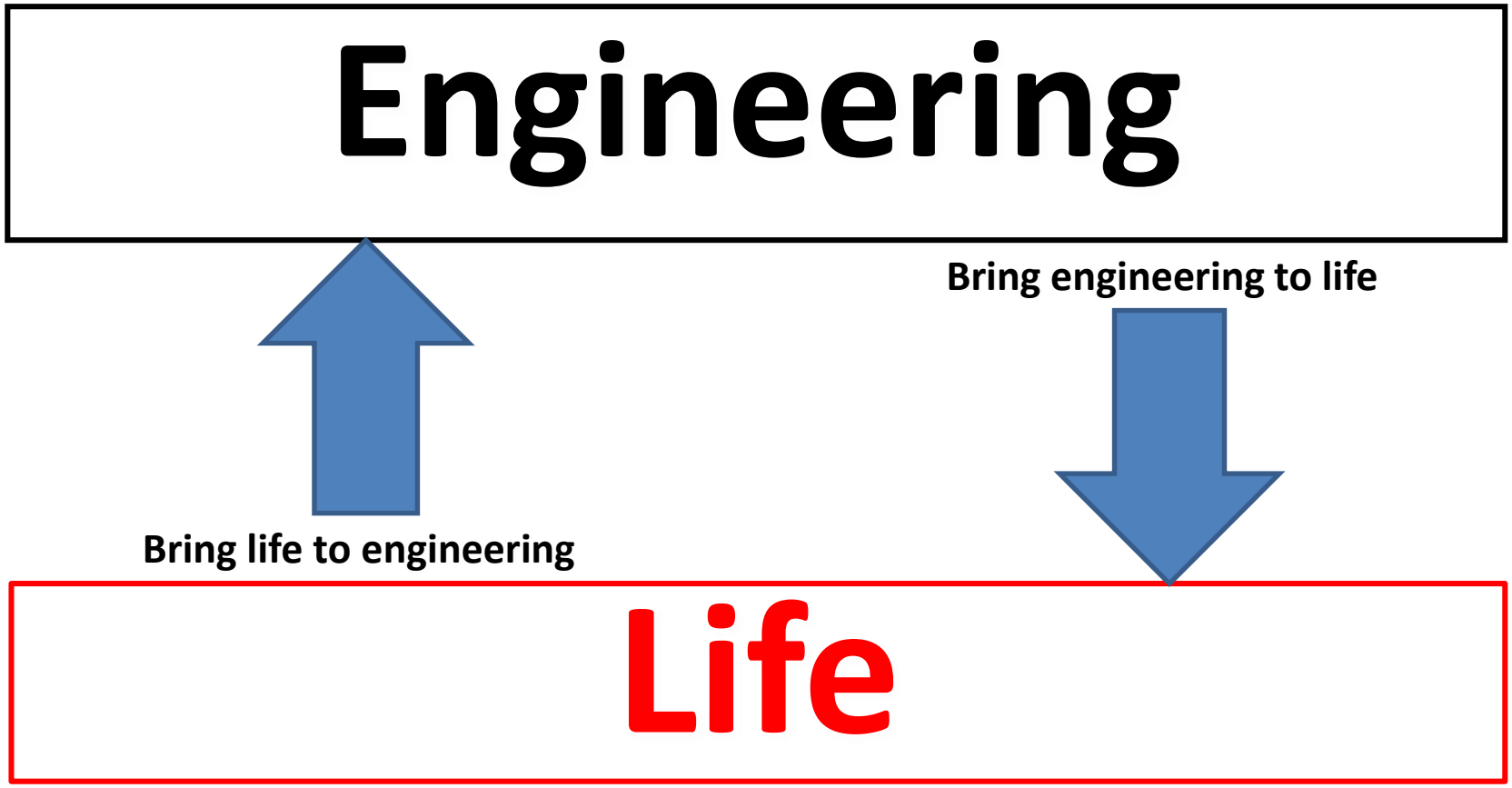
台大生物機電工程系　方煒

生機系的領域

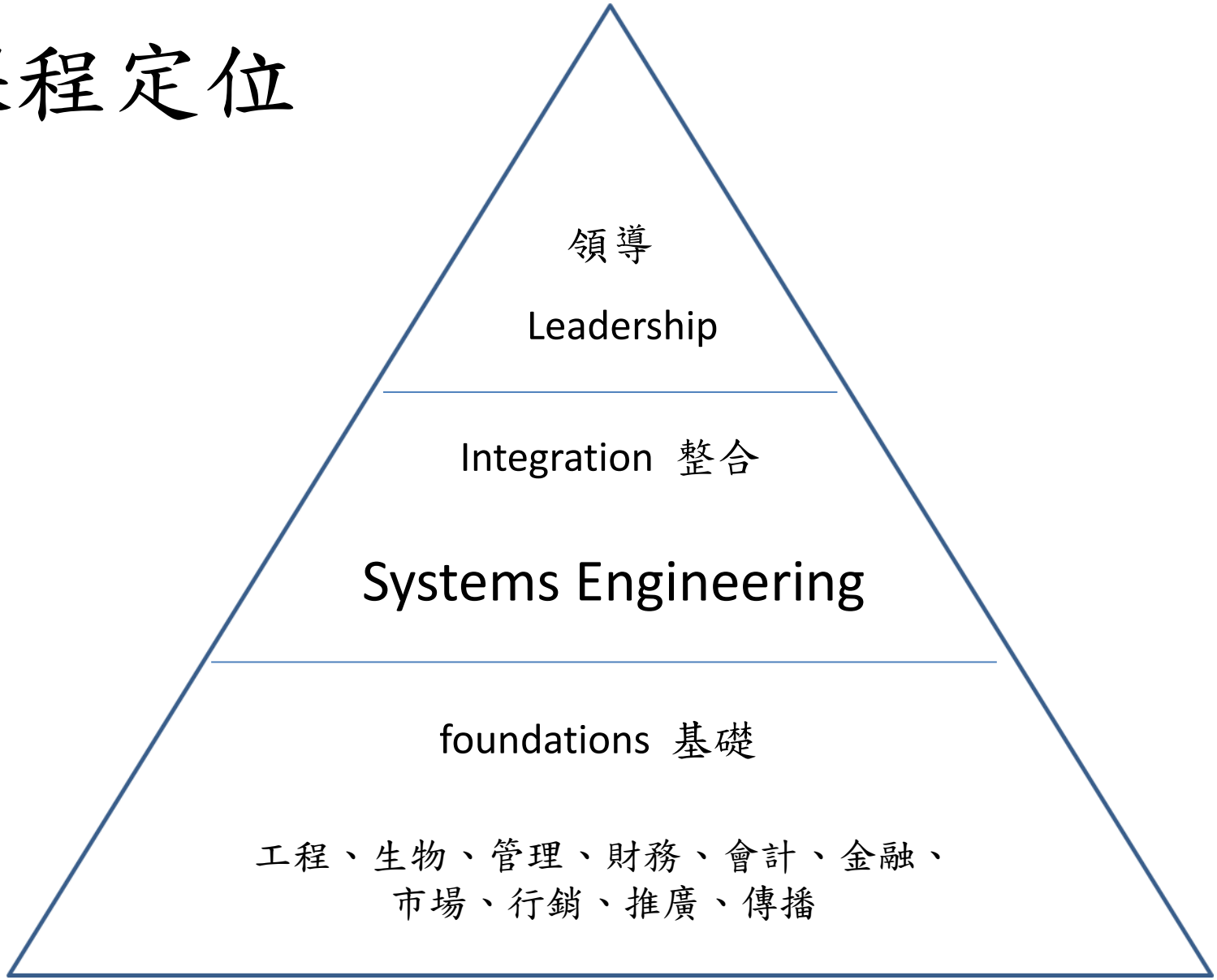
生命科學與工程的整合



生物機電
Bio-mechatronics
向大自然學習
Learn from the Nature

觸類旁通　　異中求同

課程定位


領導
Leadership
Integration 整合
Systems Engineering
foundations 基礎
工程、生物、管理、財務、會計、金融、
市場、行銷、推廣、傳播

E. vs. S.E.

Engineering

The process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective

– Accreditation Board for Engineering and Technology

Systems Engineering

INCOSE
International Council on Systems Engineering

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost
- Schedule
- Training
- Support
- Disposal

Systems Engineering

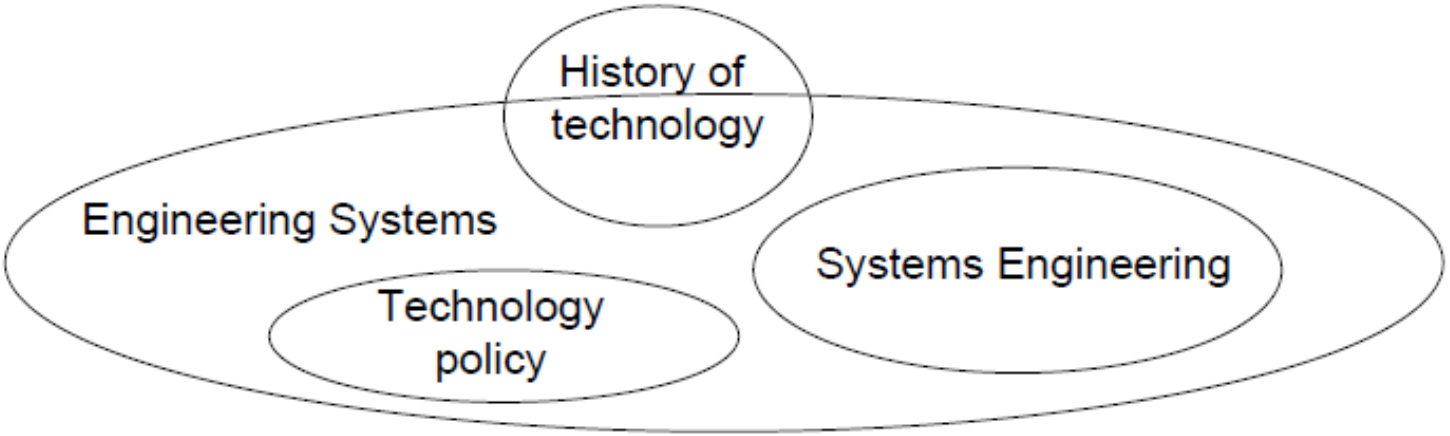
INCOSE
International Council on Systems Engineering

- Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

- Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Engineering Systems & Systems Engineering

ESD mission: To establish Engineering Systems as a field of study focusing on complex engineered systems and products viewed in a broad human, social and industrial context. Use the new knowledge gained to improve engineering education and practice.



Engineering systems in Biology
Engineering Bio-systems

- 環控農業 Controlled Environment Agriculture
  - 植物工廠 Plant Factory
    - Thermally insulated wall / roof / floor
    - Artificial light
    - Multi-layer bench
    - Water/Nutrient recirculating
    - Aero & Root Environmental control
    - Automation

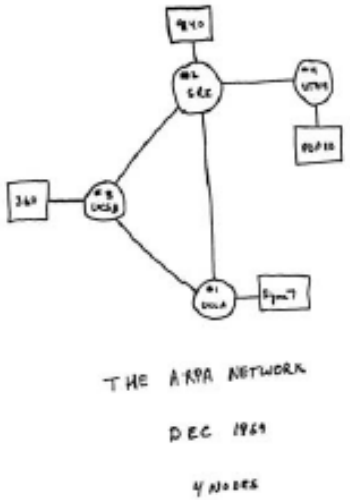
Engineering Bio-systems

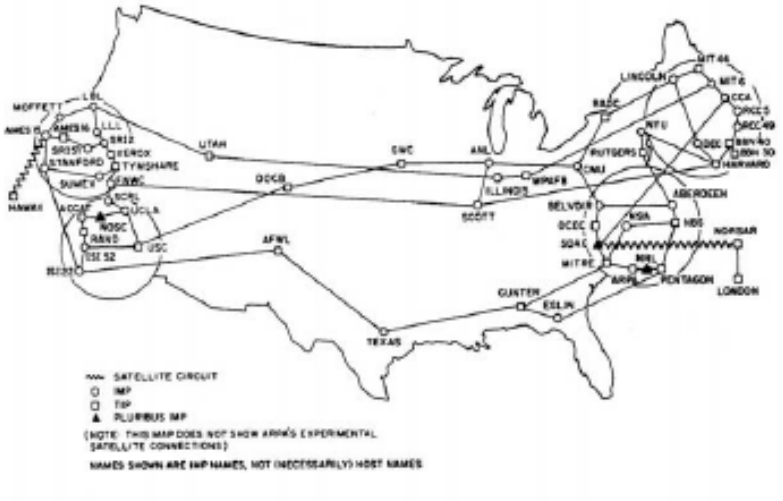
- 環控農業 Controlled Environment Agriculture
  - 複合式植物工廠
    - 氮源共享：魚菜共生 Aquaponics
    - 碳源共享：菇類栽培廠 + 植物工廠
    - 能源共享：農產品冷藏庫 + 植物工廠

History of Systems Engineering

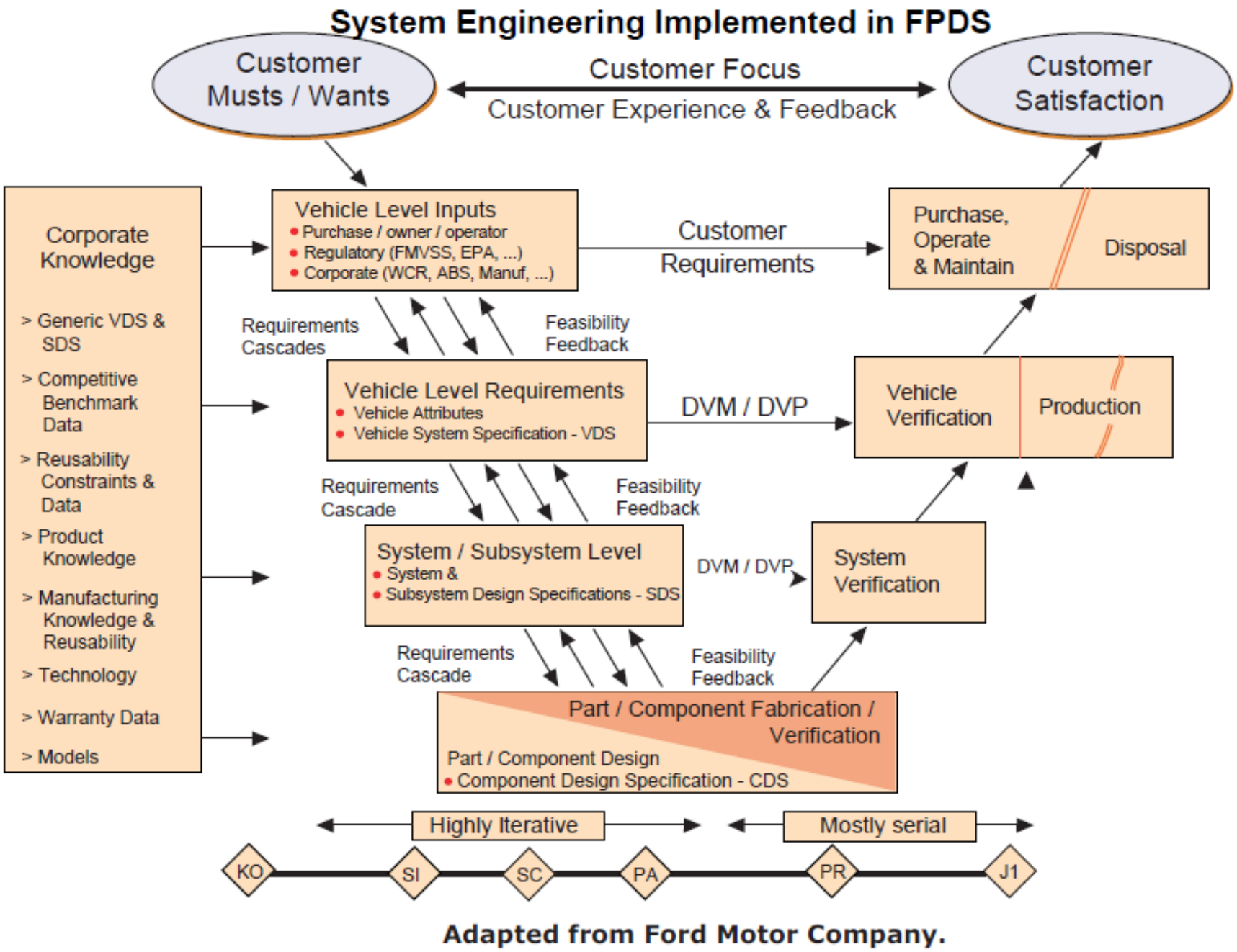
- Engineering has a long history
- Systems Engineering seems to be a more recent phenomenon
- Strongly related to management
- Post WWII government-funded projects played a major role in defining SE

System Engineering implemented: ARPANET





- A prime example of scalable architecture
- New trends in management of big projects
  - Flatter - Less centralized - Meritocratic
- Do these trends work for other systems?



