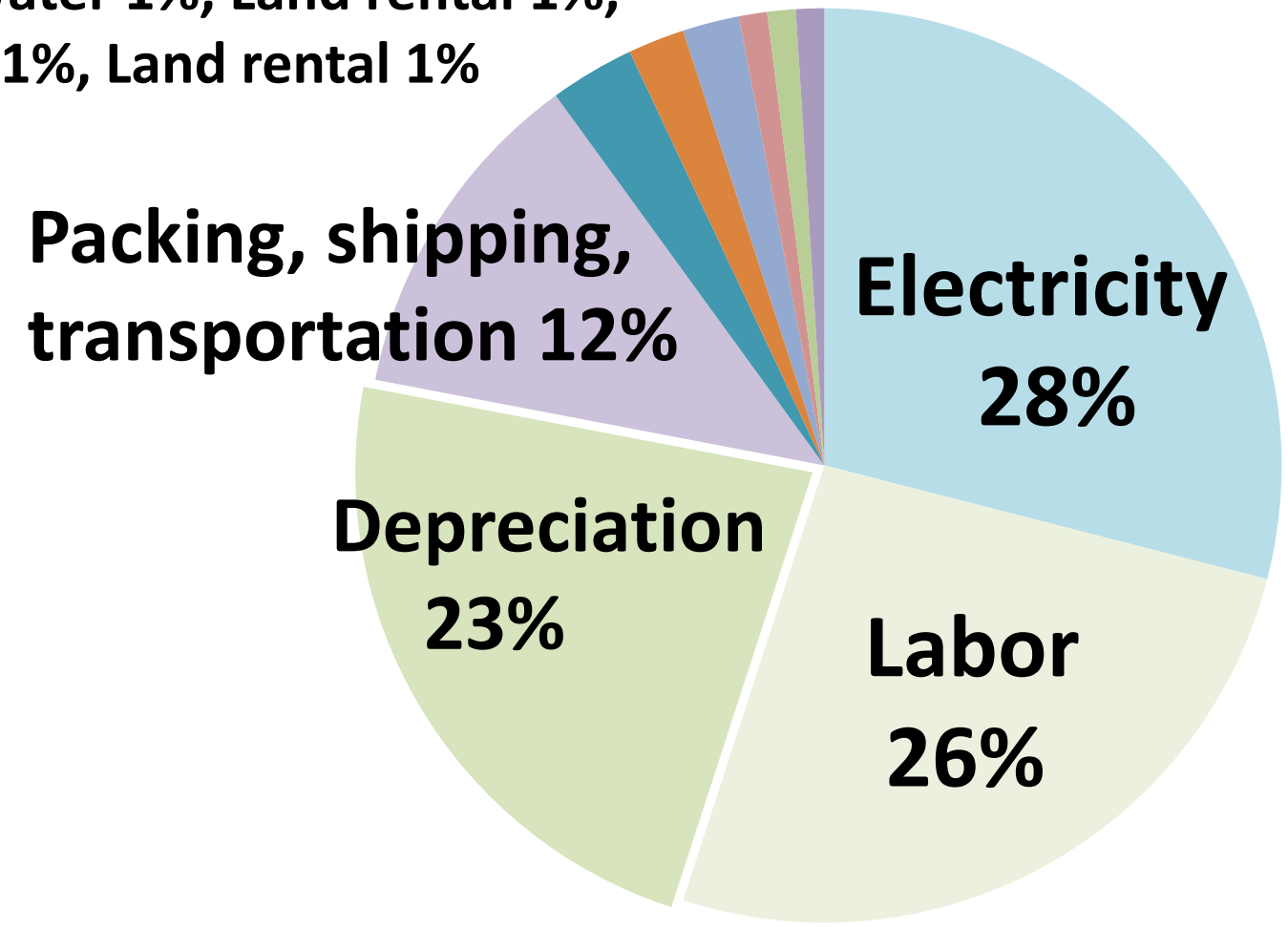
The PFAL with LEDs in Japan by Mirai Co. Ltd.

The number of PFALs has been increasing in Japan. Why?

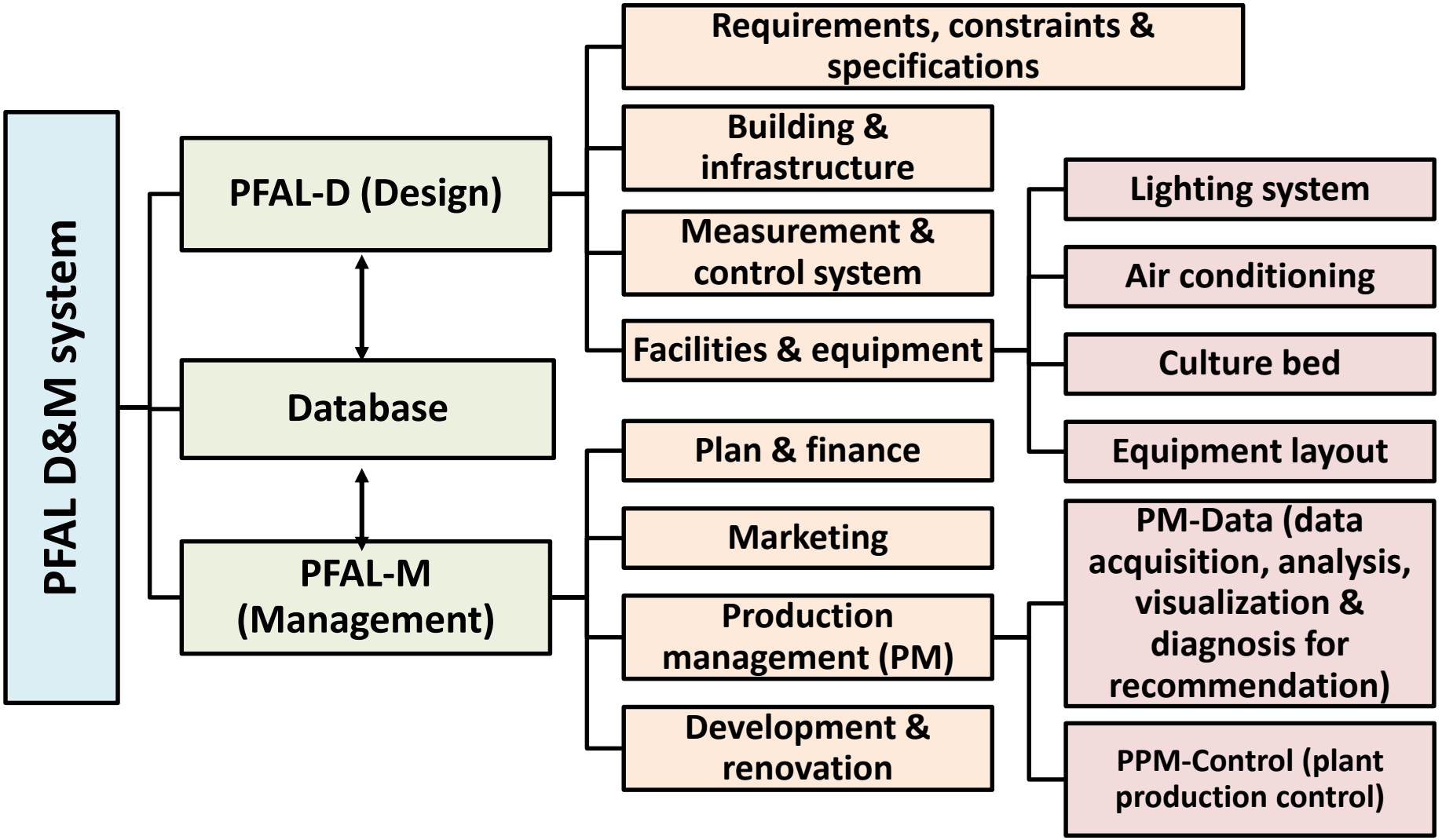


Production costs by components

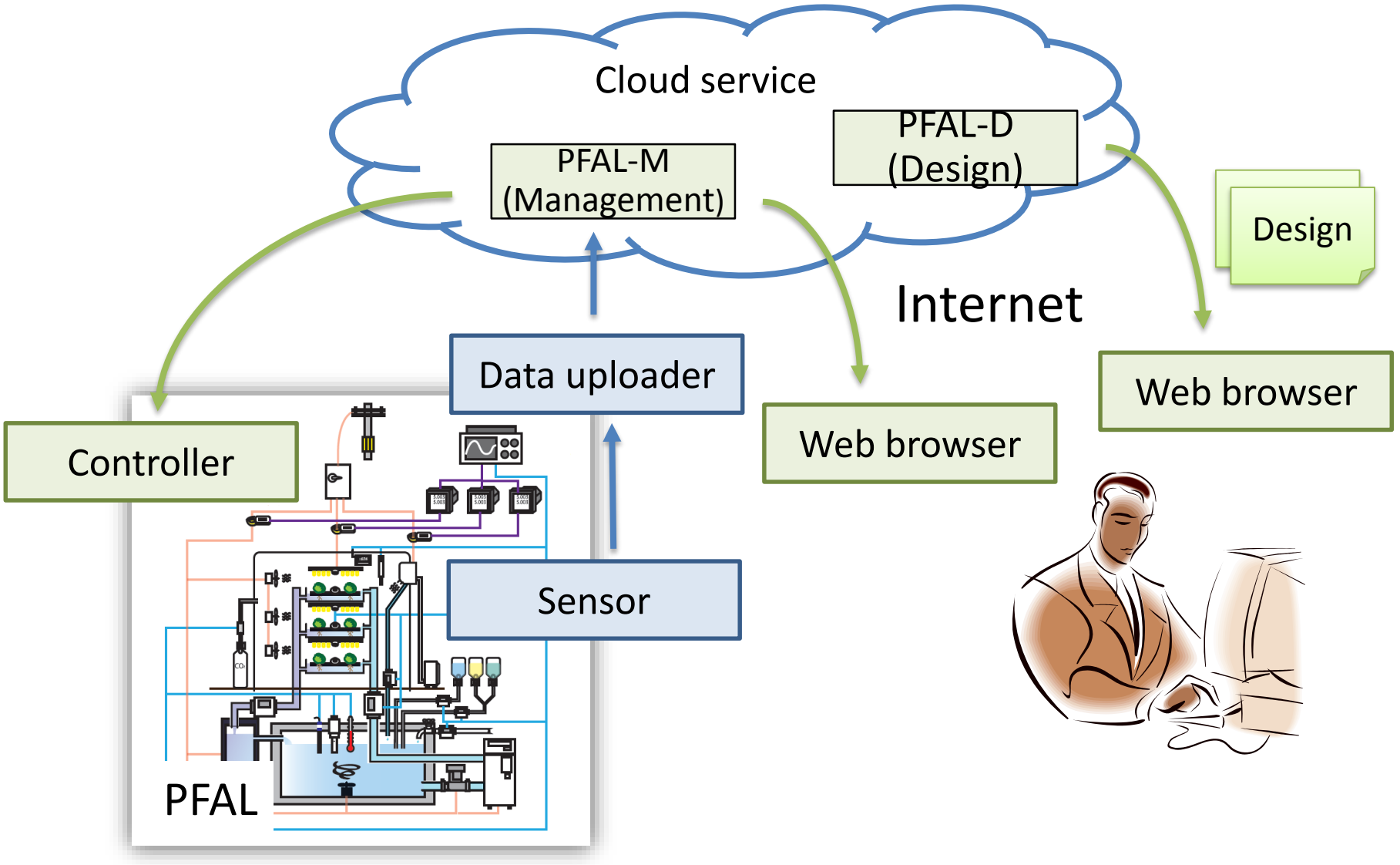
Consumables 3%, Seeds 2%, Repair 2%
Supplies 1%, Water 1%, Land rental 1%,
Miscellaneous 1%, Land rental 1%



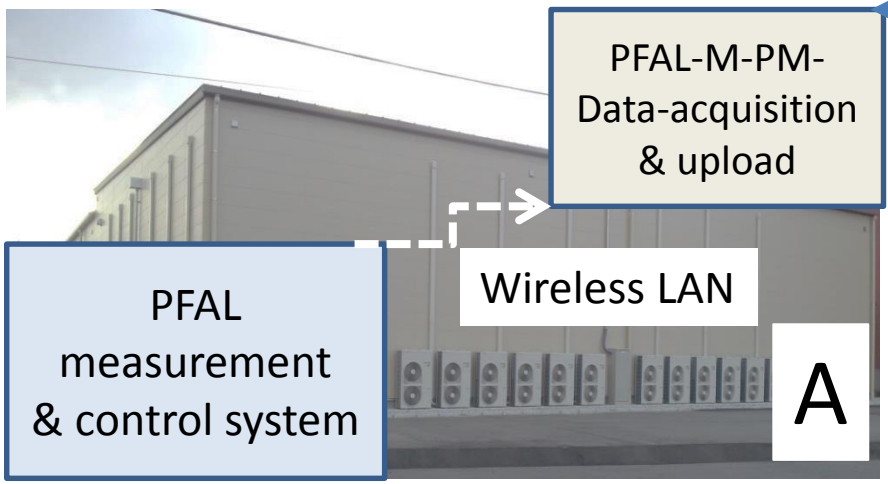
Structure of PFAL-D&M (plant factory with artificial lighting - design and management) system



Structure of PFAL-D&M system in the cloud and PFAL



PFAL-D&M is used via Internet. Type A: Installed at an existing PFAL, Type B: Installed at a newly built PFAL



PFAL-M-PM-Data-acquisition & upload

Wireless LAN

PFAL measurement & control system

A

Cloud

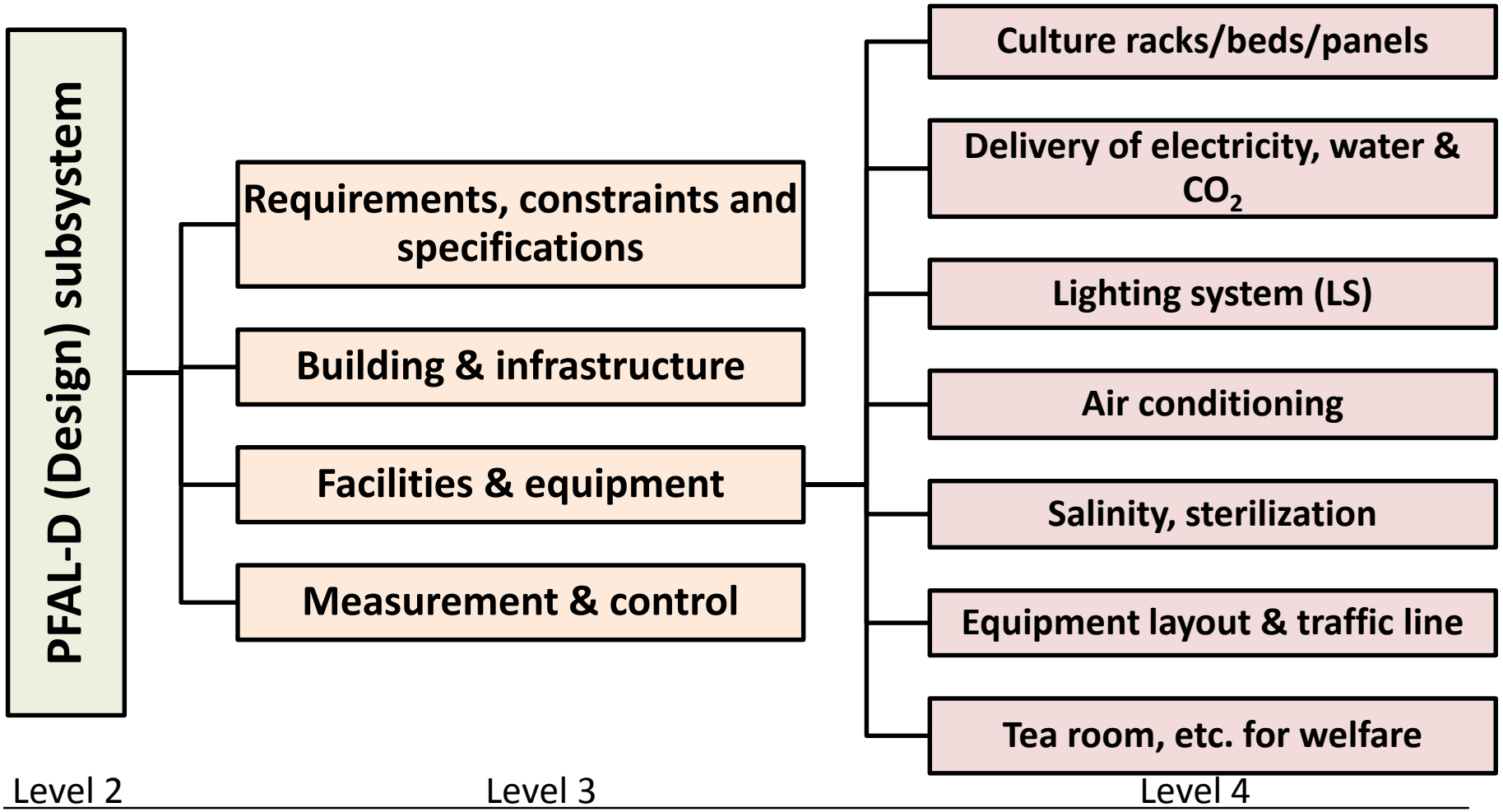
PFAL-D&M system except for 'data acquisition & upload ' of PFAL-M-PM unit

Internet

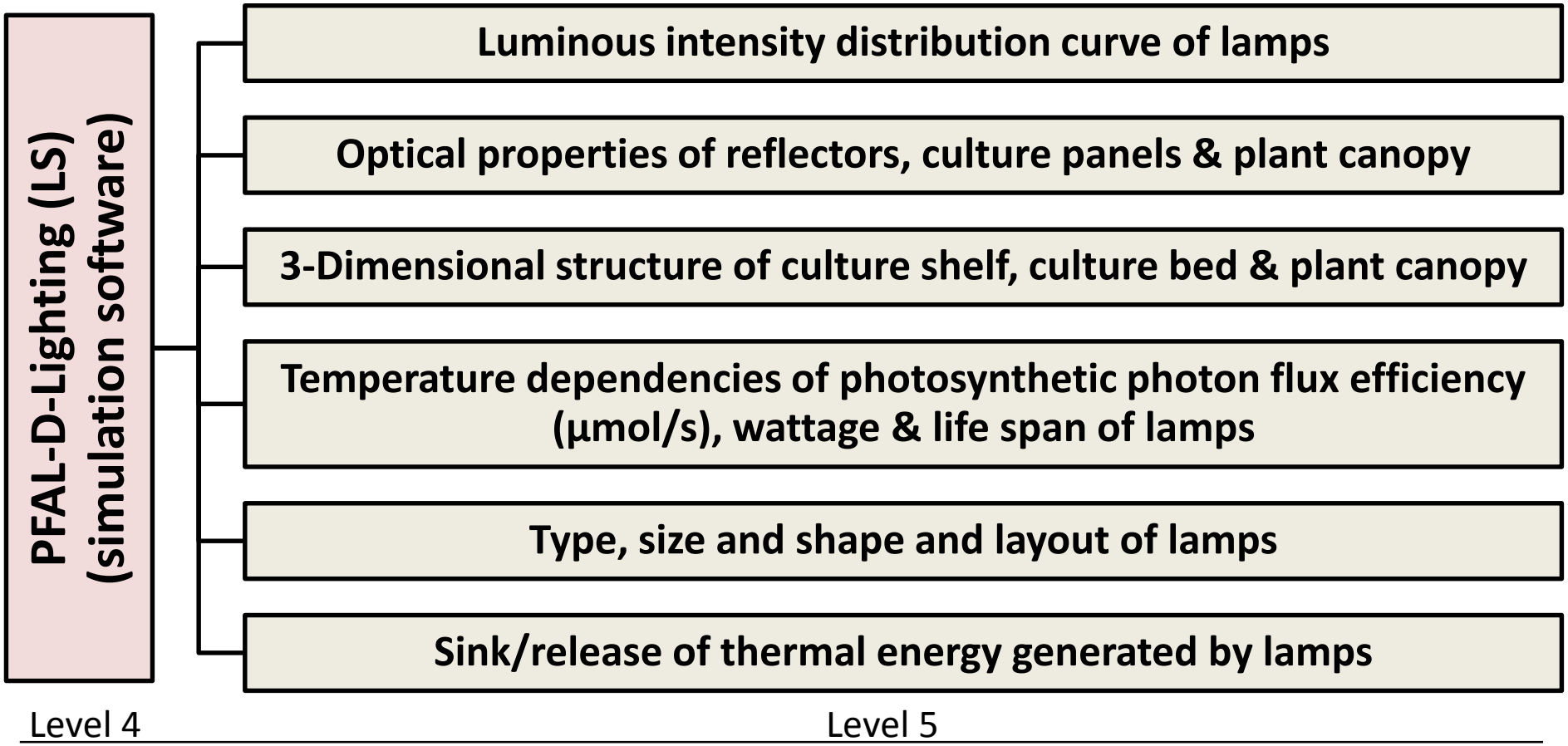
PFAL-M-PM-Data acquisition & upload with PFAL measurement & control

B

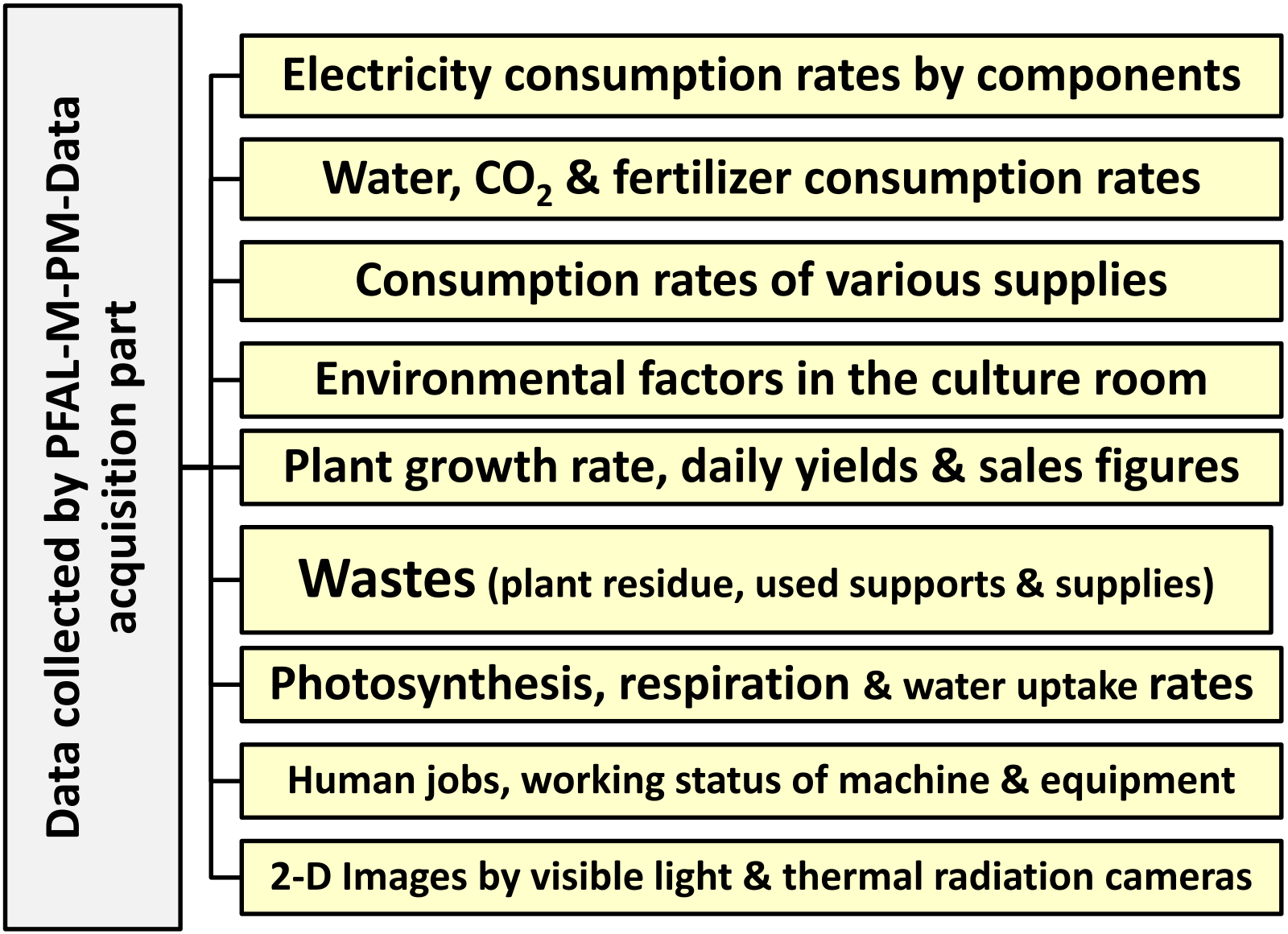
Structure of PFAL-D (Design) system



Parameters used to simulate the light environment using PFAL-D-LS (design of lighting system)