Adapted from Ford Motor Company.

History of Bio-systems Engineering

- 農業的演進
  - 露天農業 Open field Agriculture
  - 半封閉式農業 Semi-closed Agriculture
    - 設施農業：網室、溫室
  - 封閉式農業 Closed Agriculture
    - 植物工廠

- NASA:　太空農業計畫　1990 ~ 2000

  - ALSS:　先進__生命支援系統
  - BLSS：可生質再生__生命支援系統
  - CELSS：生態控制__生命支援系統

- Vertical Farming / Plant Factory　1999 ~

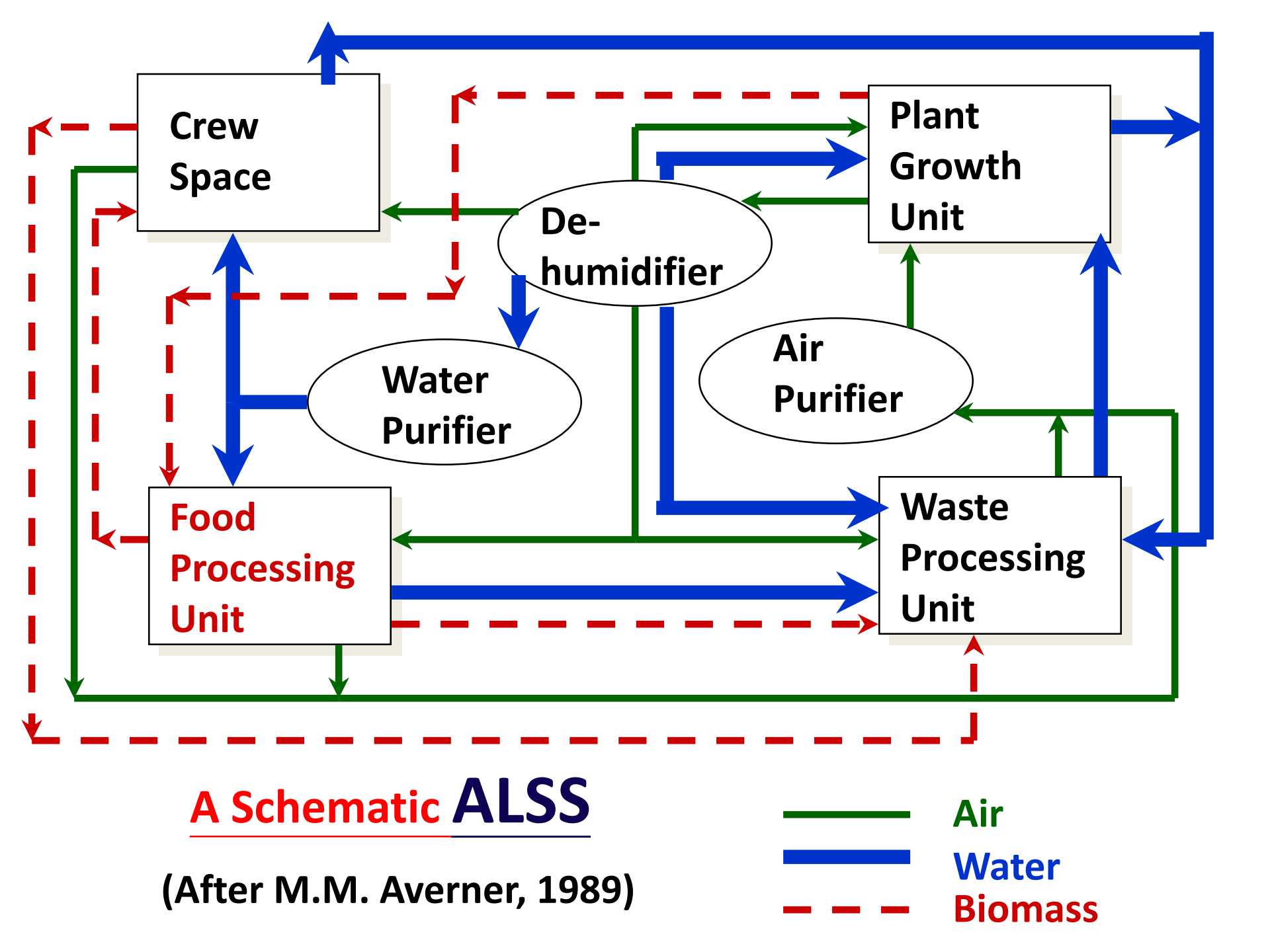
CEA

系統內的生產者、消費者、分解者
必需時時維持平衡

NASA太空農業計畫

ALSS: Advanced Life Support System
BLSS: Bio-regenerative Life SS
CELSS: Controlled Ecological Life SS

植物變成工程元件
可生產多少 Biomass 與 氧氣
可吸收多少二氧化碳，
分解多少廢棄物，都需要量化


Crew Space
Plant Growth Unit
De-humidifier
Water Purifier
Air Purifier
Food Processing Unit
Waste Processing Unit
A Schematic ALSS
(After M.M. Averner, 1989)
Air
Water
Biomass

CEA 環控農業

- Controlled Environment Ag/Aq/Ap
  - Ag: Agriculture
    - CEPPS: Plant Production System 環控作物量產系統
    - CEAPS: Animal Production System 環控動物量產系統
  - Aq: Aquaculture 循環水養殖
  - Ap: Aquaponic 複合養殖

Controlled Ecological Ag/Aq/Ap

- 生態控制下的廣義農業/養殖漁業/複合養殖

- 何謂生態控制?
  - 系統內的生產者、消費者、分解者
    能時時維持平衡
  - 允許穩態量產

何謂 穩態量產 ？

- 循環水養蝦、養藻與養牡蠣
- 如何確保能夠穩態量產
  - 假設生產期程需要 16 週
  - 生產系統便需要 16 套
  - 每週供應固定數量的飼料
  - 每週收穫固定數量的產品

a microalgae-based recirculating oyster and shrimp system

Table 1
Estimated system production

Tank number	Number of shrimp	Average shrimp weight (g)	Shrimp biomass (kg)	Daily shrimp feed (kg)	Daily algae production (kg)
1	100 000	2	200	3	2.4
2	98 524	4	348	5	4
3	97 070	5	492	7	5.6
4	95 637	7	631	9	7.2
5	94 225	8	766	11	8.8
6	92 835	10	897	13	10.4
7	91 464	11	1024	15	12
8	90 114	13	1147	17	13.6
9	88 784	14	1266	19	15.2
10	87 474	16	1382	21	16.8
11	86 183	17	1494	22	17.6
12	84 911	19	1602	24	19.2
13	83 657	20	1706	26	20.8
14	82 423	22	1807	27	21.6
15	81 206	23	1905	29	23.2
16	80 007	25	2000	30	24
Sub-Total			18 668	280	224

每天隨時有 18668 kg 的蝦子在養數量
每週可收穫 2000 kg 的蝦子
每天餵飼 280 kg 的飼料
每天產出 224 kg 的藻類
每天產出 112 kg 的牡蠣肉，相當於 700 kg 的牡蠣

何謂 穩態量產 ？

- 立體化短期葉菜類栽培
- 35天生長期
- 育苗 14 天，育成 21 天
  - 3套系統 → 每週收穫
  - 21套系統 → 每天收穫

一年收穫 18 次

- 育苗 21 天，育成 14 天
  - 2套系統 → 每週收穫
  - 14套系統 → 每天收穫

一年收穫 26 次

Qualitative / Quantitative Evaluation of Performance

Evaluation of Performance

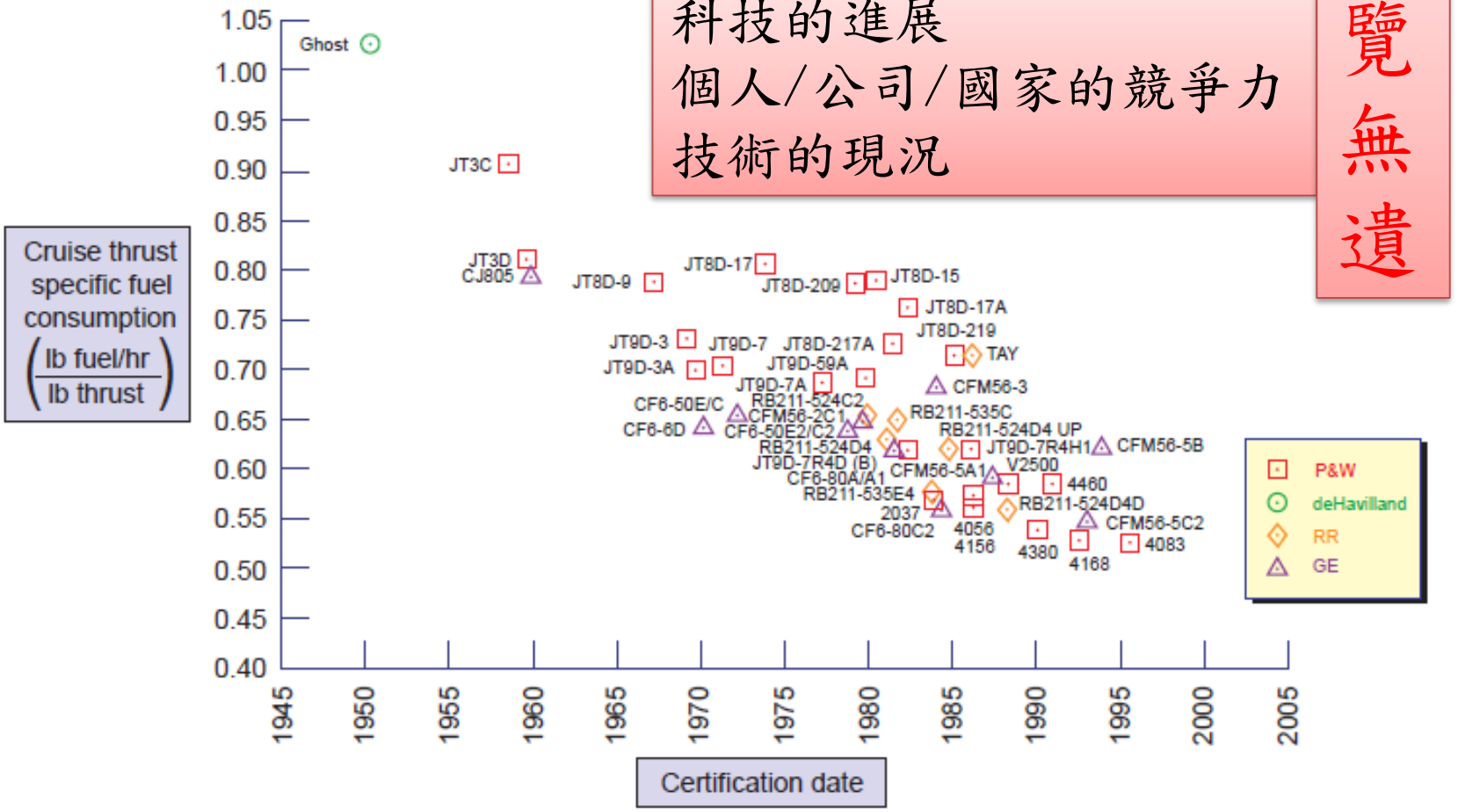
- Qualitative is OK but not accepted for engineering tasks

- Quantitative is better
  - KPI such as COP, EER, VER, RUE, ..

Evolution of Gas Turbine Engine Performance

科技的進展
個人/公司/國家的競爭力
技術的現況

一覽無遺



Adapted from Koff, B. L. "Spanning the World Through Jet Propulsion." AIAA Littlewood Lecture. 1991.