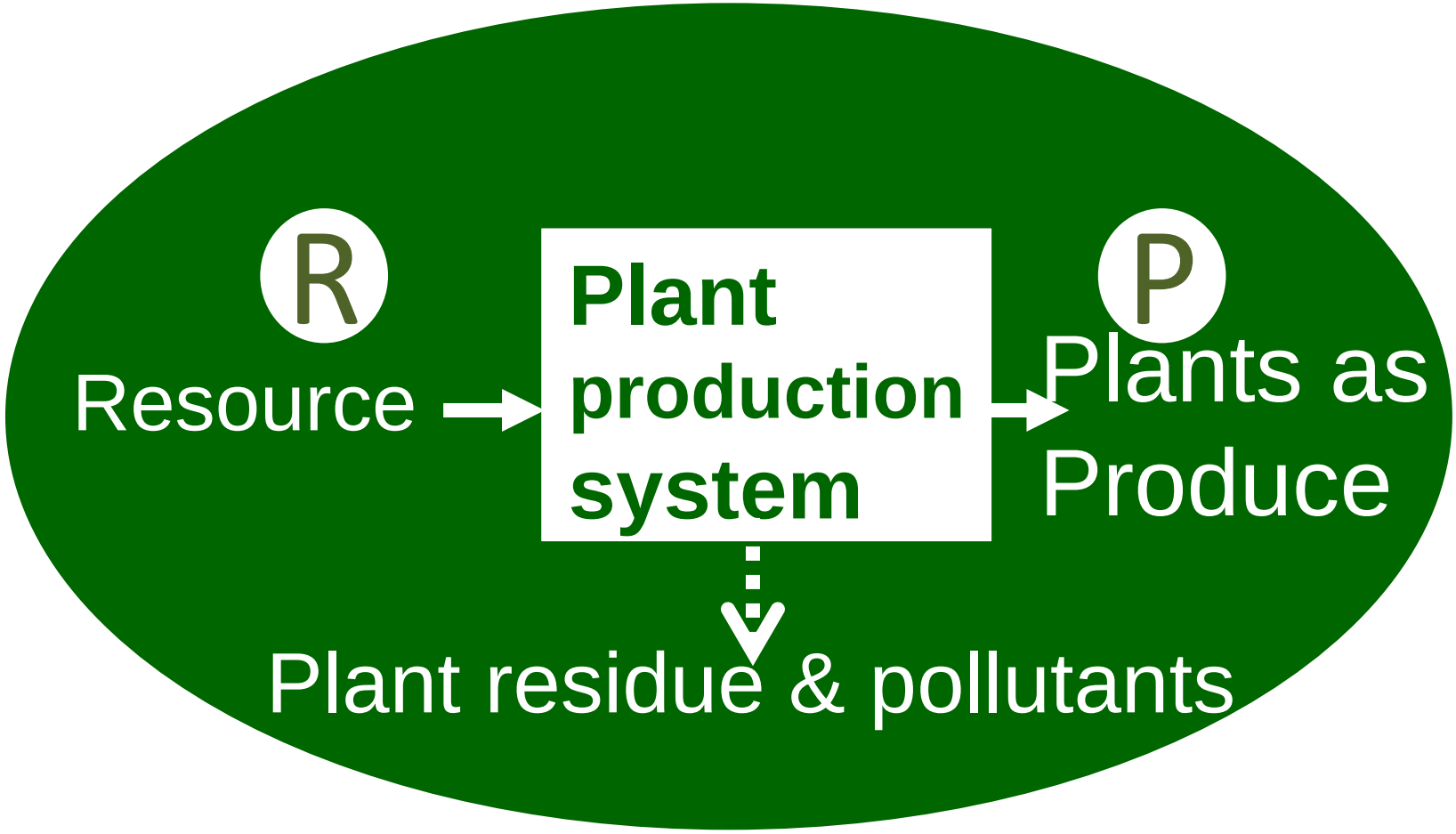


Data collected by PFAL-M-PM Data acquisition part



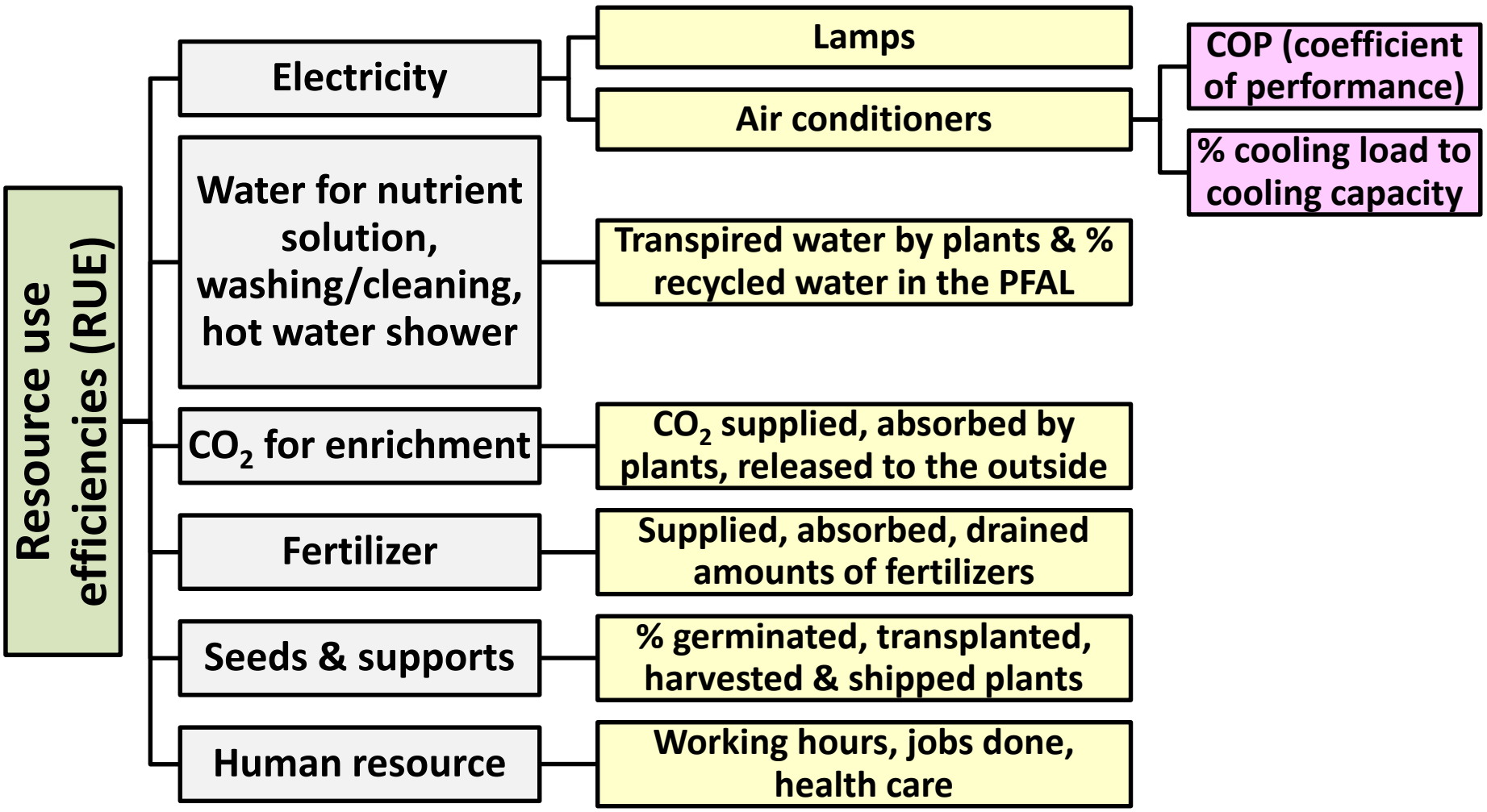
Level 7 Level 8

Resource Use Efficiency (RUE) = P/R



Resource: electricity, light, water, CO_2, fertilizer
Seeds/cuttings, human power, PFAL building

Resource use efficiencies (RUE) to be displayed on the screen



Tabulated list of variables on electricity consumption and light environment together with their attributes ①～⑭ stored in PFAL-M

①serial number ②variable name ③ symbol ④unit ⑤category ⑥ time interval
⑦ equations ⑧equations in TEX ⑨ URL ⑩definition ⑪explanations
⑫ reference ⑬equation number ⑭ variable name in English

① ② ③ ④⑤⑥ ⑦ ⑧⑨ ⑩ ⑪ ⑫ ⑬ ⑭

SAIBAI Systemにおける変数・定数一覧　※この表から、必要に応じて、"変数仕様書(Word)"、"変数IN-OUTマトリックス"、"変数チャート"等を生成する。各列の説明は、"変数一覧(列説明)"シートにて。　2014.9.14 PLANTX

No	名称	記号	単位	値種類	推奨取得頻度	式(画像)	式(TeX)	式(URL)	概要	詳細	参照	章番号/式番号	英語表記
1	電力に関する変数・定数												
2	電力基本料金単価		円/kW	定数	-	-	-	-	単位電力当たりの基本料金	電力会社に応じて料金体系は異なる。	各電力会社のWebサイト等参照		
3	電力量料金単価		円/kWh	定数	-	-	-	-	単位電力量当たりの使用料金	電力会社に応じて料金体系は異なる。	各電力会社のWebサイト等参照		
4	使用電力量	A_T	MJ m^-2 h^-1 (kWh/h?)	測定値	1分	$A_T = A_A + A_L + A_M$	A_T = A_	http://late	使用した電力量の合計	消費電力とも言う。※ここでは、電力会社の用語に統一	[Koza2013]	Eq. 11	Total electricity consumption
5	電気料金		円	指標値	1時間	-	基本料金	-	電力基本料金と電力量料金の合計	電力会社によっては、再生可能エネルギー発電促進賦課金や太陽光発電促進付加金などが加算される場合がある。			
6	電力量料金		円	指標値	1時間	-	電力量料	-	一定期間に使用した電力の使用料	契約電力別、季節別、時間帯別で料金体系が異なる場合が多い。			
7	電力基本料金		円	指標値	1ヶ月	-	電力基本	-	一ヶ月当たりの電力の基本料金	契約電力に応じた1ヶ月当たりの基本料金。東京電力の場合、過去11ヶ月のピーク電力に応じて決まる。			
8	成績係数	COP	-	指標値	1分	$COP = \frac{H_h}{A_A}$	COP = \f	http://late	エアコンの冷却性能に相当する値	ヒートポンプによって栽培室から除去された熱エネルギー（H_h）とヒートポンプの電力消費量（A_A）との比で表わされる。実用上は、H_hの代わりに照明消費電力（A_L）とその他消費電力（A_M）の合算値を用いる。		Eq. 9, 12	Coefficient Of Performance of heat pumps for cooling
9	エアコン負荷率		%	指標値	-	-	エアコン	-	エアコン定格消費電力に対するエアコン消費電力の				
10	PAR_Lに関する光エネルギー利用効率	LUE_L	%	指標値	1時間	$LUE_L = \frac{f \cdot D}{PAR_I}$	LUE_L =						with respect to PAR_L
11	PAR_Pに関する光エネルギー利用効率	LUE_P	%	指標値	1時間	$LUE_P = \frac{f \cdot D}{PAR_P}$	LUE_P =						with respect to PAR_P
12	電気エネルギー利用効率	EUE_L	%	指標値	1時間	$EUE_L = h \cdot LUE_L = \frac{h \cdot f \cdot D}{PAR_L}$	EUE_L =						ncy
13	エアコン消費電力量	A_A	MJ m^-2 h^-1 (kWh/h?)	測定値	1分	-	-	-	単位時間にエアコンが消費した電力量		[Koza2013]	Eq. 9,11,12	Electricity consumption of air conditioners (heat pumps)
14	照明消費電力量	A_L	MJ m^-2 h^-1 (kWh/h?)	測定値	1分	-	-	-	単位時間に照明機器が消費した電力量		[Koza2013]	Eq. 8,11,12	Electricity consumption of lamps
15	その他消費電力量	A_M	MJ m^-2 h^-1 (kWh/h?)	測定値	1分	-	-	-	単位時間に消費したA_AとA_L以外の電力量		[Koza2013]	Eq. 11,12	Electricity consumption of water pumps, air fans, etc.
16	エアコン定格消費電力		kW	定数	-	-	-	-	定格能力で運転した時の消費電力	定格冷房・暖房能力で運転した時に必要となる消費電力。			Rated power of air conditioners (heat pumps)
17	エアコン定格冷房能力		kW	定数	-	-	-	-	単位時間当たりに室内から取り除ける熱エネルギー	※以前は"kcal/h"を使っていたが、単位の国際統一でkWになっている。			Rated cooling capacity of air conditioners (heat pumps)
18	エアコン定格暖房能力		kW	定数	-	-	-	-	単位時間当たりに室内に加えられる熱エネルギー	※以前は"kcal/h"を使っていたが、単位の国際統一でkWになっている。			Rated heating capacity of air conditioners (heat pumps)
19	電気-PARエネルギー変換率	h	-	指標値	-	-	-	-	電気エネルギーから光源のPAR_Lへの変換率		[Koza2013]	Eq. 7, 8	Conversion factor from electric energy to PAR_L
20	ヒートポンプによって栽培室から除去された熱エネルギー	H_h	MJ m^-2 h^-1 (kWh/h?)	指標値	-	-	-	-	ヒートポンプによって栽培室から除去された熱エネルギー		[Koza2013]	Eq. 9, 12	Heat energy removed from culture room by heat pumps
21	空気の漏れによって交換された熱エネルギー	H_v	MJ m^-2 h^-1 (kWh/h?)	指標値	-	-	-	-	空気の漏れによって交換された熱エネルギー		[Koza2013]	Eq. 9, 12	Heat energy exchange by air infiltraction and penetration through w
22	生体乾物重量-化学エネルギー変換係数	f	MJ kg^-1	定数	-	-	-	-	生体乾物重量から化学エネルギーに変換する係数	fの値は植物体が含む炭水化物、タンパク質、脂肪の比率にやや影響されるが、概ね20 MJ kg^-1程度である。	[Koza2013]	Eq. 5, 6, 7	Conversion factor from plant dry mass to chemical energy
23	光に関する変数・定数												
24	光束		lm	測定値	?	-	-	-	人間の視感度を基準とした場合の可視光の量	光束の大小は、波長ごとの可視光域エネルギー量と視感度を乗じた積の積算値の大小に相当する。	[吉年2012]	7.3.6	luminous flux
25	光度		cd	測定値	?	-	-	-	点光源から単位立体角当たりに発散する光束		[吉年2012]	7.3.6	luminous intensity
26	照度		lx	測定値	?	-	-	-	光束を面積で除したもの	人の目にとっての明るさを表す。1 lmの光束が1 m^2に入射した時のその面の照度が1 lxとなる。	[吉年2012]	7.3.6	illuminance
27	PPF		μmol/m^2/s	測定値	?	-	-	-	光合成有効放射束密度	単位面積あたりの光合成有効光子の毎秒のフラックス（束）のこと。PPFDとも呼ばれる。	[吉年2012]	7.3.7	Photosynthetically Active Radiation flux Density
28	光源の光合成有効放射	PAR_L	MJ m^-2 h^-1	測定値	?	-	-	-	光源が出力する光合成有効放射	波長範囲400～700nm。	[Koza2013]	Eq. 5, 7, 8	Photosynthetically active radiation emitted from lamps

Variables

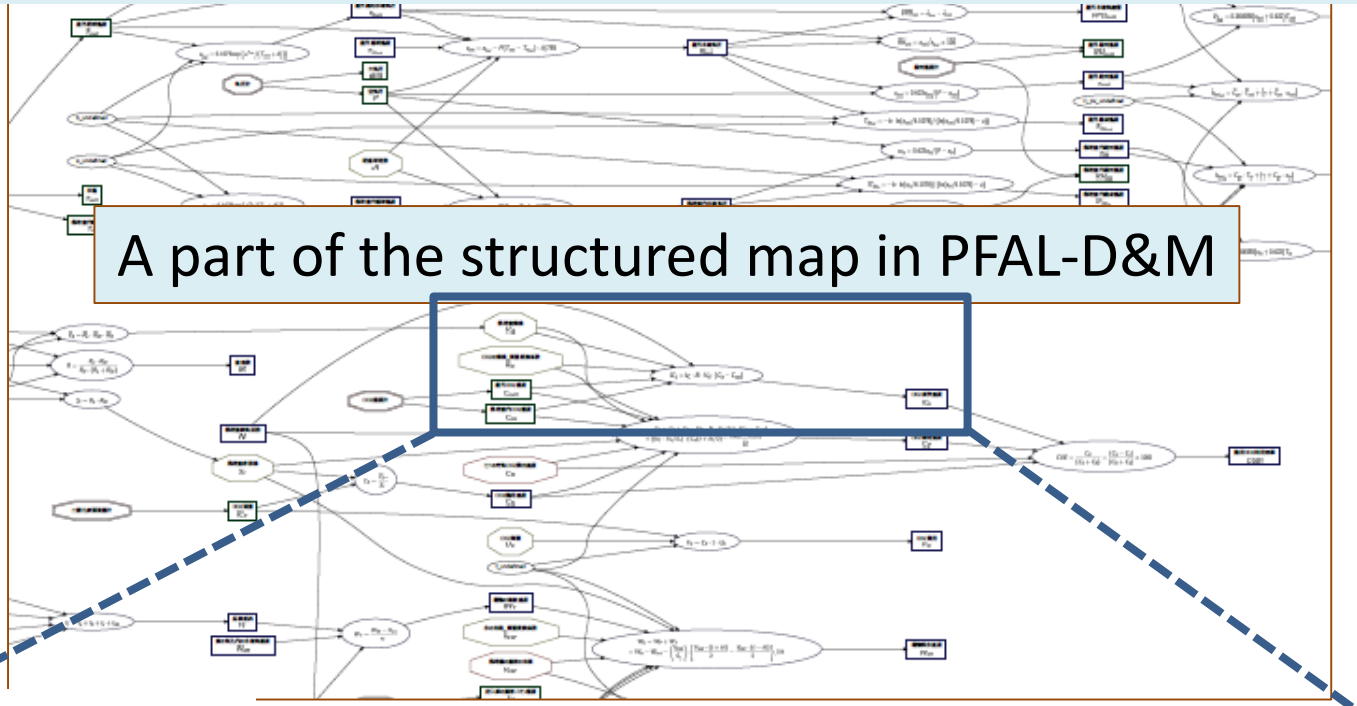
250 equations in this table

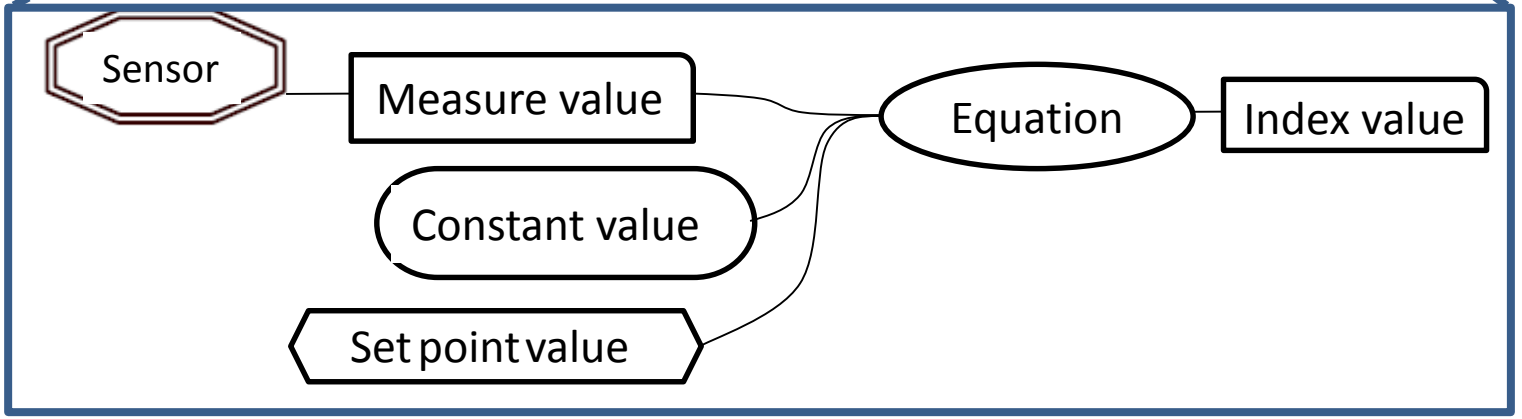
Electricity consumption

Light

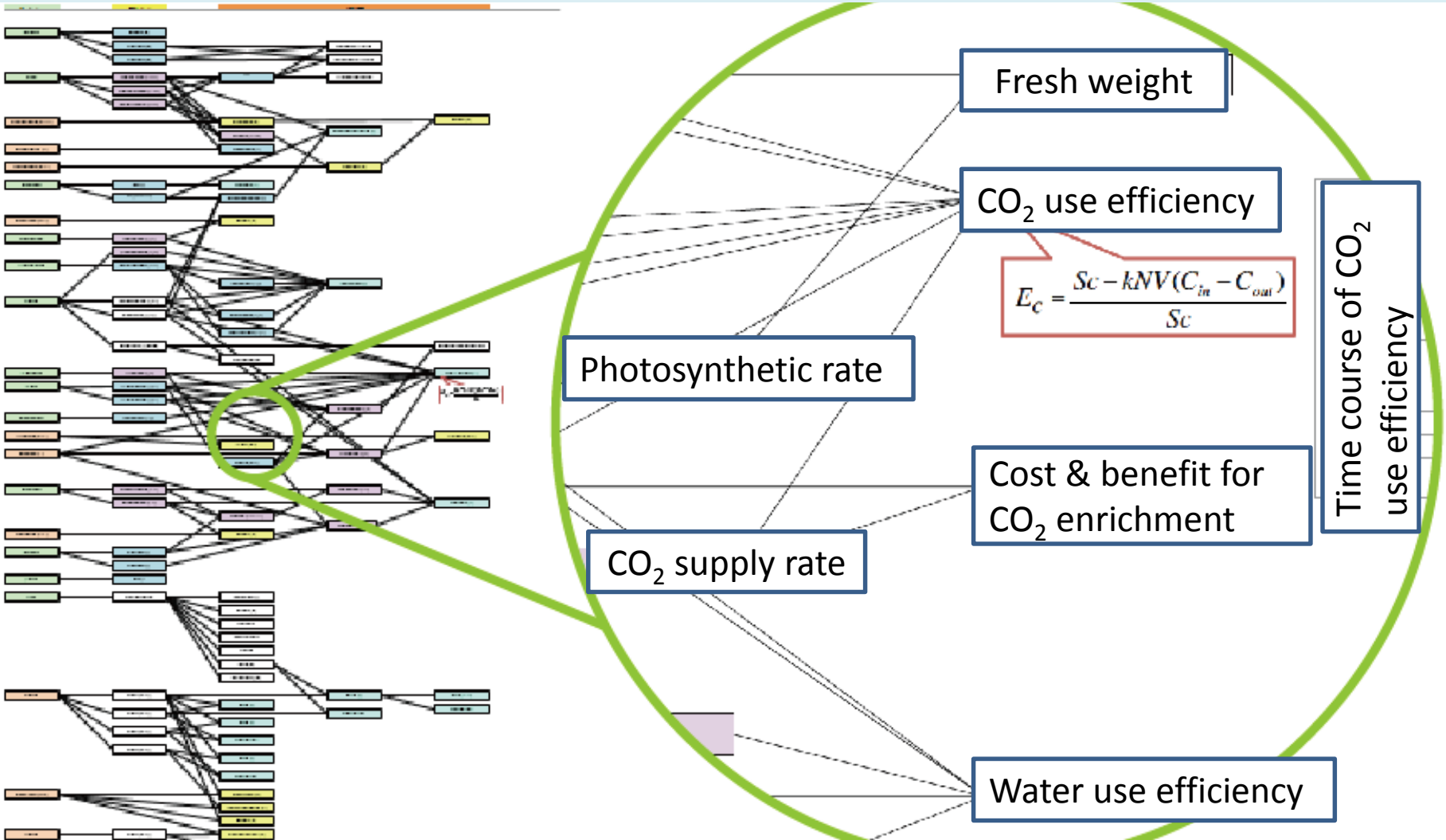
The variables on CO_2, water, heat energy, plant growth, etc. are also stored in the same way.

A part of the structure map in PFAL-D&M showing how to obtain the index value from the measured value, constant value, set point value and equation

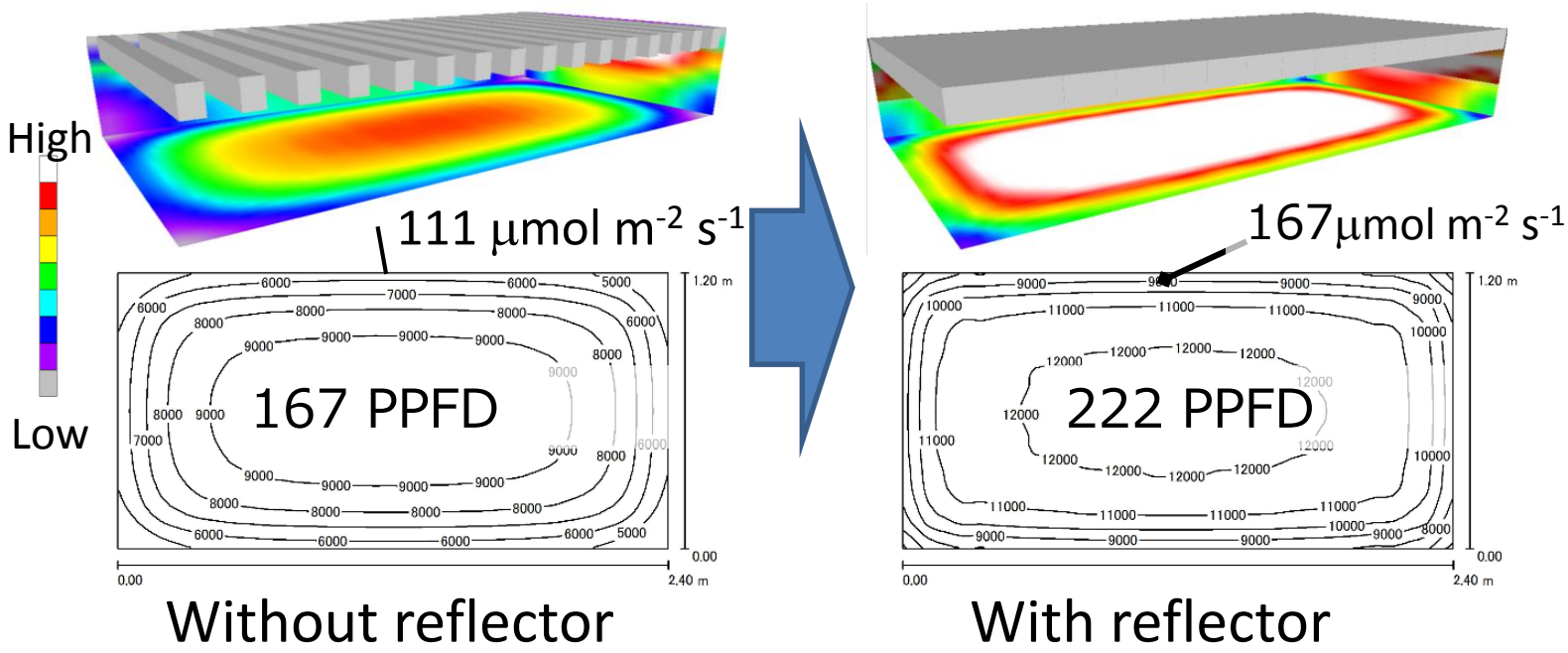




A logical structure of the equations stored in PFAL D&M. Equations are logically connected as show. The variables in the circle show the indices such as CO_2 and water use efficiencies and rates of photosynthesis and CO_2 supply