Evaluation of performance of artificial lights

- Lighting efficiency：lm/W　每瓦產生的流明

- 照度：
  - lm/ft^2 : candle 燭光
  - lm/m^2: lux 勒克斯

- 照度以人眼對光譜的敏感度為基準
- 人眼與植物葉綠體對光譜的敏感度有很大差異
- 照度單位不適用於植物照明

多種植物照明用人工光源的發光效率

Comp_Spec of Light sources	Reflectors on top	No. of tubes or panels	PPF* μmol m^{-2} s^{-1}	PPF x Area (μmol s^{-1})	Power consumption, W	Efficiency, μmol J^{-1}
S_CW1.8	Y	6 Tubes	334.9 ± 86.6	723.4	172.97	4.2
T_V	Y	9 tubes	281.6 ± 59.4	608.4	195	3.1
H_CW	Y	9 tubes	273.9 ± 79.8	73.9	212	3.1
T_A	Y	9 tubes	225.8 ± 49.1	487.8	189	2.6
E_CW	**Y**	**9 tubes**	**263.8 ± 64.2**	**569.8**	**228**	**2.5**
T_A	no need	12 panels	411.5 ± 103.2	888.9	432	2.1
T_N	Y	9 tubes	186.7 ± 39.3	403.2	196	2.1
E_WW	**Y**	**9 tubes**	**210.8 ± 51.0**	**455.3**	**229**	**2.0**
T_N	no need	12 panels	378.4 ± 95.4	809.6	428	1.9
T_M	Y	9 tubes	168.0 ± 39.1	326.9	193	1.9
T_M	no need	12 panels	387.3 ± 99.4	836.5	442	1.9
T_Y	Y	9 tubes	168.3 ± 34.7	363.5	188	1.9
S_R	no need	12 panels	291.0 ± 71.3	628.6	334	1.9
T5FL_CW	Y	9 tubes	250.0 ± 57.5	540	283	1.9

* Measured at 10 cm distance under light except the T5FL treatment (at 20 cm distance)

** Area of culture Bed on bench per layer = 1.8 m x 1.2 m = 2.16 m^2

Profit from production

- Profit = Revenue – Cost
- What's missing?
  - Time involved
  - Space occupied
  - Cost breakdown into details
    - Depreciation counted?
- A better KPI in plant production:

$$\$/(week*m^2)$$

An example on
‘parallel installation of compressors’

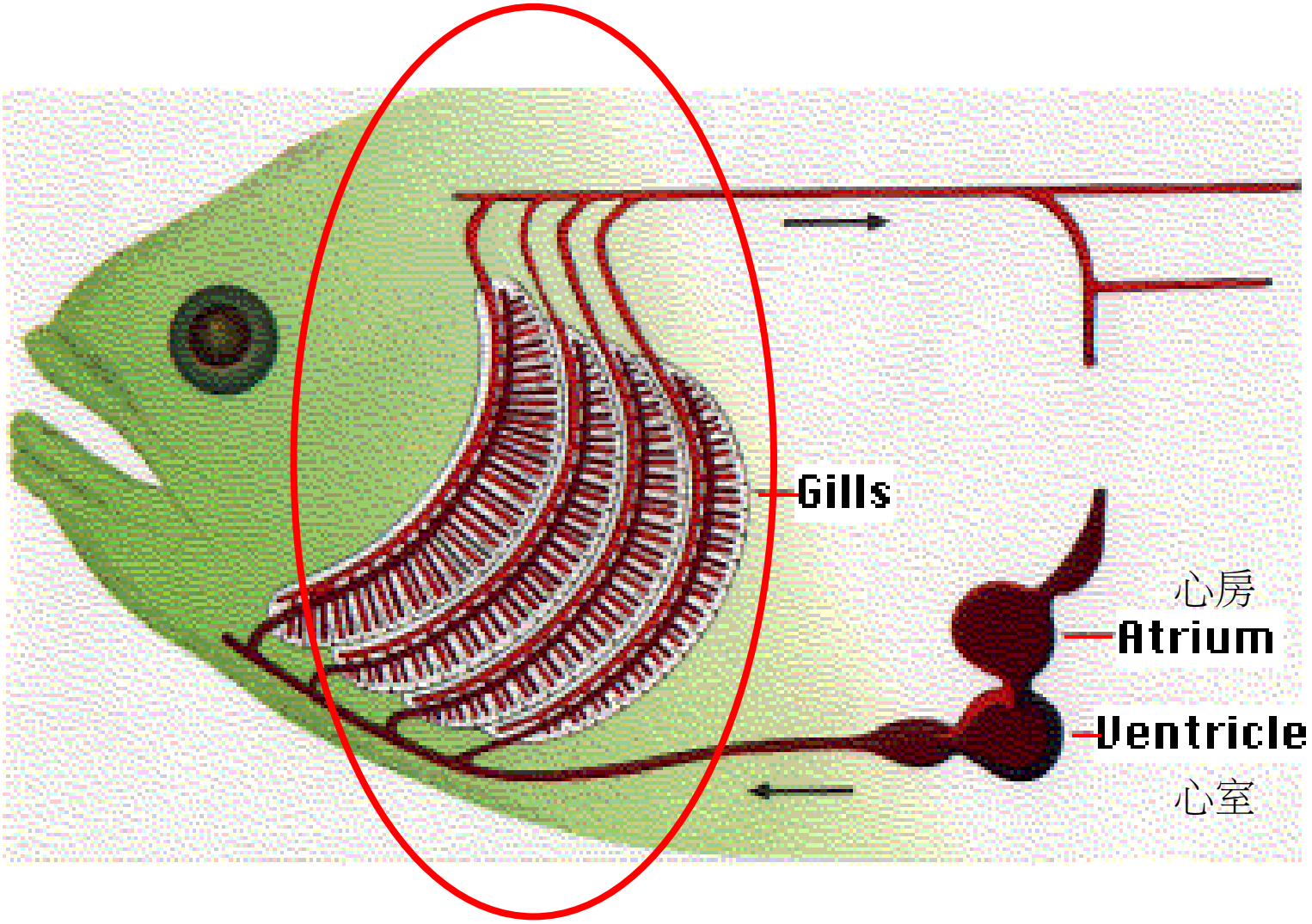
仿生 Bio-mimicry


背血管
腹血管
"心臓"

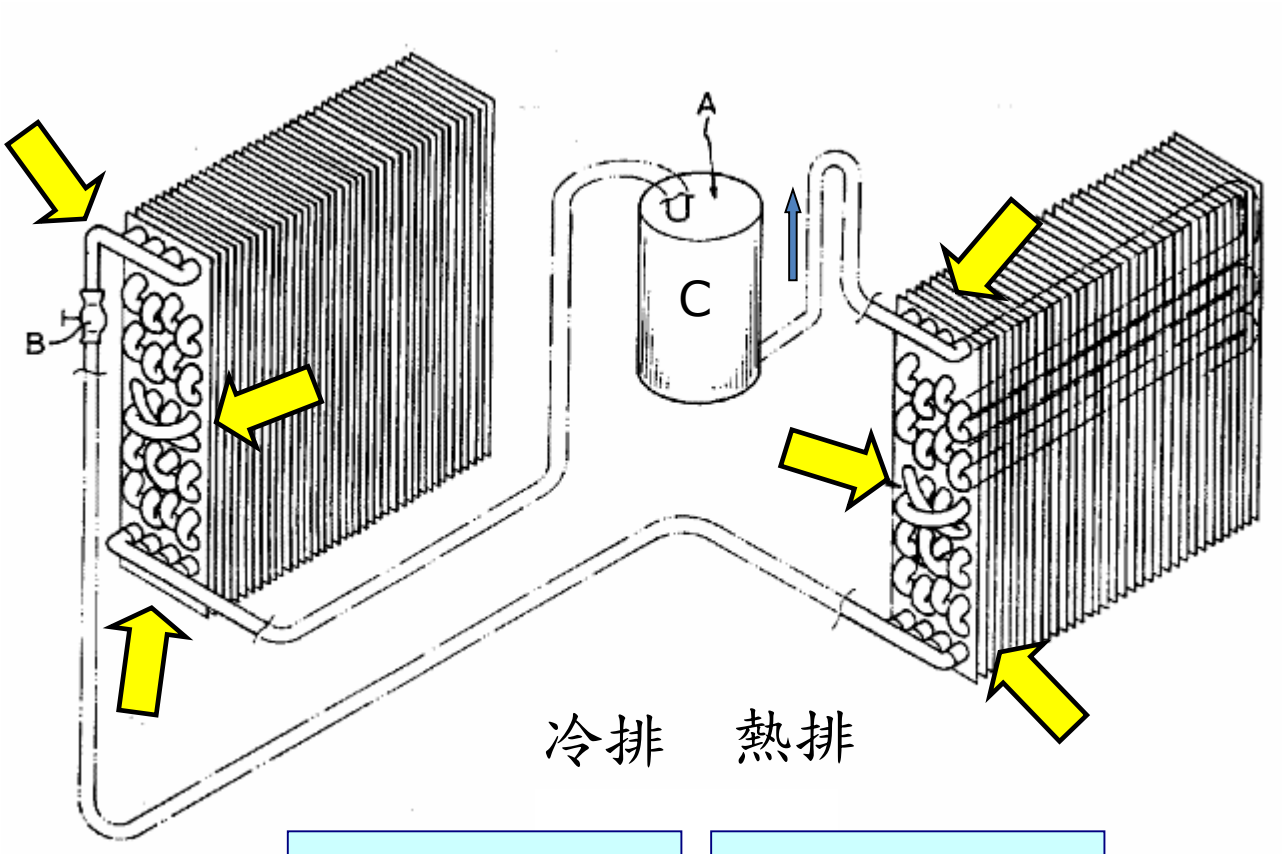
多台壓縮機並聯

An example on
‘parallel distribution of pipes’

仿生 Bio-mimicry


Gills
心房
Atrium
Ventricle
心室

冷媒流向：分流，對調與合流

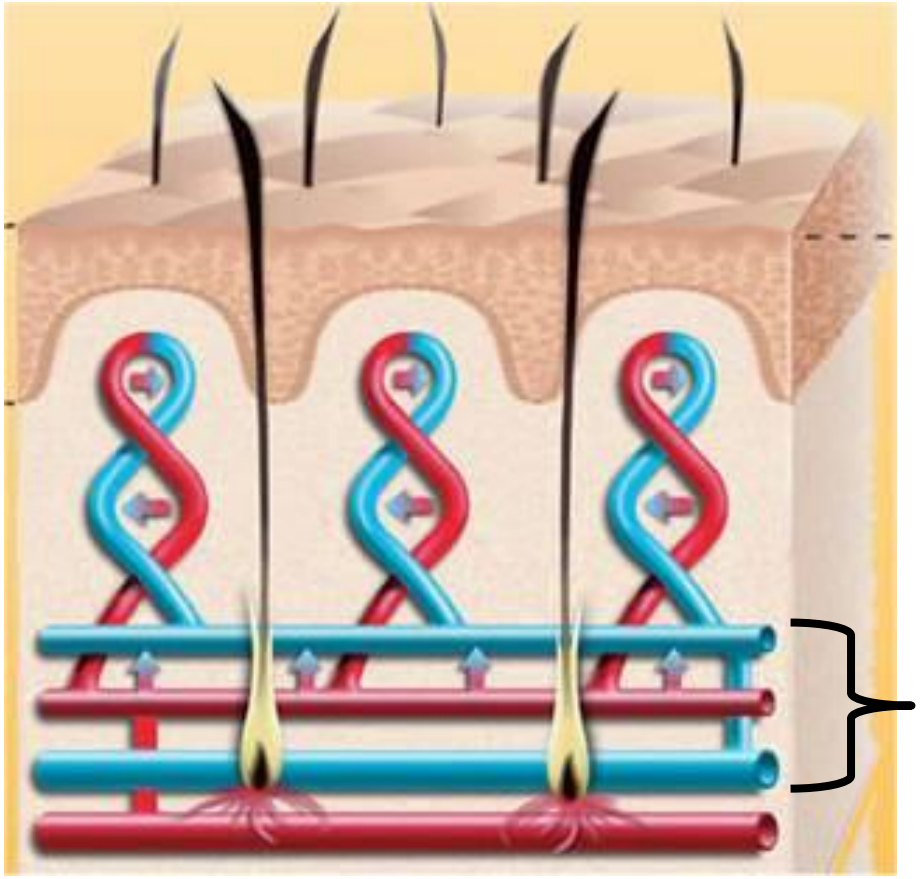


均勻吸熱　均勻散熱

An example on
‘3 head pipes for even distribution’