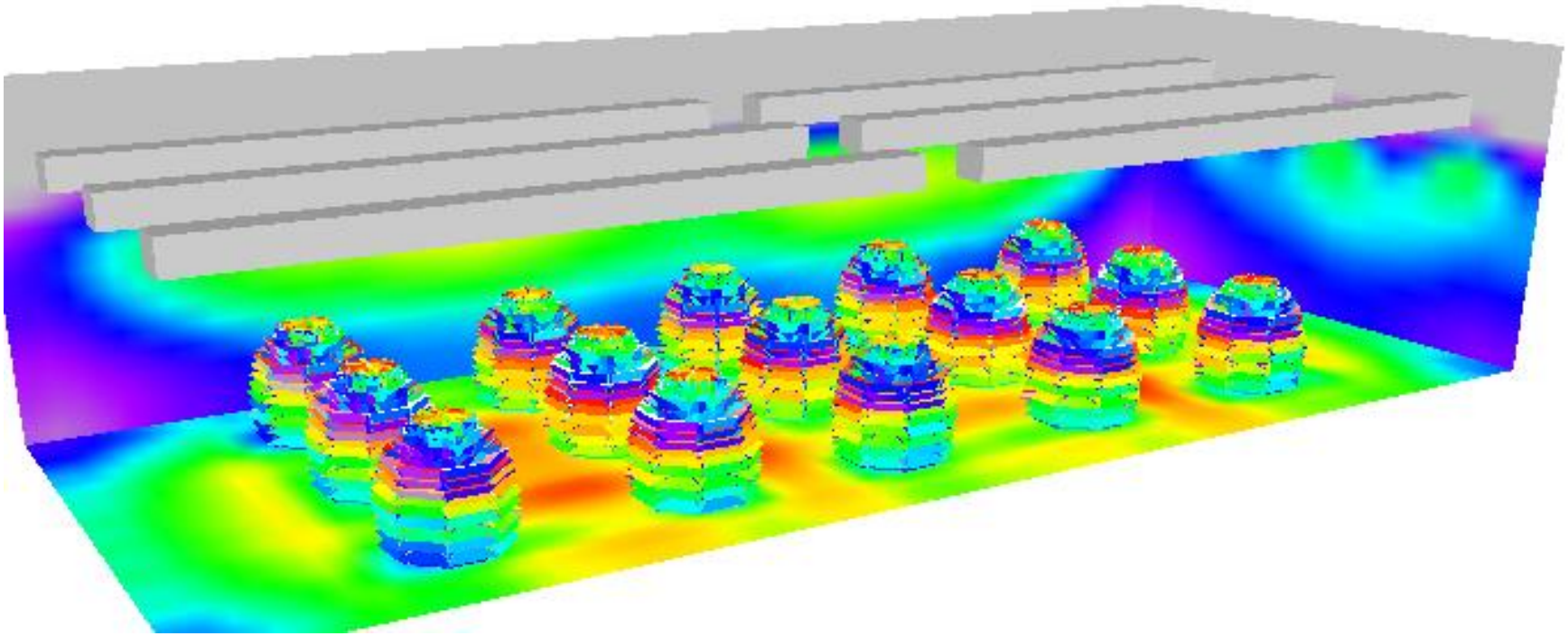


An output example of PFAL-D for light environment improvement by use of light a reflector

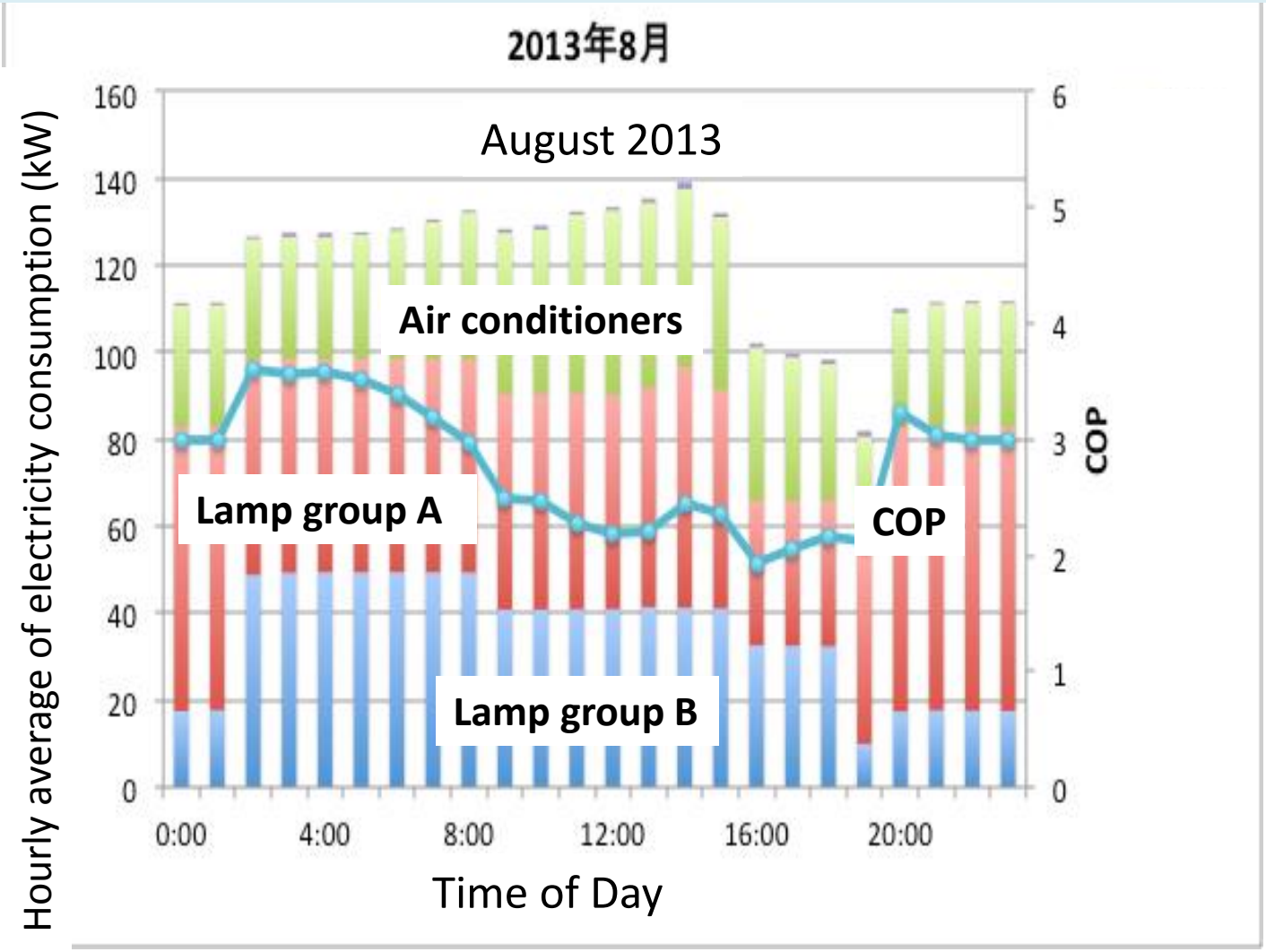


	Without (PPFD) μmol m^{-2} s^{-1}	With (PPFD) μmol m^{-2} s^{-1}	Effect of reflector
Average (A)	146	202	38% up
Highest (H)	181	227	25% up
Lowest (L)	58	76	31% up

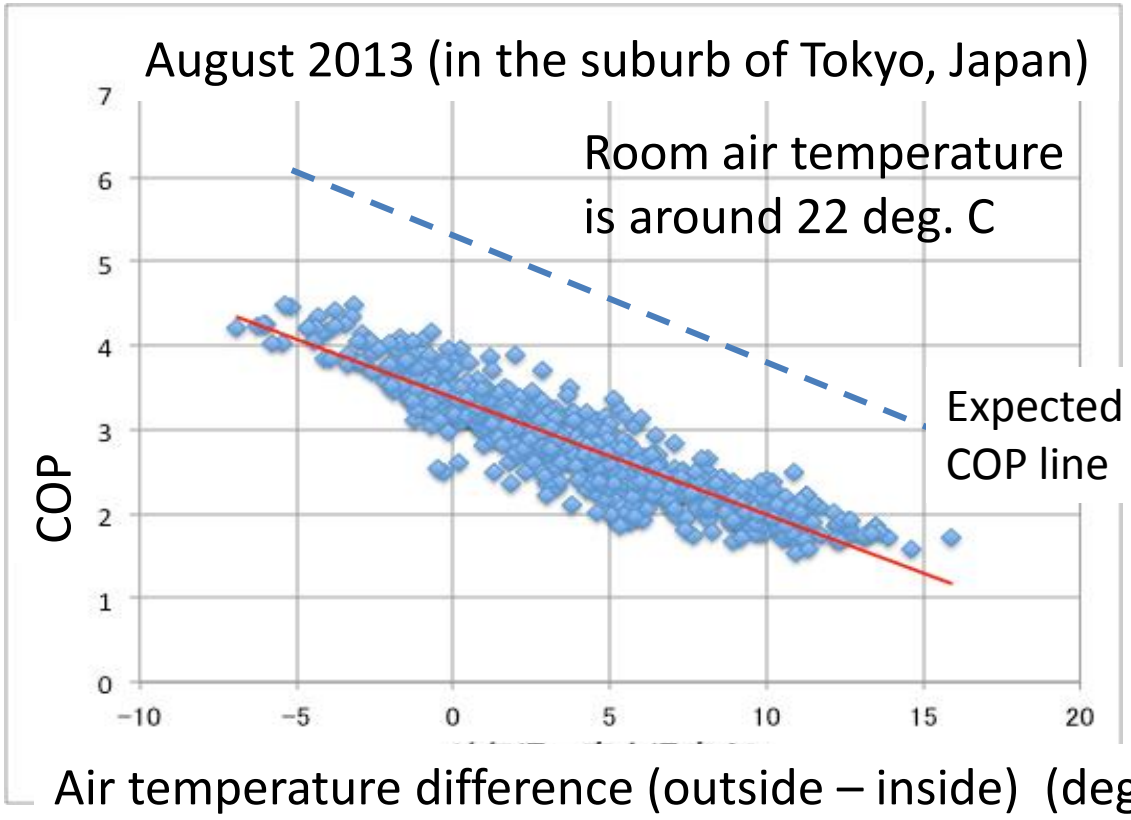
A simulated result using PFAL-D of 3 dimensional PPFD distribution on crisp head lettuce plants planted on the culture panels



Daily changes in electricity consumption by lamp groups A and B, and COP (coefficient of performance) of air conditioners in a PFAL. Lamps of each tier are turned on together for 16 continuous hours a day, but shifting the light period.

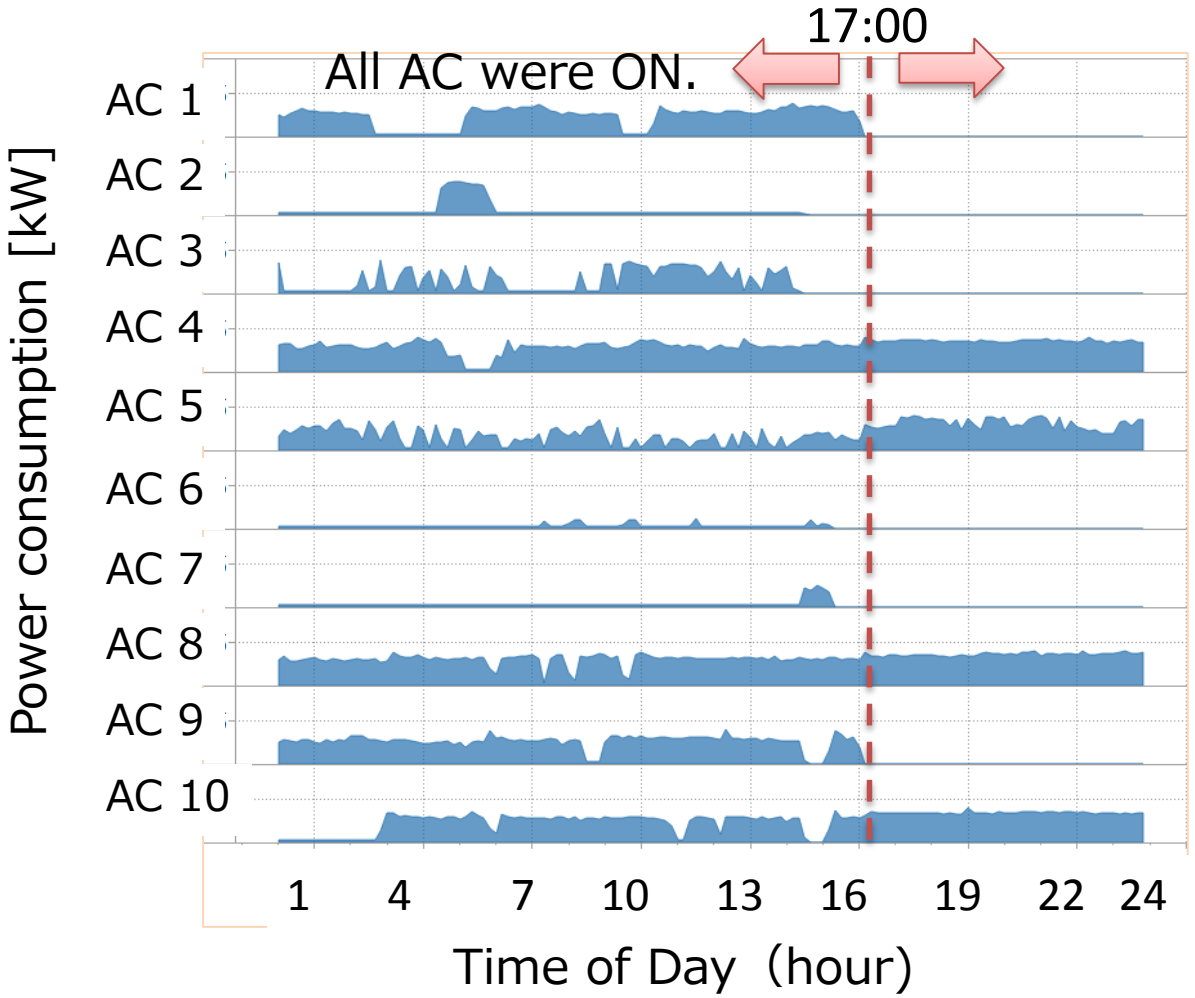


COPs of air conditioners in August as affected by air temperature difference between inside and outside. The dashed line indicates the maximum possible COP at the cooling load of around 70% of the cooling capacity

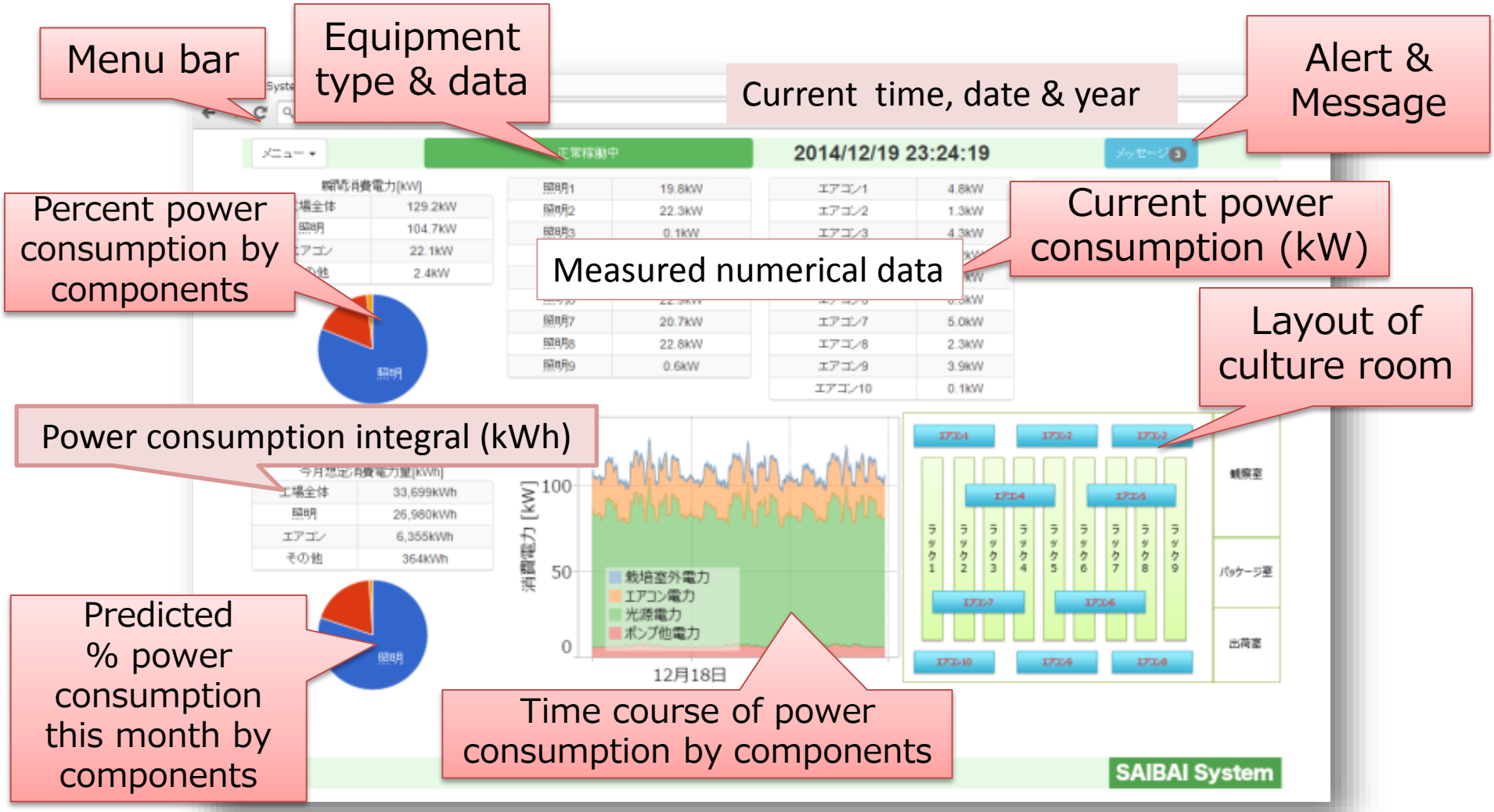


Electricity cost for air conditioning is halve when COP is doubled.

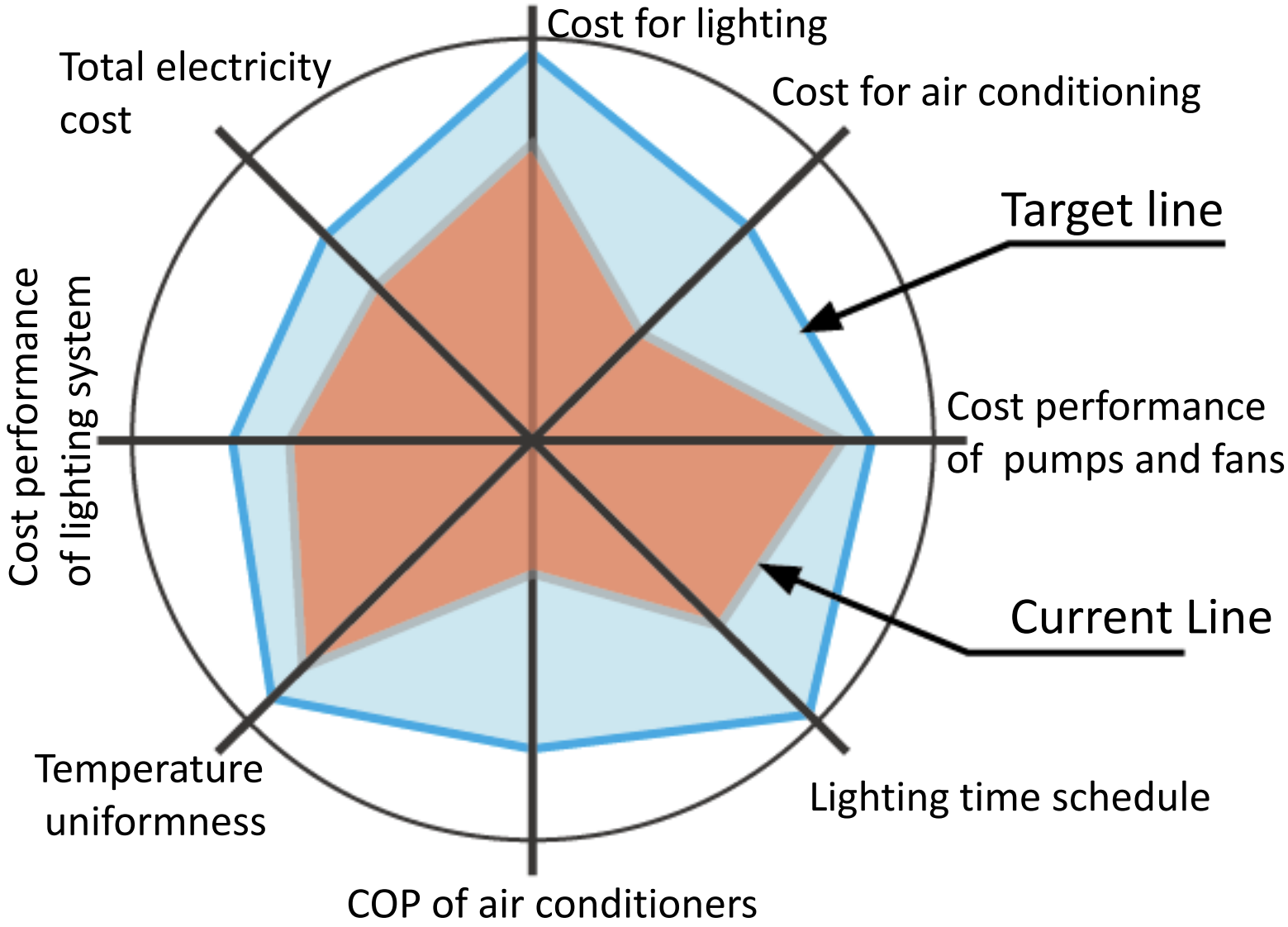
Diurnal courses of power consumptions of air conditioners (AC). From 1:00 to 17:00, all ACs were turned on, but 4 ACs only were turned on after 17:00. In either case, air temperature was controlled at the set point of 22. Average COP of ACs in operation was 20-25% higher after 17:00 than before 17:00.



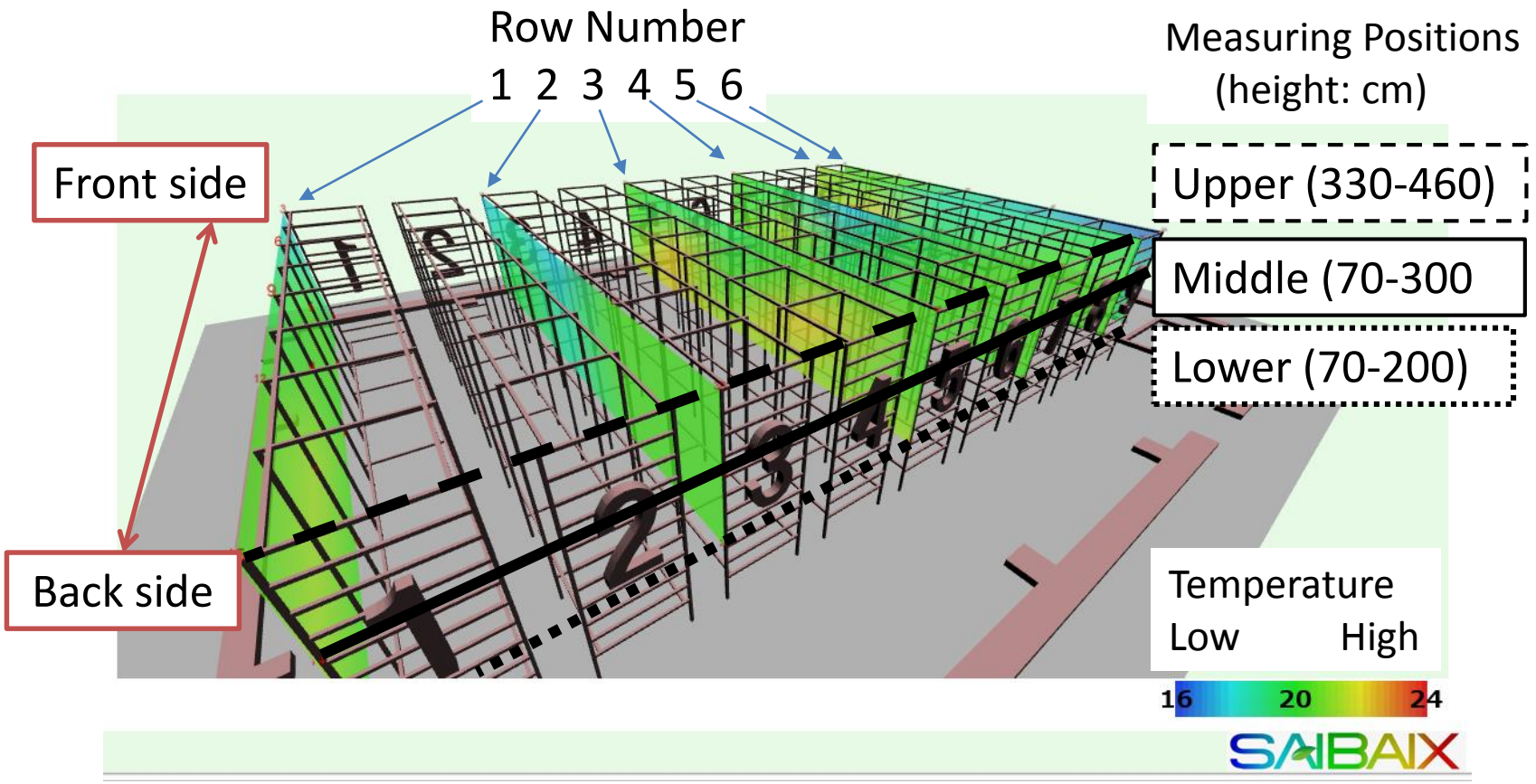
Visualized daily report of power consumptions by components on the computer display screen for the PFAL manager as a daily report