仿生 Bio-mimicry

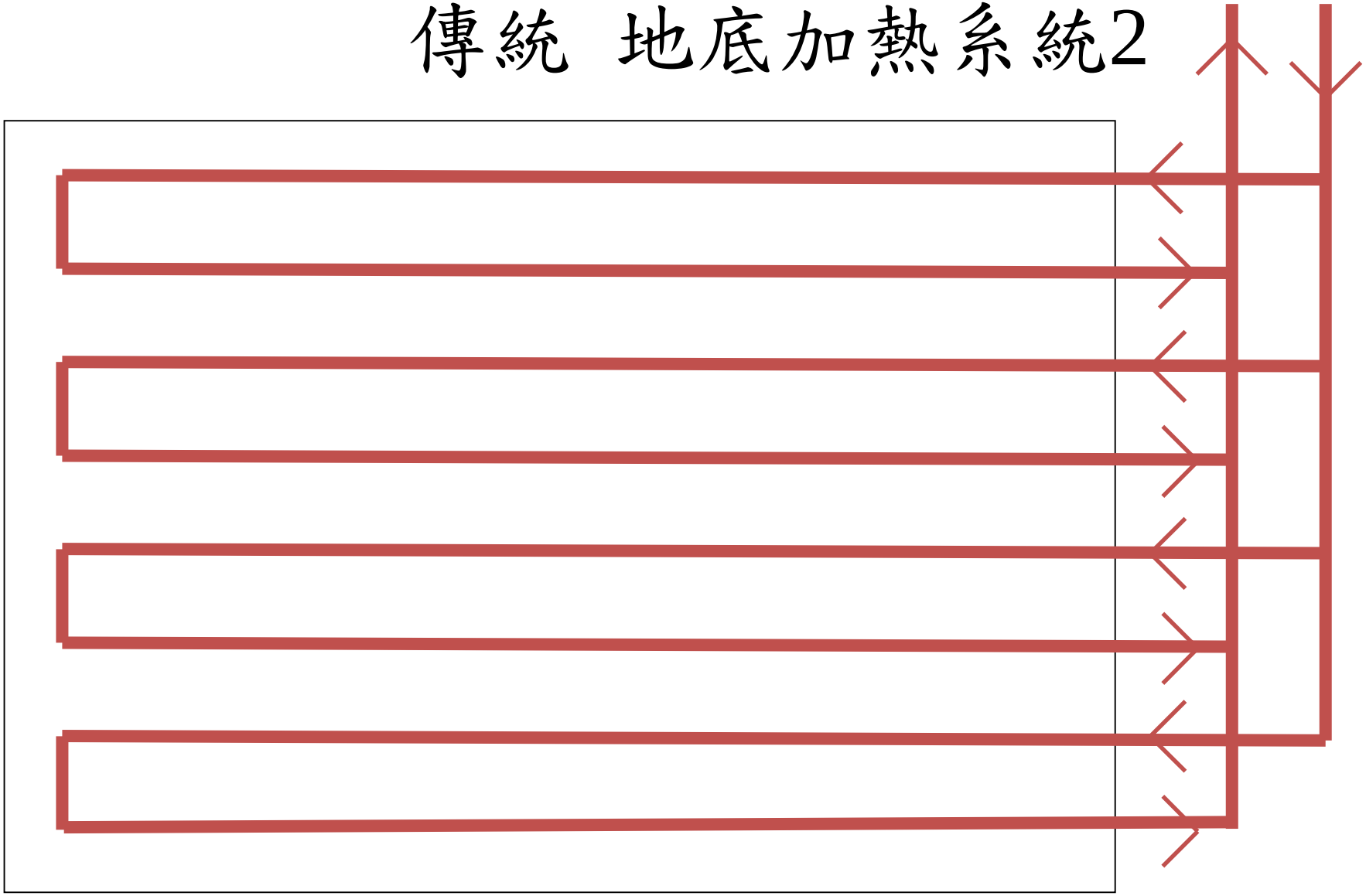
血管：如何均勻輸送



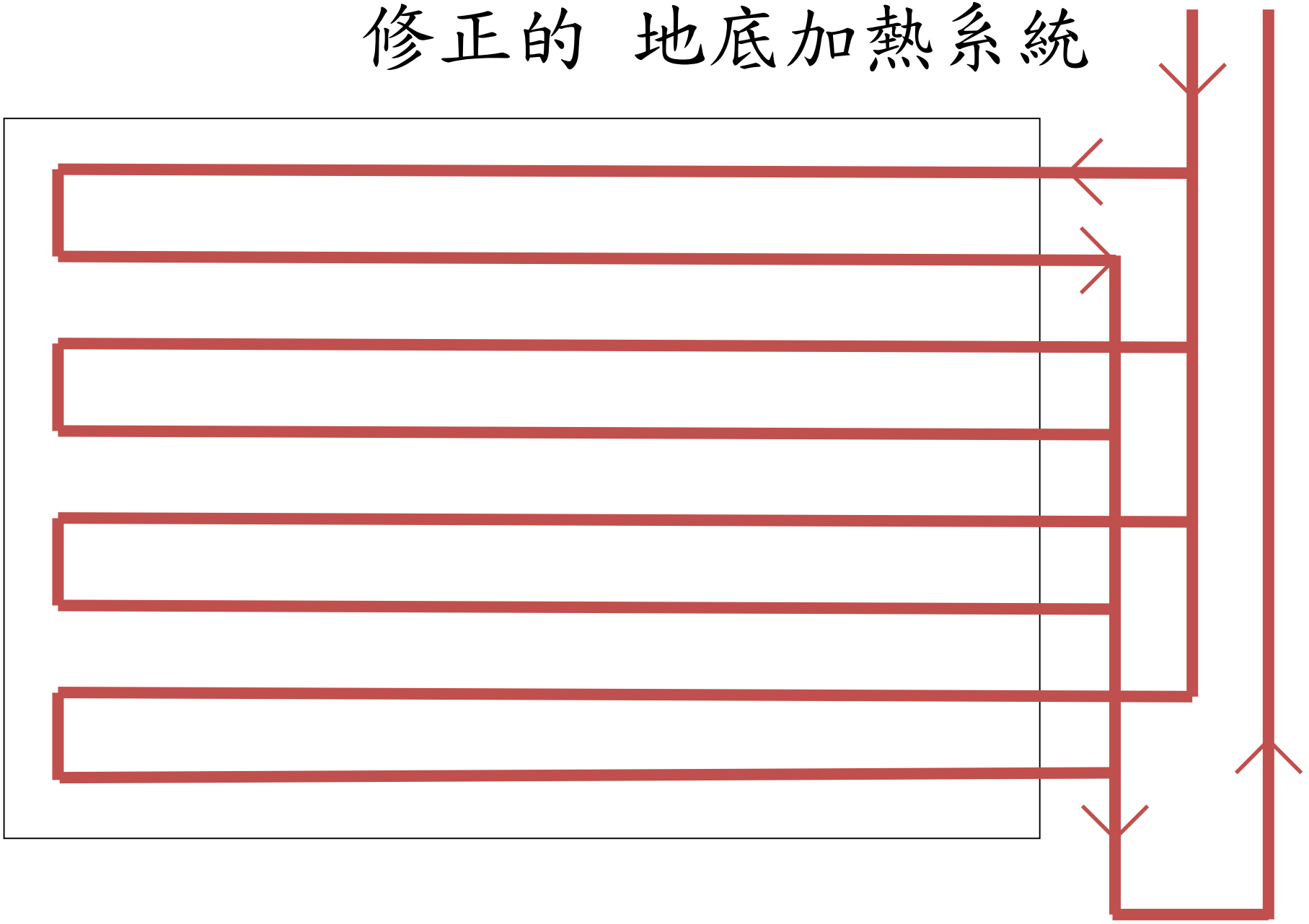
3 head pipes

傳統　地底加熱系統1

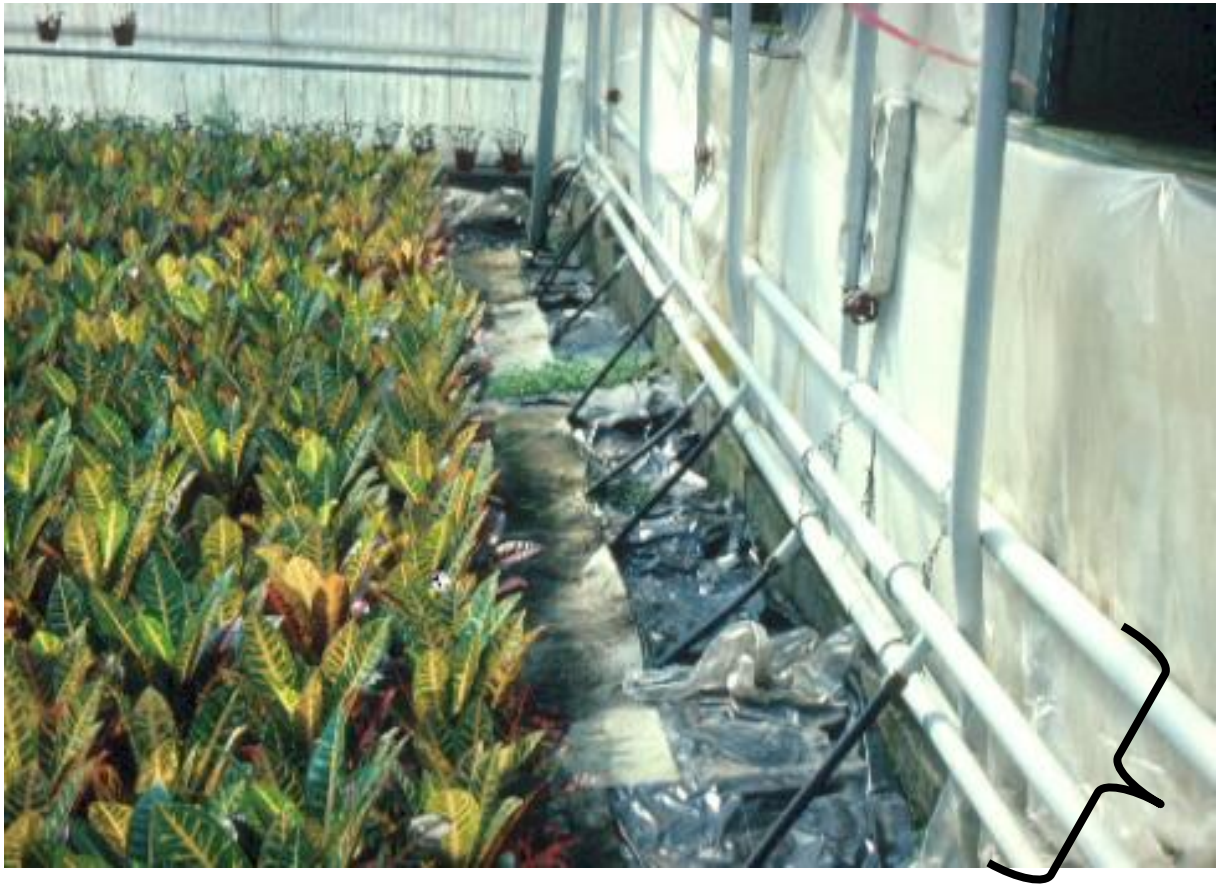
傳統 地底加熱系統2



修正的 地底加熱系統

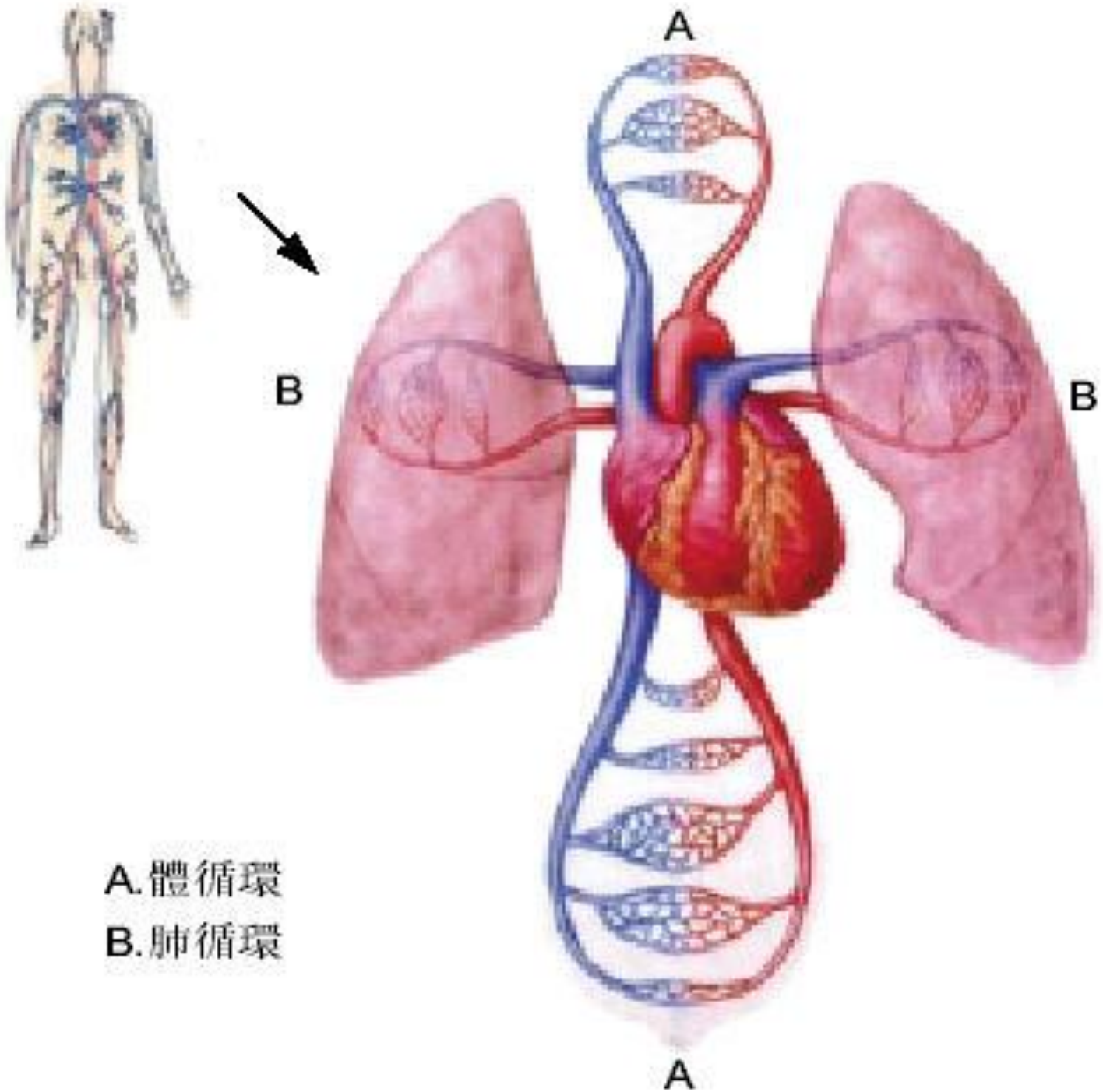


修正的溫室地底加熱系統



A biomimicry example on
‘oxygen/heat exchange’

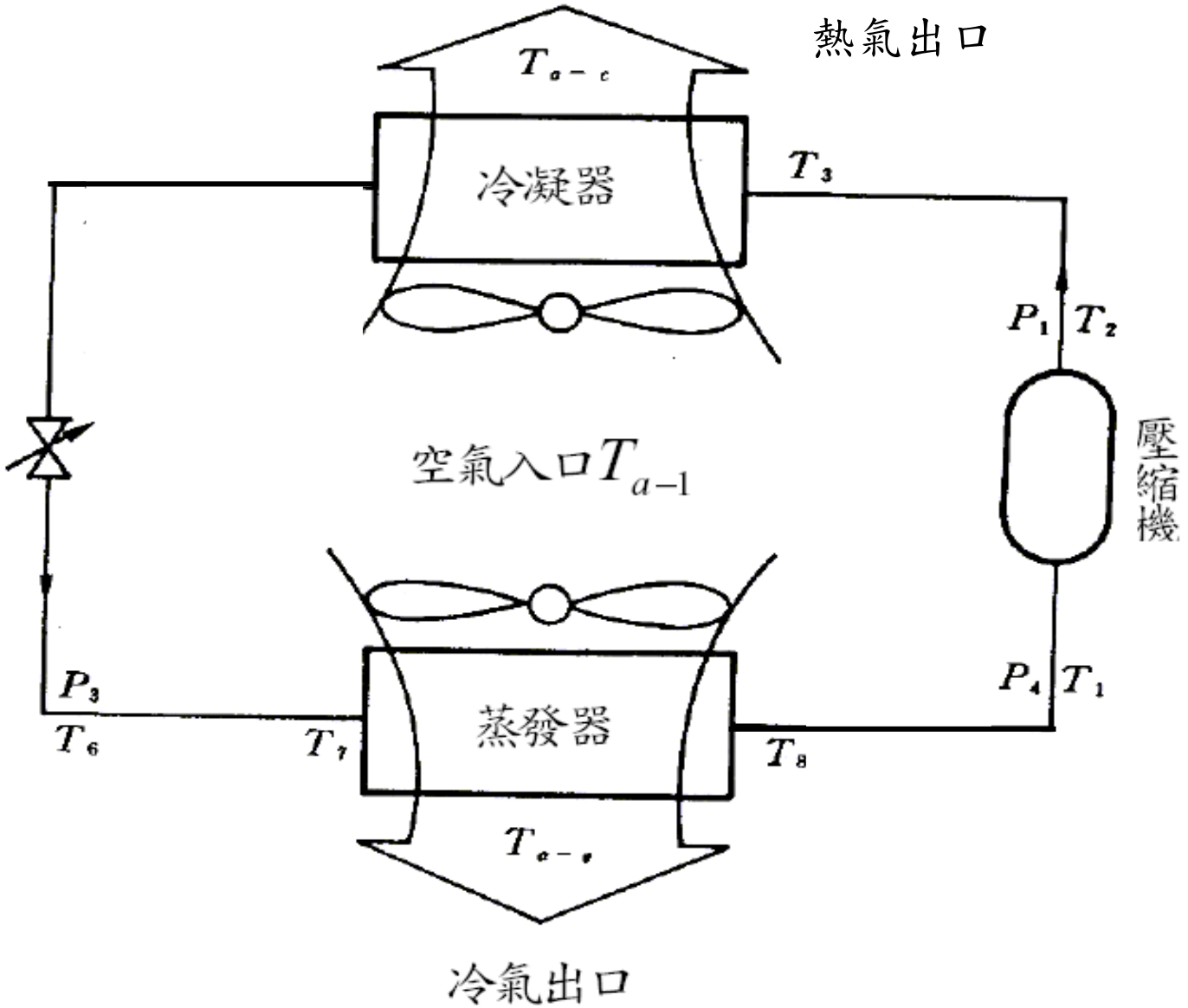
仿生 Bio-mimicry



A.體循環

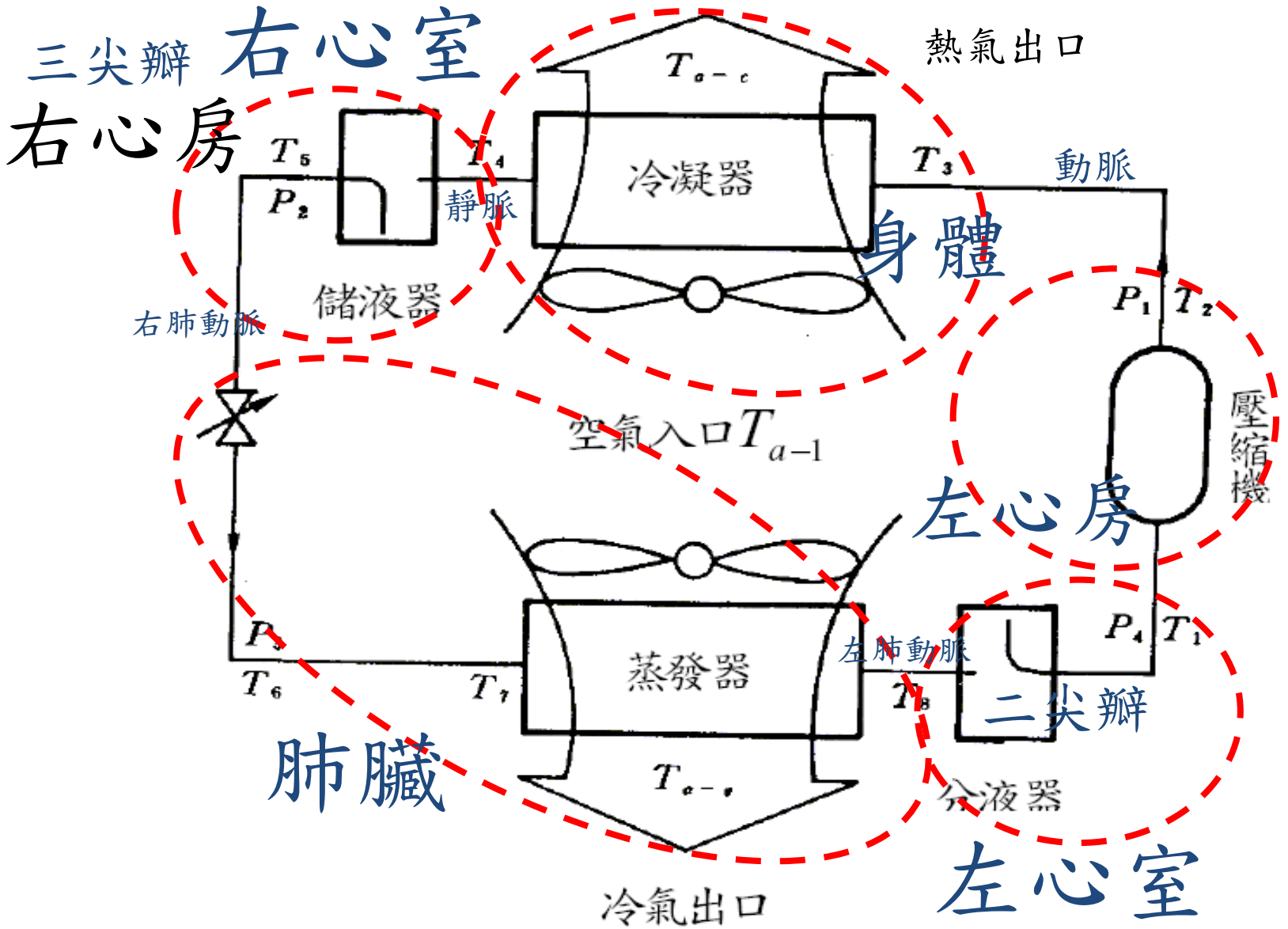
B.肺循環

傳統 冷凍空調系統

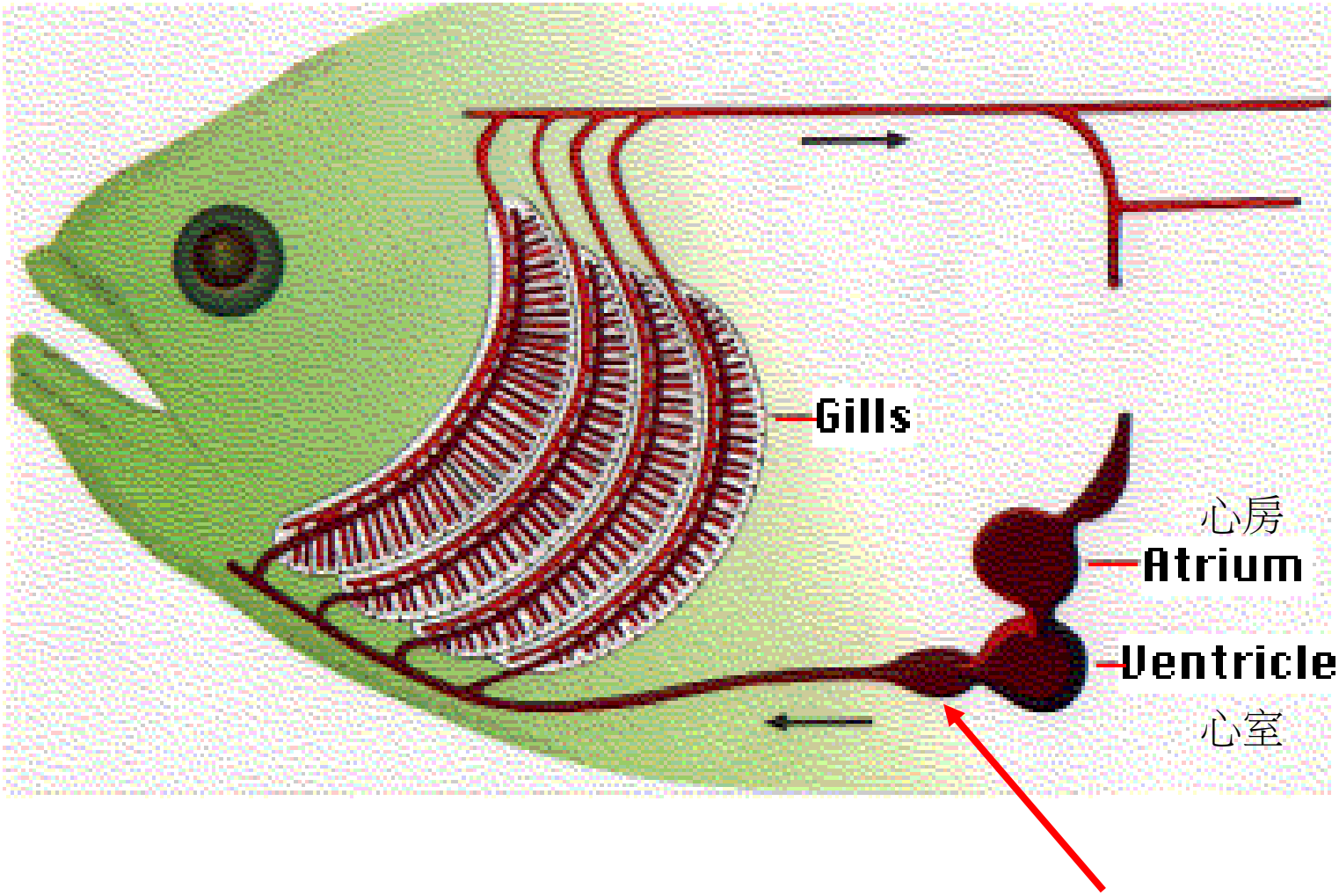


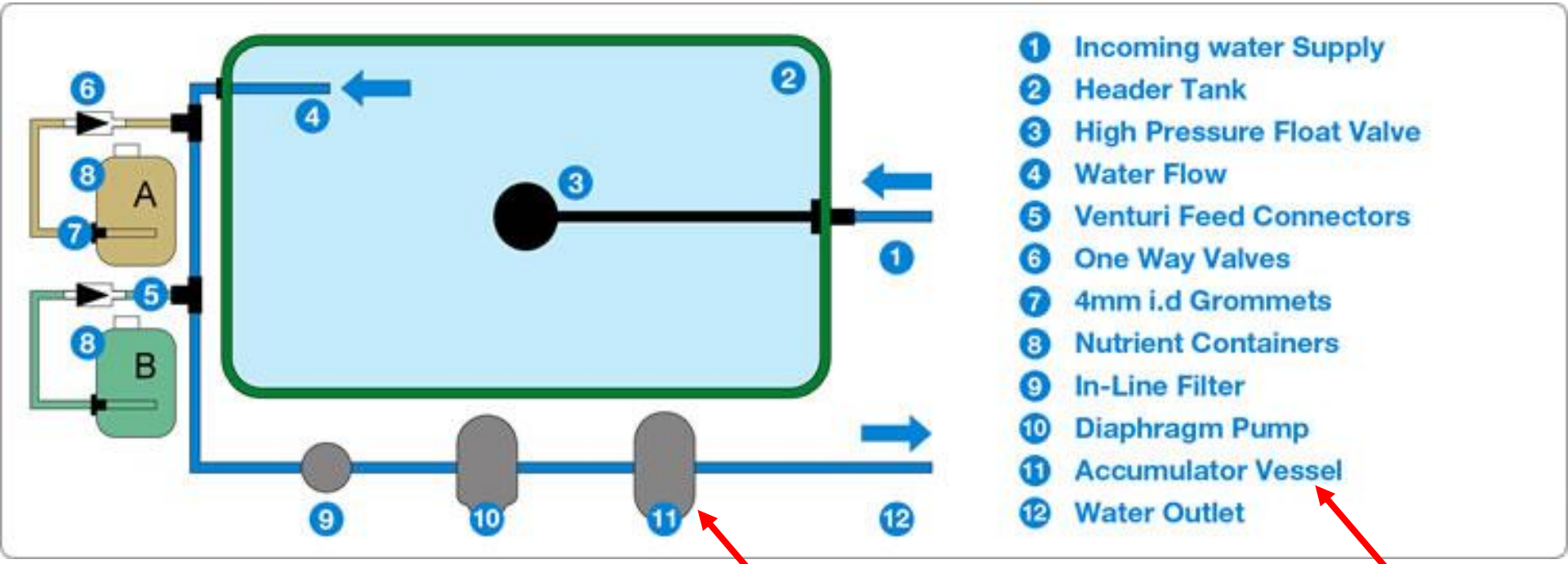
血液循環	冷凍空調
血管缺乏舒張壓就没有彈性位能，血管與器官都會扁掉	冷媒管缺乏低壓側壓力，大氣壓力與壓縮機的負壓會把冷媒管壓扁
收縮壓（血液擠向動脈） 動態調配血液的力量	高壓側壓力
舒張压（血液由動脈流出） 保持血管彈性的力量	低壓側壓力 讓冷媒流回壓縮機的力量
體循環供給身體氧氣	高壓側散熱
肺循環交換取得氧氣	低壓側吸熱

Modified 冷凍空調系統

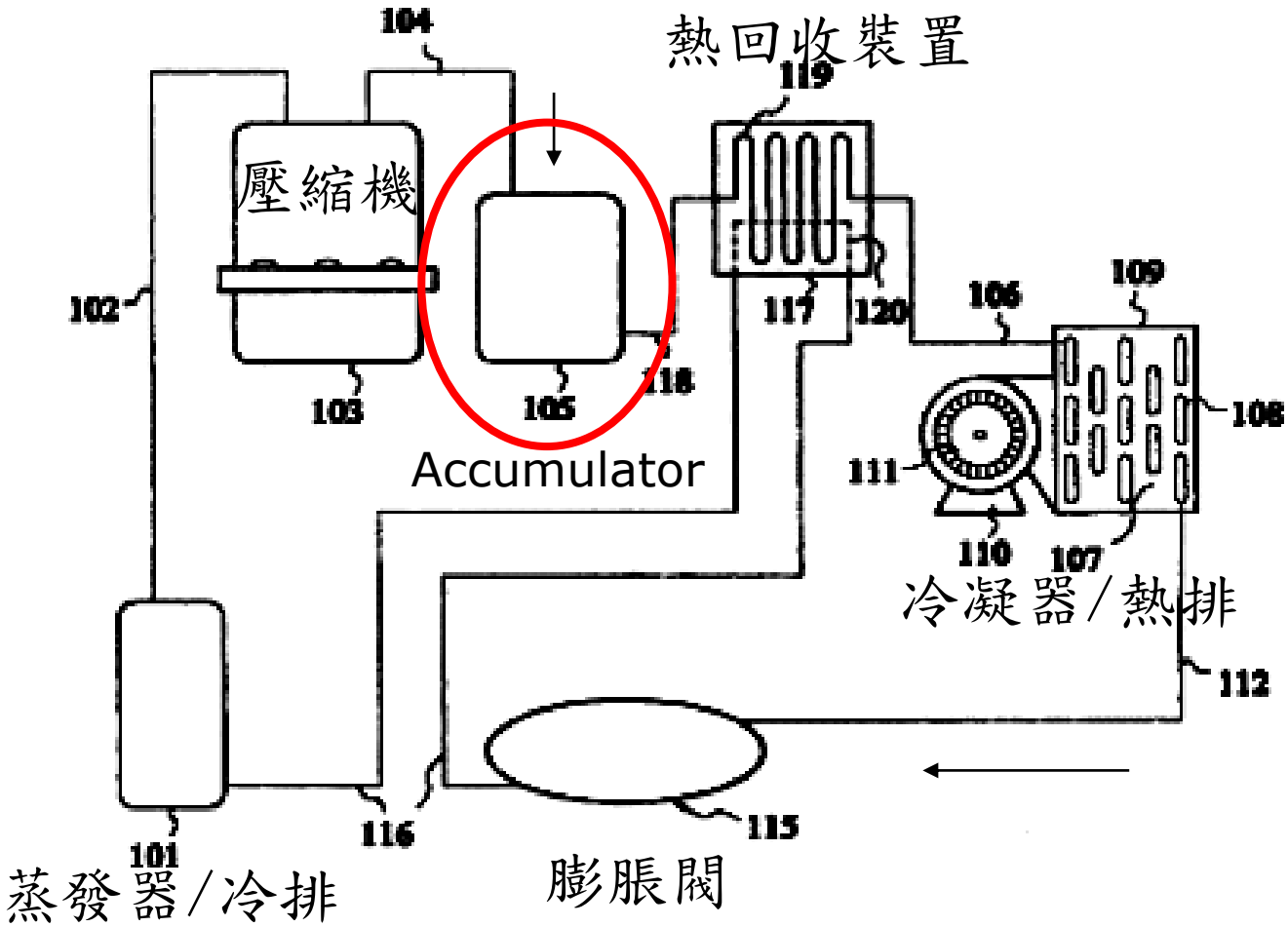


A biomimicry example on ‘accumulator vessel’