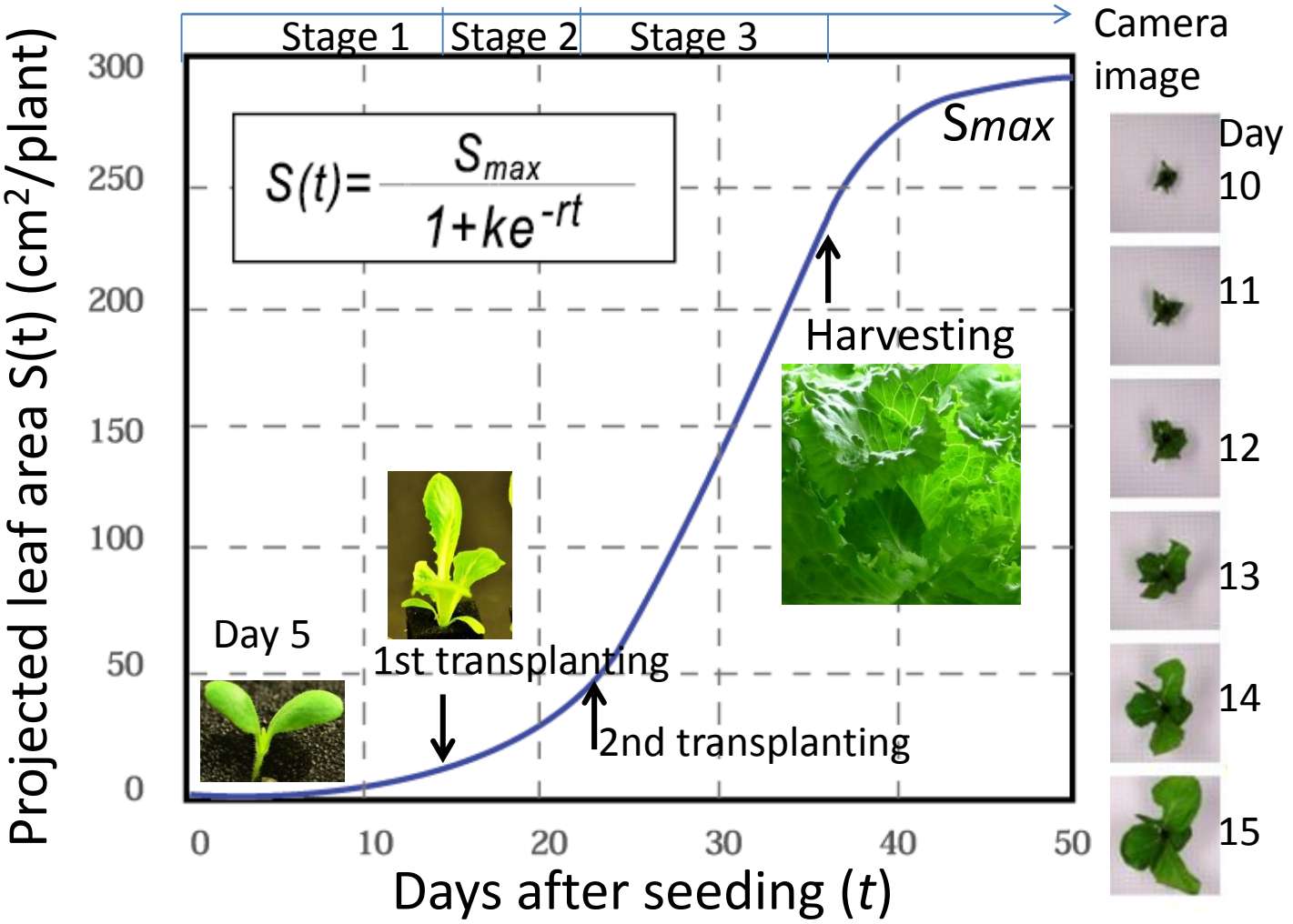
Radar chart showing the overall performance of electricity. Each axis is automatically scaled.



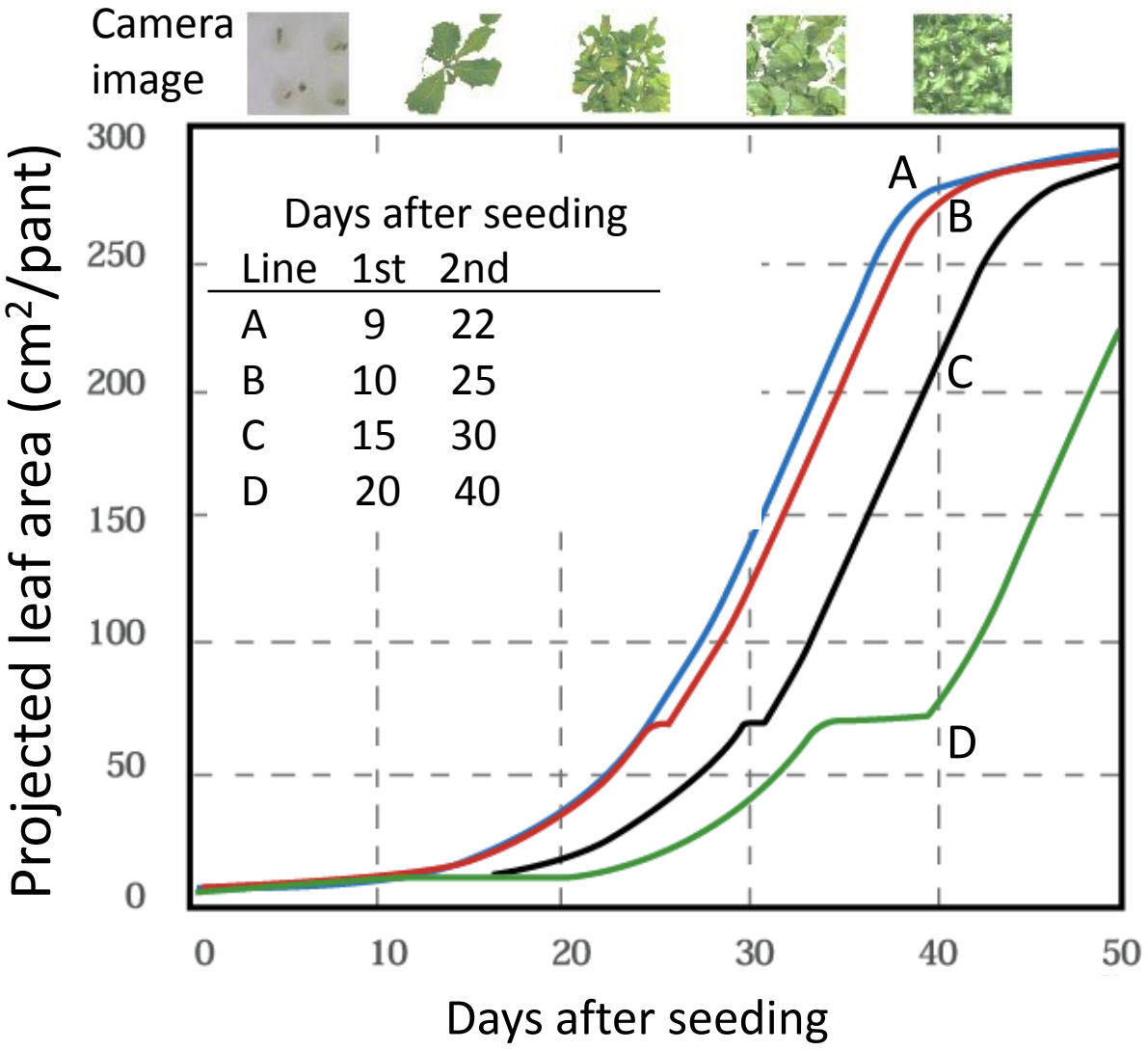
An example of three dimensional air temperature distribution in the culture room with 9 rows & 10 tiers in the PFAL.

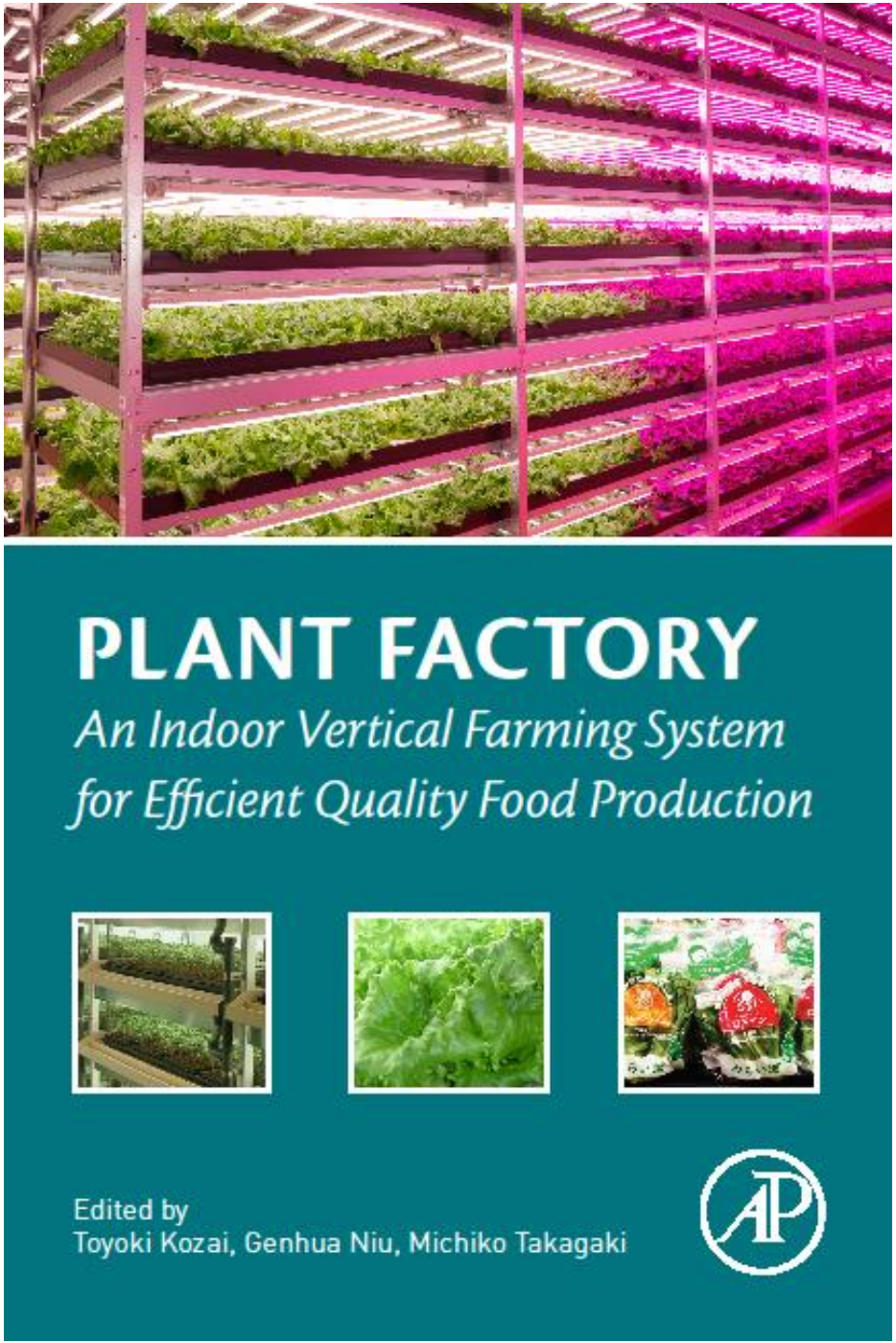


Plant growth curve expressed as logistic growth equation.
Stage 1: from seeding to 1st transplanting; Stage 2: from 1st to 2nd transplanting; Stage 3: from 2nd transplanting to harvesting.



Projected leaf areas as affected by the days after seeding of 1st and 2nd transplanting





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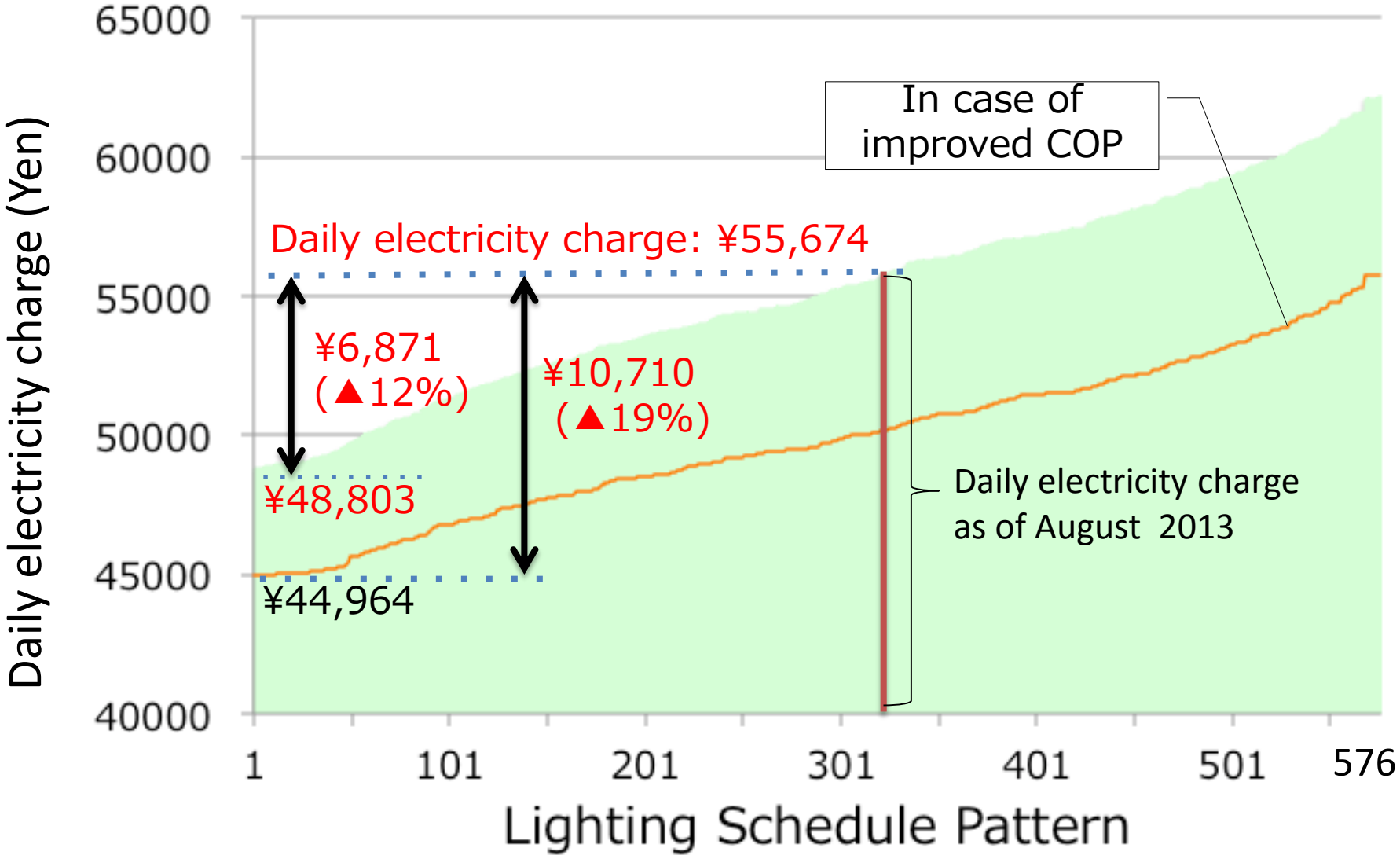
Conclusion