Gills
心房
Atrium
Ventricle
心室

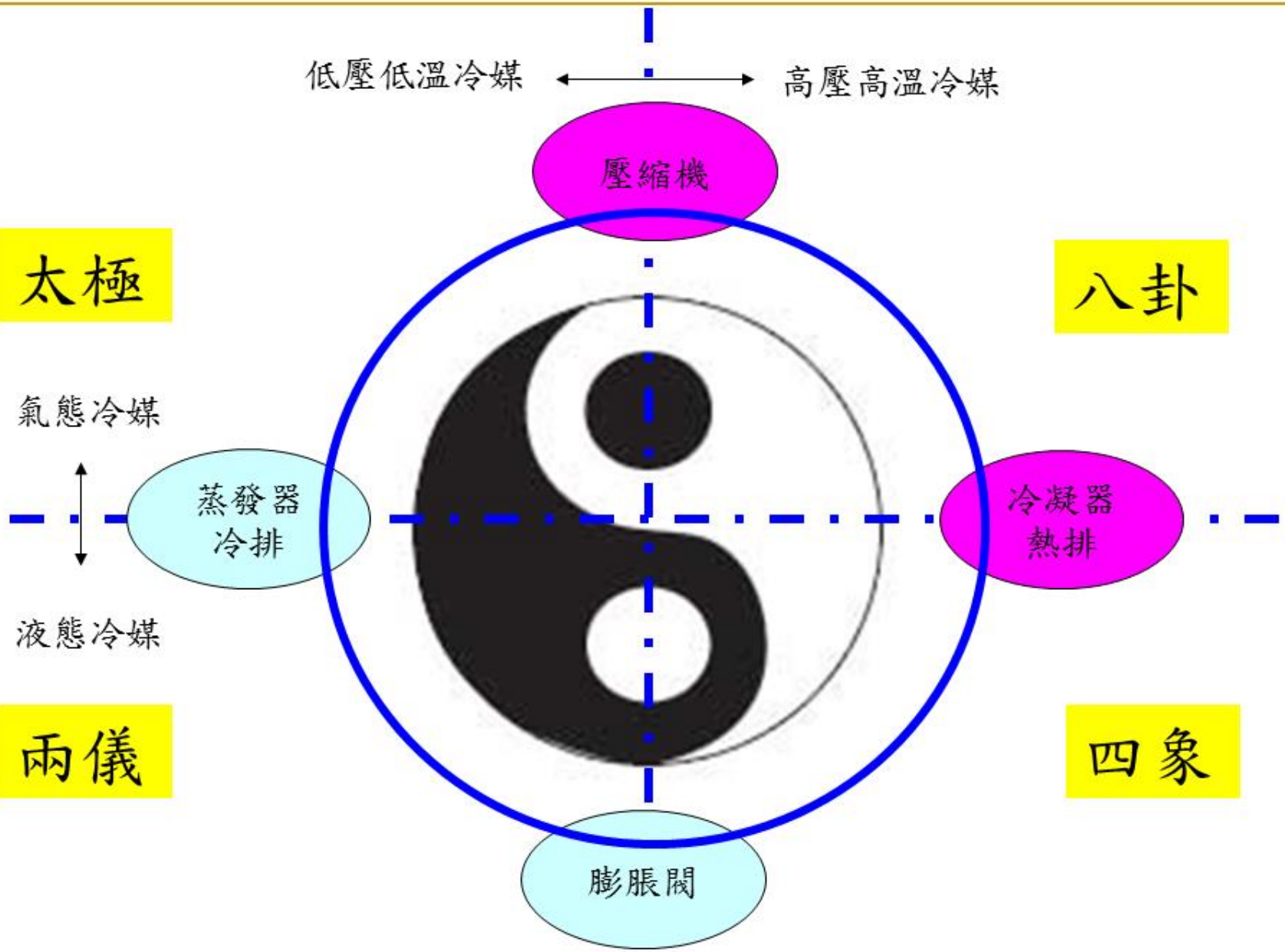

1 Incoming water Supply
2 Header Tank
3 High Pressure Float Valve
4 Water Flow
5 Venturi Feed Connectors
6 One Way Valves
7 4mm i.d Grommets
8 Nutrient Containers
9 In-Line Filter
10 Diaphragm Pump
11 Accumulator Vessel
12 Water Outlet
A
B

Modified 冷凍空調系統



更多範例

- 觸類旁通、異中求同
- 太極理念應用於冷凍空調系統之研發



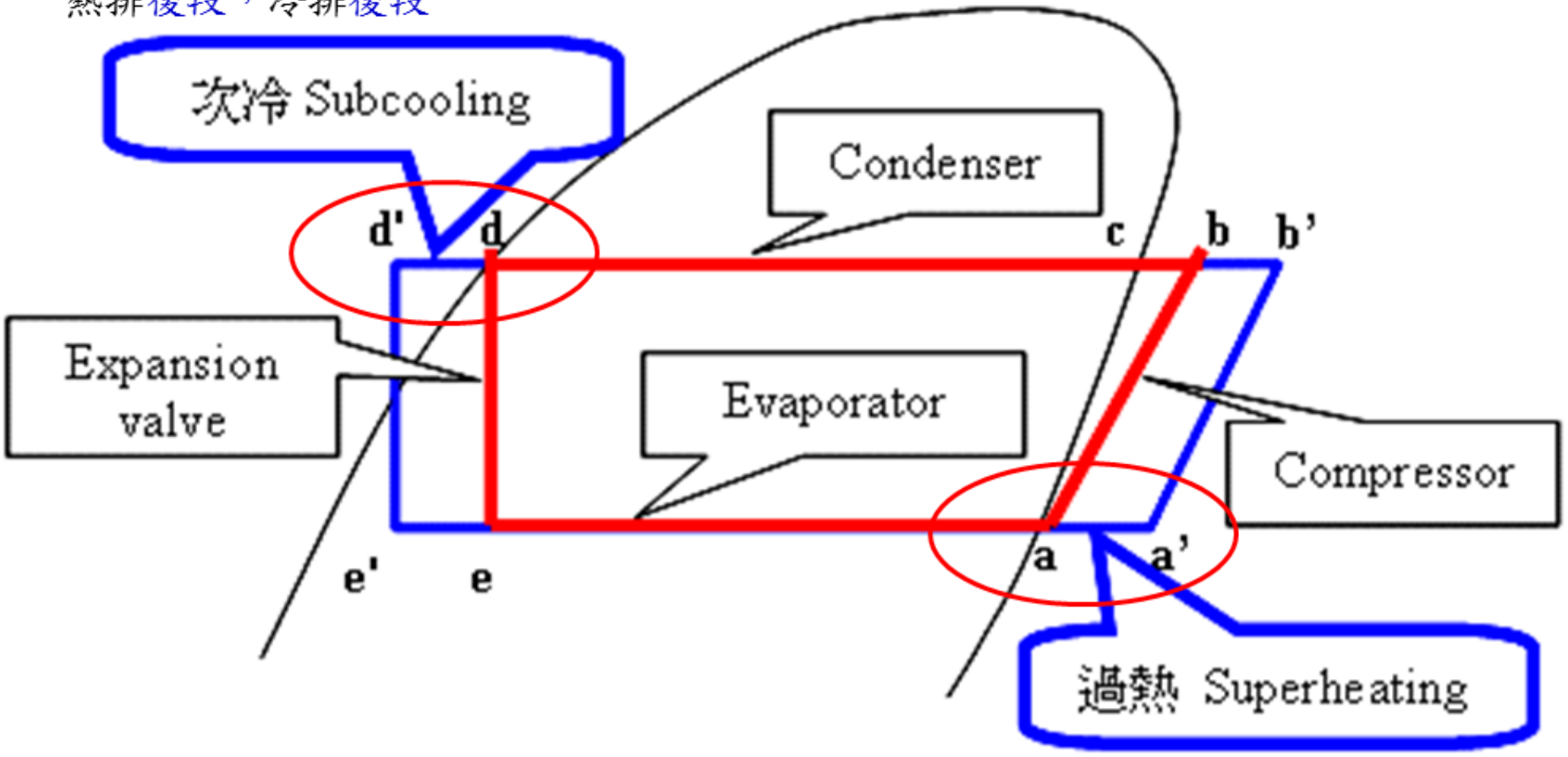
循環cycle就是一個畫圓的動作

太極理念應用於冷凍空調系統的研發

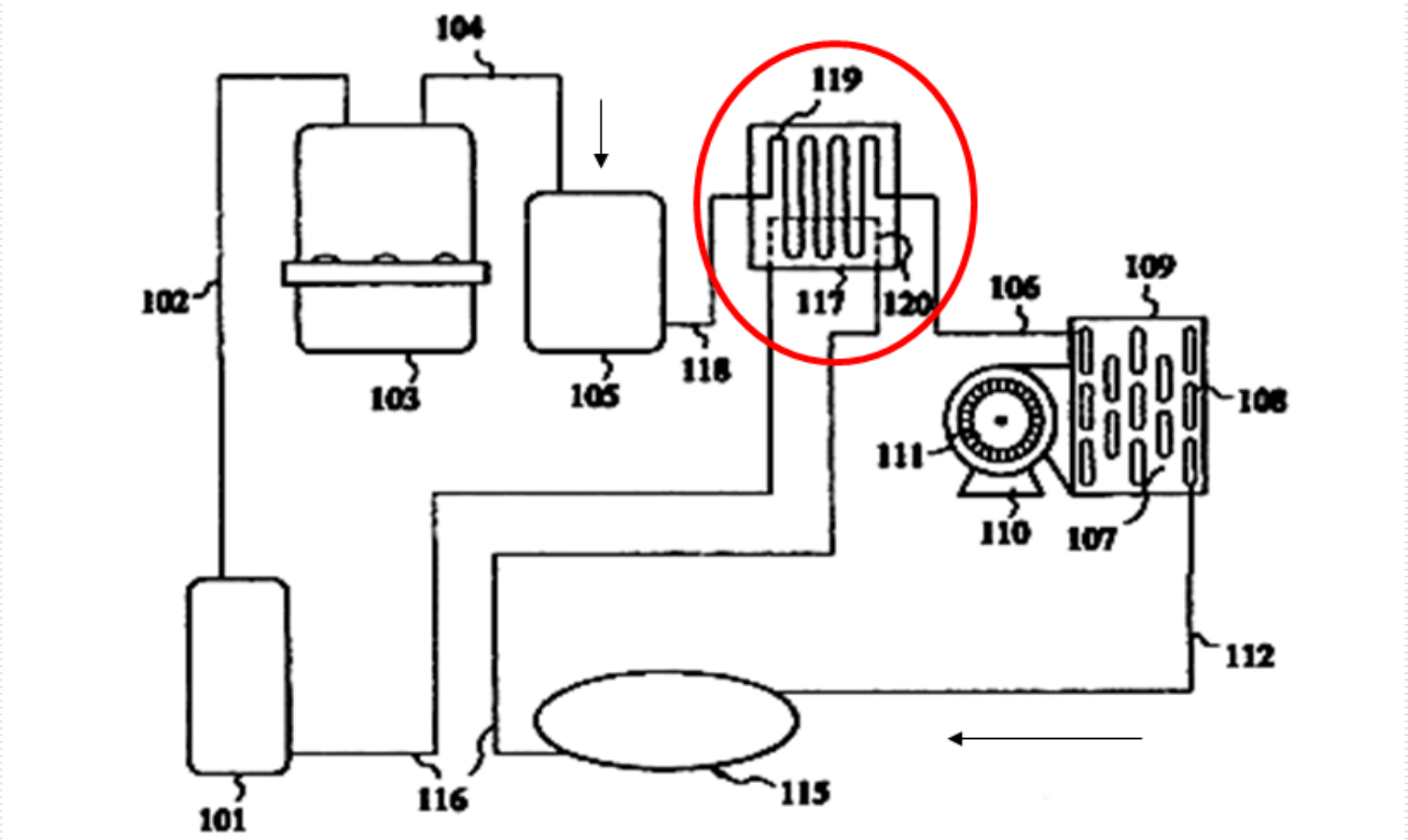
- 借力使力：機由己發，力從人借
  - 熱排後段，冷排後段：加強散熱與吸熱利用
  - 熱排前段，冷排前段：預冷與預熱

P-h Diagram

熱排後段，冷排後段



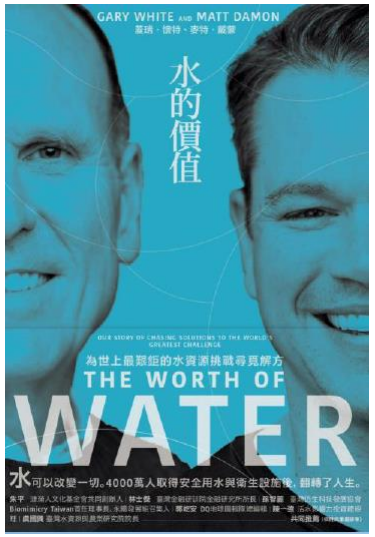
機由己發：熱排前段與冷排前段結合新增一個熱交換器



2000,2001 方 & 蕭

更多範例

- 觸類旁通、異中求同
- 發散式思考



水的價值

水

物以稀為貴

利之所趨

關鍵的就會成為趨勢

參與者眾，就會形成產業

水產業

- 提供潔淨的淡水：水處理
- 提供美容、醫療功能的水：機能水
- 提供滅菌功能的水：電解水
- 提供量化指標：檢測儀器、感測器

- 物理法、化學法、生物法
- 物化法、生化法、生物物理法

光

人工照明 --> 需求引導趨勢

LED 應用於生物產業

- 美容醫療：
  - 柔光回春
  - 免疫提升
  - 光動力療法
- 照明：路燈、車燈、室內照明
- 植物照明：光質、光量、光週
- 經濟動物催情、肌肉增生
- 昆蟲誘捕、水下魚蝦誘引
- 檢測儀器