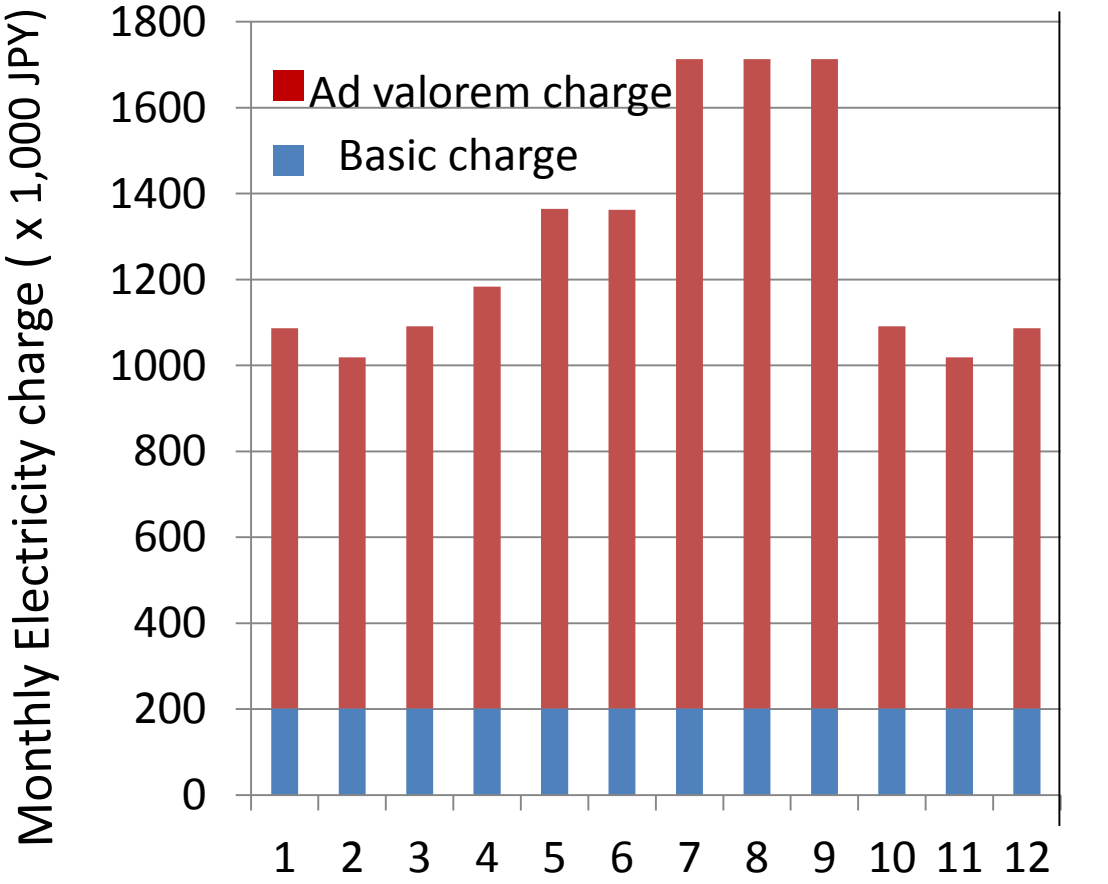
- **A design and operation tool for PFAL was developed as a cloud computing service.**
- **By improving the design and operation of current PFAL, it is expected that:**
  - **Electricity costs is halved.**
  - **3-D distributions of light and temperature distributions are significantly improved.**
  - **Labor cost is saved and productivity is improved.**

Daily electricity charge of 'ad valorem' as affected by lighting time scheduling pattern in Tokyo.
(1 US$ = 120 Yen as of 2013)

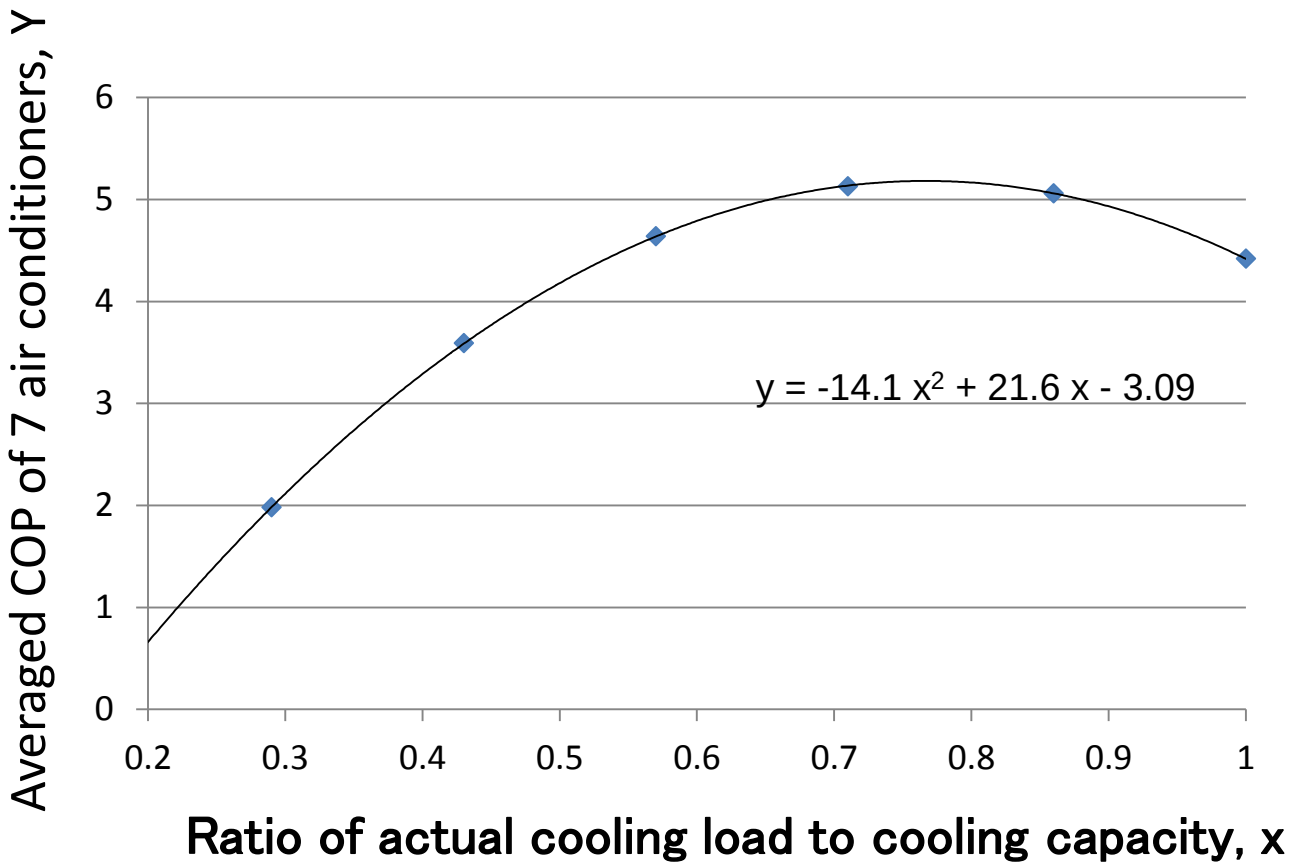


An example of monthly electricity charge for a PFAL in Japan, producing about 100,000 leaf lettuce heads per month. Percent base charge is lowest (12%) in summer and highest in winter (16%) with average of 16%. In Japan, monthly basic charge is determined by the maximum 30-minute power consumption (kW) during the past one year.

1,200,000 JPY is approximately 10,000 US$.



Averaged COP of 7 air conditioners as affected by the ratio of actual cooling load to full cooling capacity. Total electricity consumption of 7 air conditioners at full cooling capacity is 58.6 kW (Sekiyama and Kozai, 2015).



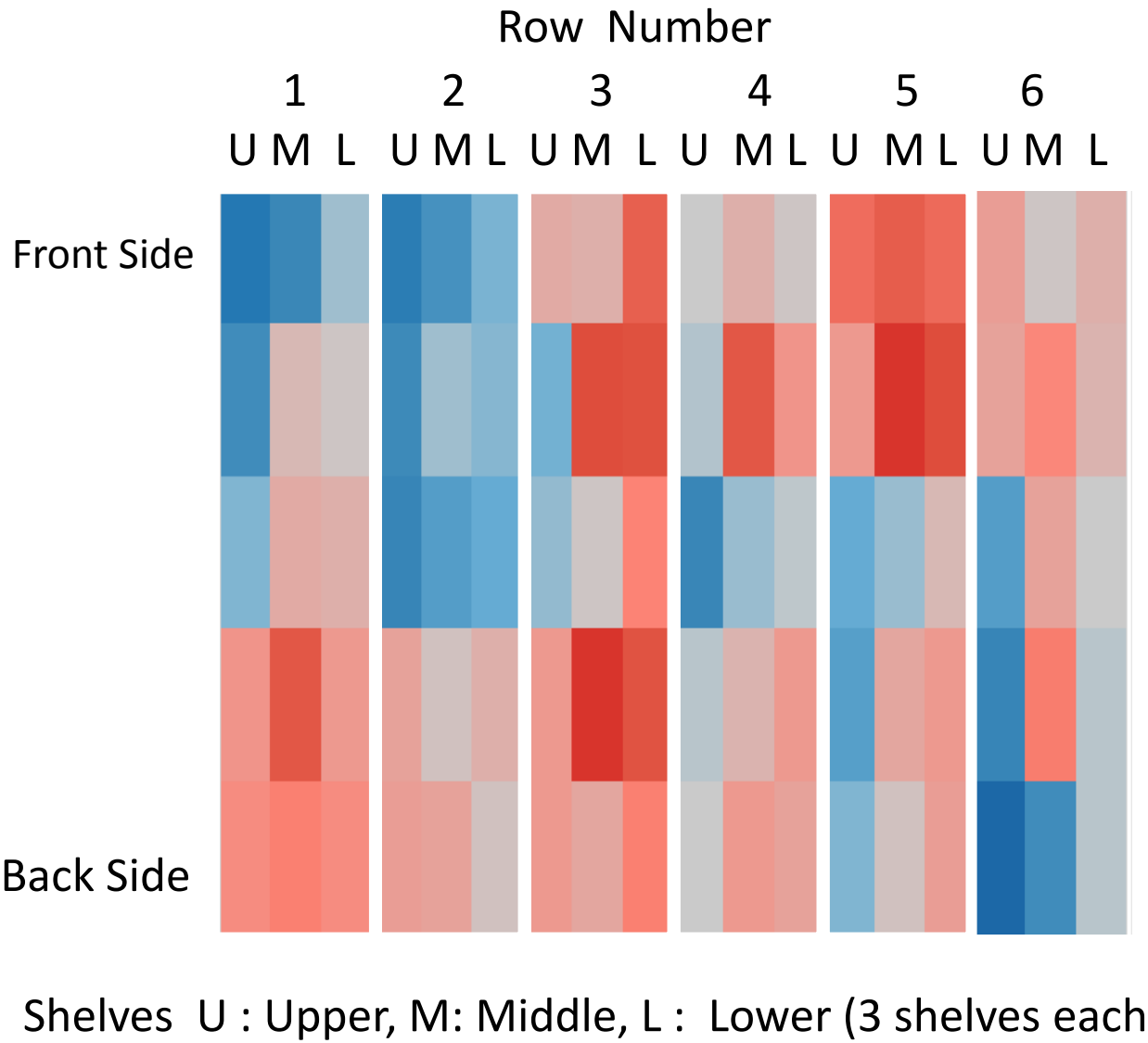


Fig. 22.22 Three dimensional air temperature distributions in the culture room of PFAL. U, M and L denote the upper, middle and low shelves. For row numbers, floor layout and heights of shelves, see Fig. 22.21.