更多範例

- 吾道一以貫之

- 相通技術應用於不同對象
- 範例：
  - 環控農業
    - 環控：地上環境、地下環境（水下）
    - 農業：廣義定義包含農漁牧

甚麼是 Phytomation？

由**設施農業**（**Protected cultivation**）

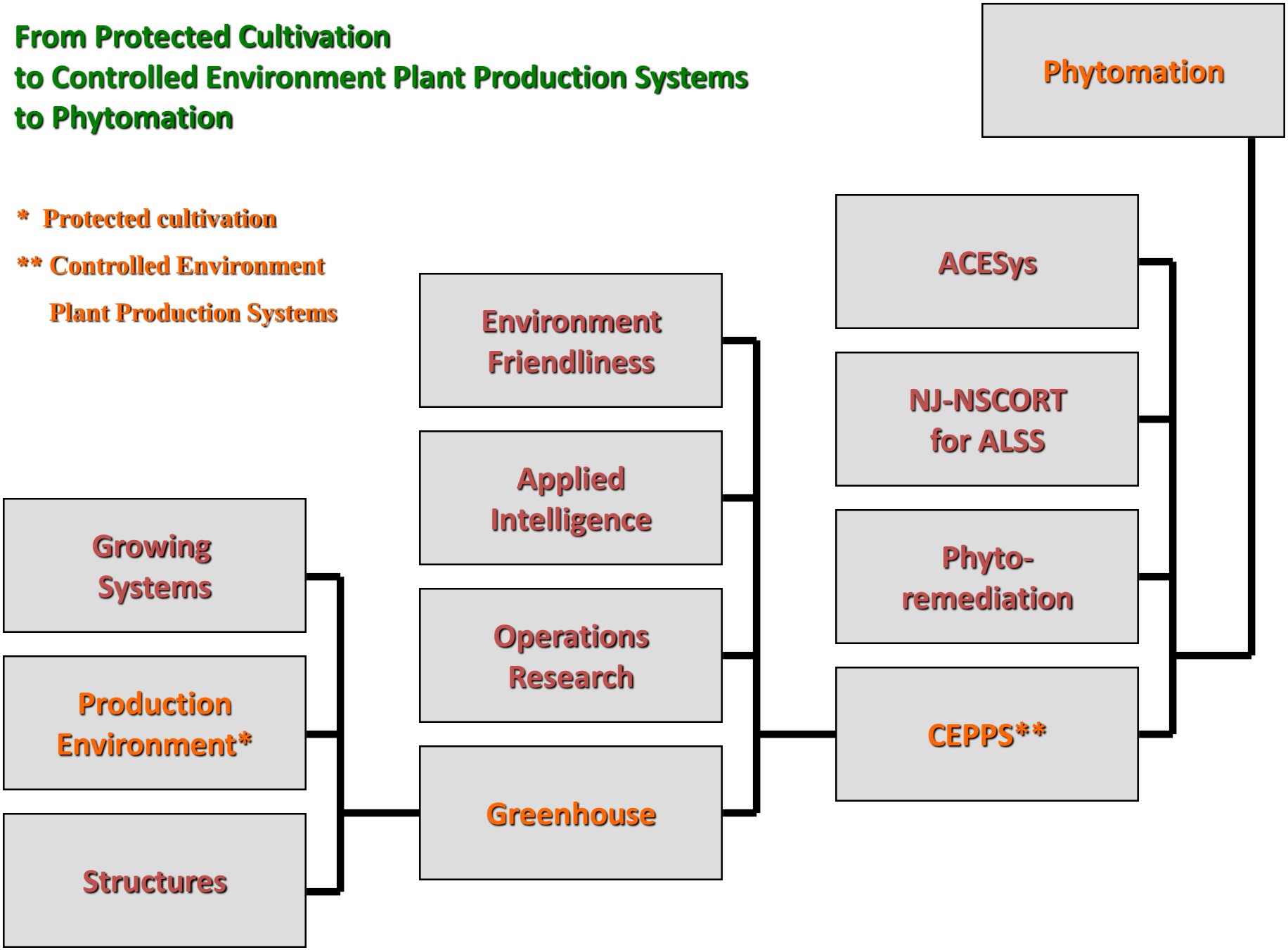
發展到**環控作物生產系統**（**Controlled Environment Plant Production Systems**）

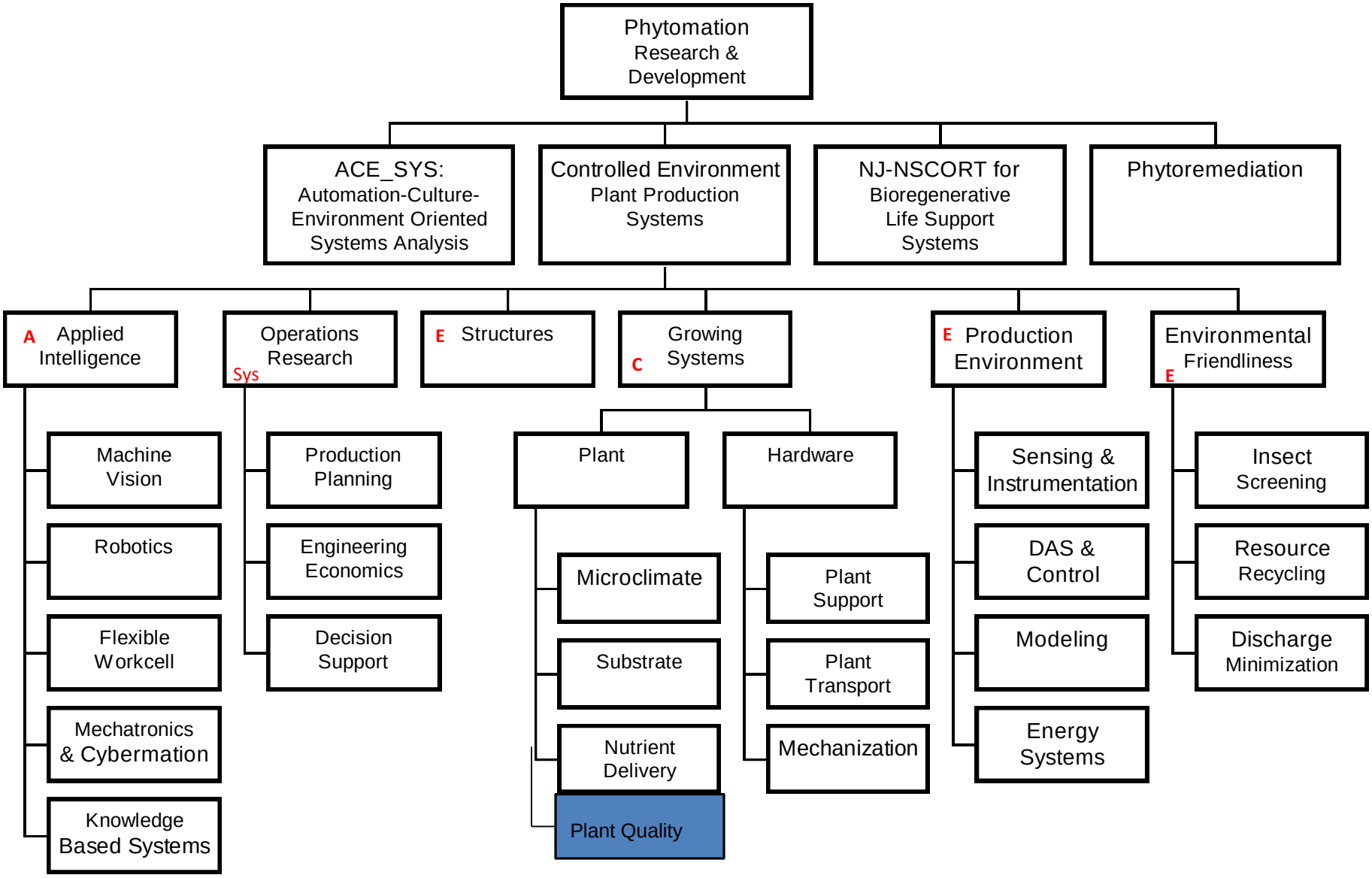
再下一步的進階就是**Phytomation**

From Protected Cultivation to Controlled Environment Plant Production Systems to Phytomation

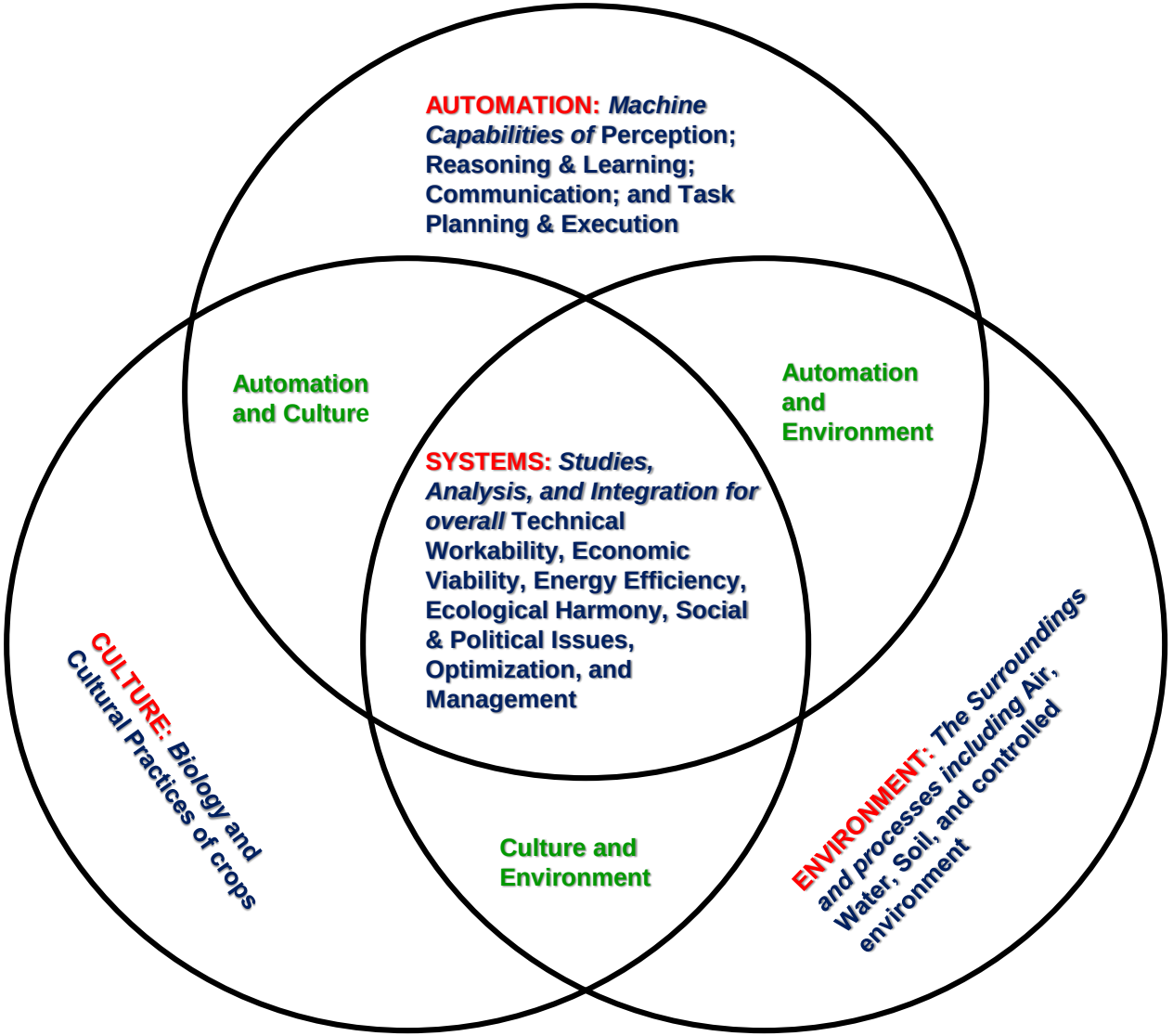
* Protected cultivation

** Controlled Environment Plant Production Systems




Phytomation
Research &
Development
ACE_SYS:
Automation-Culture-
Environment Oriented
Systems Analysis
Controlled Environment
Plant Production
Systems
NJ-NSCORT for
Bioregenerative
Life Support
Systems
Phytoremediation
A Applied
Intelligence
Operations
Research
Sys
E Structures
Growing
C Systems
E Production
Environment
Environmental
E Friendliness
Machine
Vision
Robotics
Flexible
Workcell
Mechatronics
& Cybermation
Knowledge
Based Systems
Production
Planning
Engineering
Economics
Decision
Support
Plant
Hardware
Microclimate
Substrate
Nutrient
Delivery
Plant Quality
Plant
Support
Plant
Transport
Mechanization
Sensing &
Instrumentation
DAS &
Control
Modeling
Energy
Systems
Insect
Screening
Resource
Recycling
Discharge
Minimization

Automation-Culture-Environment-Systems (ACESys) Oriented Approach to Phytomation



Concept of Automation-Culture-Environment Oriented Systems Analysis (ACESYS)

Components and Processes of Controlled Environment Bio-Production Systems may be categorized into three classes: (K.C. Ting, 1994)

- **Automation – machine capabilities of information processing and physical work (including perception, reasoning/learning, communication, and task planning/execution)**

- **Culture – factors and practices that can directly describe and/or modify the growth and development of biological objects (e.g. morphological and physiological conditions, as well as cultural tasks including multiplication, nutrient delivery, disease prevention, harvesting, etc.)**

- **Environment – surroundings of biological objects (including climatic, nutritional, structural, and mechanical conditions)**

Automation

Information Processing & Task Execution, e.g.

- **Perception**
- **Reasoning / Learning**
- **Communication**
- **Task Planning & Execution**

Culture

Factors and Practices which can Describe and/or Modify Growth and Development of Biological Objects, e.g.

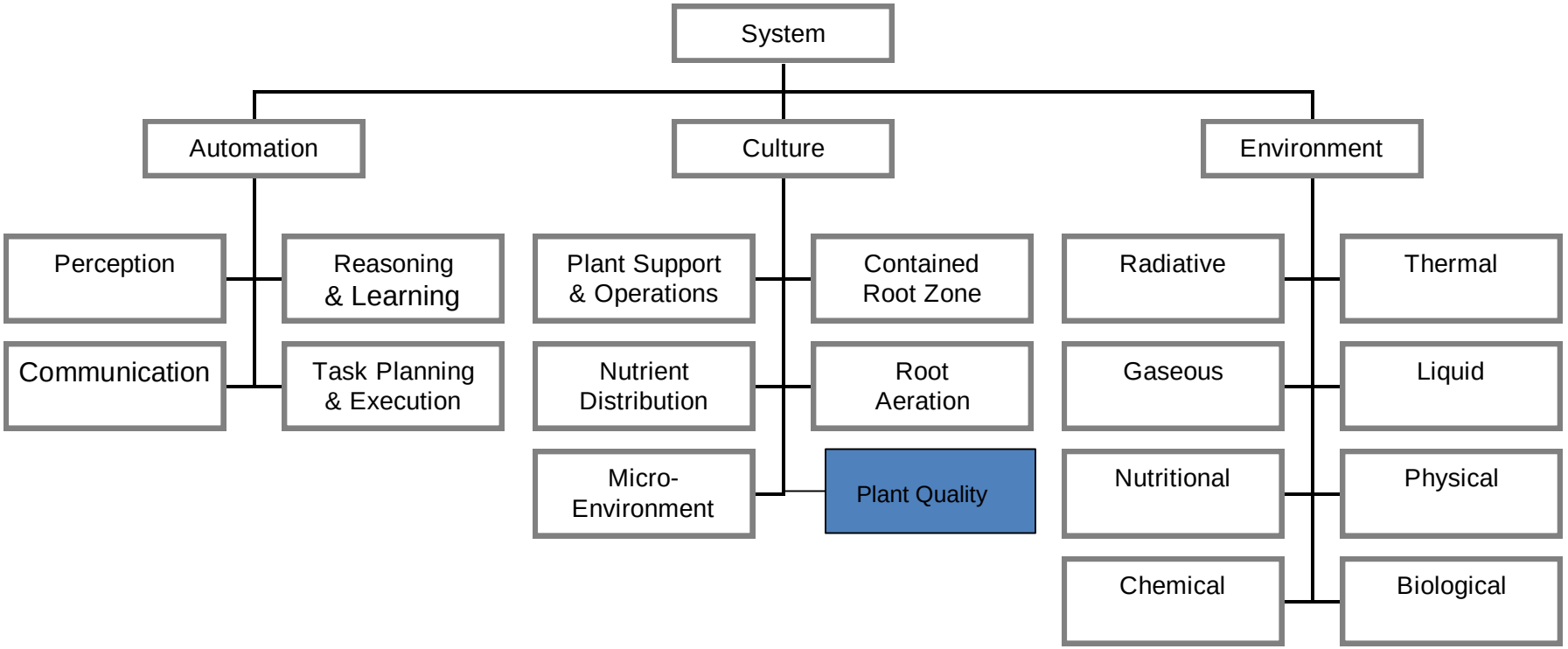
- **Plant Support & Operations**
- **Nutrient Distribution**
- **Micro-Environment**
- **Contained Root Zone**
- **Root Aeration**

Environment

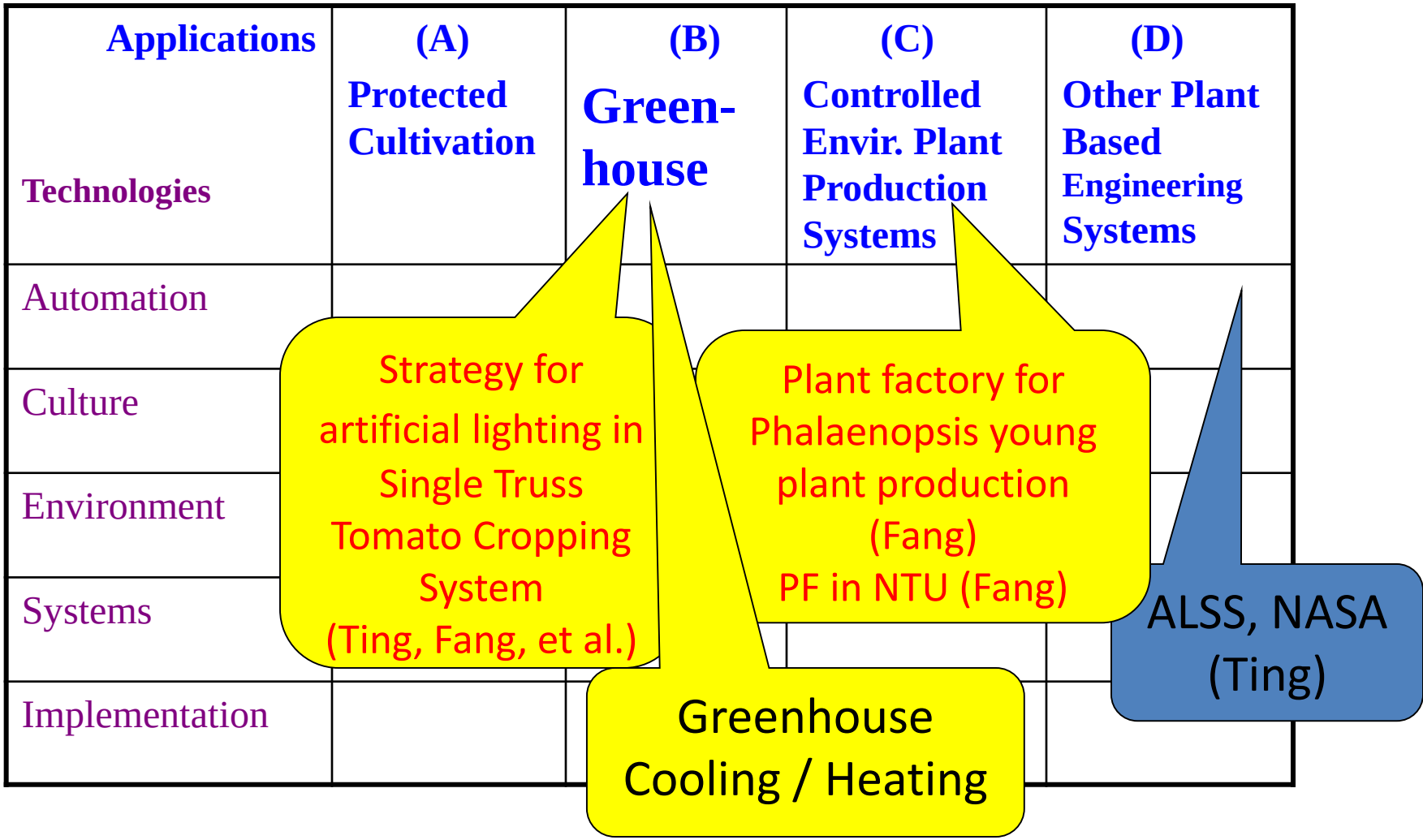
The Surrounding of Biological Objects, e.g.

- **Radiative, Thermal**
- **Gaseous, Liquid**
- **Physical, Chemical, Biological**

ACESys 架構


System
Automation
Culture
Environment
Perception
Reasoning & Learning
Communication
Task Planning & Execution
Plant Support & Operations
Contained Root Zone
Nutrient Distribution
Root Aeration
Micro-Environment
Plant Quality
Radiative
Thermal
Gaseous
Liquid
Nutritional
Physical
Chemical
Biological

Application of ACESYS to Phytomation Systems (i.e. using ACESYS to **describe** and implement Phytomation systems**)**



STTCS 單果串番茄量產系統

Applications / Technologies	Single Truss Tomato Cropping System
Automation	❖ Artificial lighting ❖ Fan & Pad, Ebb & Flood, Chiller
Culture	❖ Cultural practice ❖ Varieties
Environment	❖ Local weather, Indoor environment, ❖ Structure, walls ❖ Light quantity, quality, ❖ Air T, RH, CO_2, ❖ Water T, DO, EC,pH, etc.
Systems	❖ Engineering economic analysis, ❖ Number of crops per year, other DSS

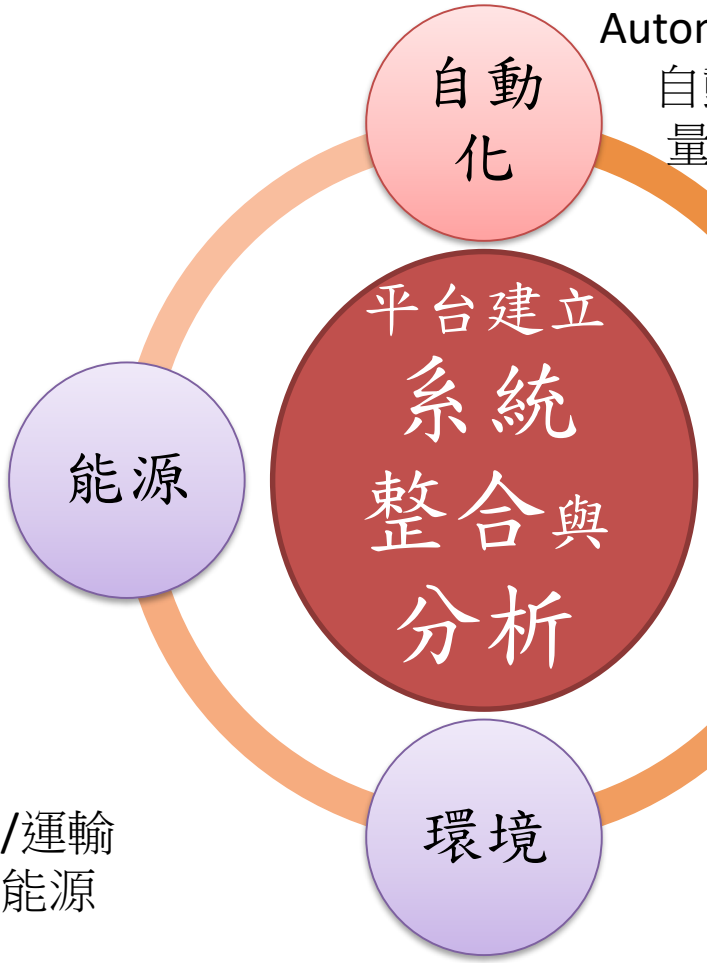
Applications / Technologies	GH_cooling / heating
Automation	❖ Control system: hardware/software ❖ Various means to cool / heat the GH
Culture	❖ Cultural practice
Environment	❖ Local weather, Indoor environment, ❖ Structure, walls ❖ Light quantity, quality, ❖ Air T, RH, CO_2, ❖ Water T, DO, EC,pH, etc.
Systems	❖ Engineering economic analysis, ❖ Risk analysis, other DSS

Applications Technologies	Plant Factory **of *Phalaenopsis*** **Controlled Environment Plant Production Systems**
Automation	❖ Moving light, Multi-layer benches ❖ Fan & Pad, Ebb & Flood, Chiller
Culture	❖ 12 cm leaf span young *Phalaenopsis* ❖ Flower forcing of 30 cm leaf span young *Phalaenopsis*
Environment	❖ Local weather, Indoor environment, ❖ Structure, walls ❖ Light quantity, quality, ❖ Air T, RH, CO_2, ❖ Water T, DO, EC,pH, etc.
Systems	❖ Engineering economic analysis, ❖ Risk analysis, other DSS

Applications / Technologies	Plant Factory in NTU Controlled Environment Plant Production Systems
Automation	❖ Artificial light, Multi-layer benches ❖ Environmental control, Fertigation ❖ Nondestructive quality/nutrient detection
Culture	❖ Leafy greens
Environment	❖ Structure, walls ❖ Light intensity, quality, duration ❖ Air T, Wind speed, RH, CO_2, ❖ Water T, DO, EC, pH, etc.
Systems	❖ Engineering economic analysis, ❖ Growth model, other Decision Support System


精緻農業高效節能植物工廠

ACE²S approach



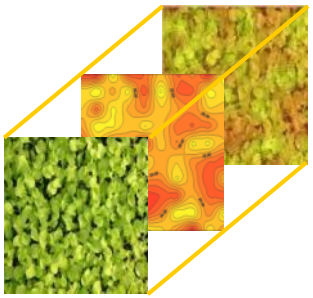
Automation
自動監控、感測器開發
量測分析

Culture
栽培管理
肥培管理
葉片分析
病蟲害防治

Environment
光風水養氣

Energy
隔熱/保溫
燈光/冷氣/運輸
節能/再生能源

Automation



各類監測裝置

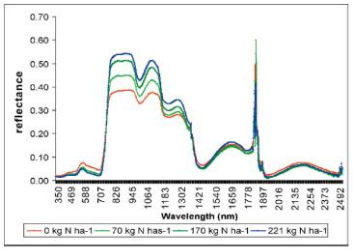


Figure 4: Canopy reflectance of wheat at various levels of preseason N using a spectroradiometer

影像監測系統

光照-CO_2
耦聯光合調控系統

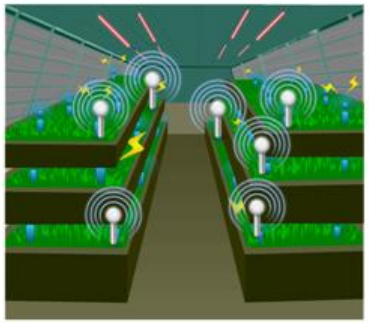
Microsoft .net

NATIONAL INSTRUMENTS LabVIEW

資料管理暨
系統監看平台

調溫控濕系統
營養液供給系統

WSN作物環境監測系統



Culture

青梗白菜

小白菜

萵苣

洋芫荽

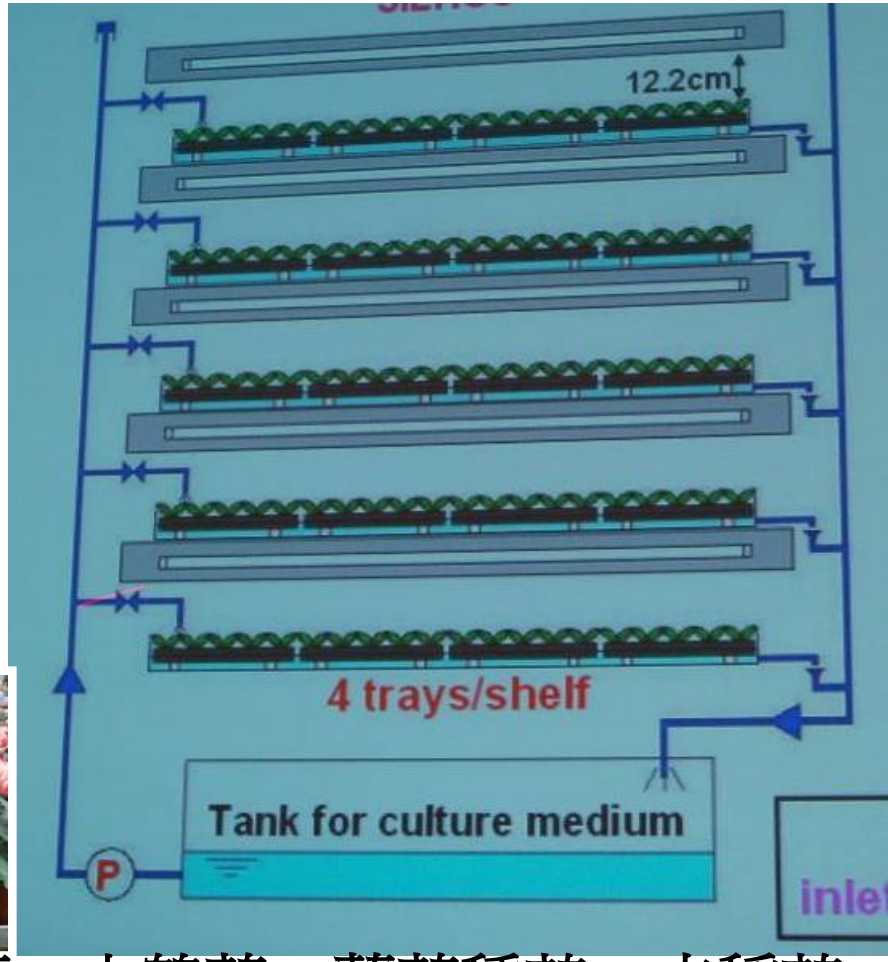
羅勒

菠菜

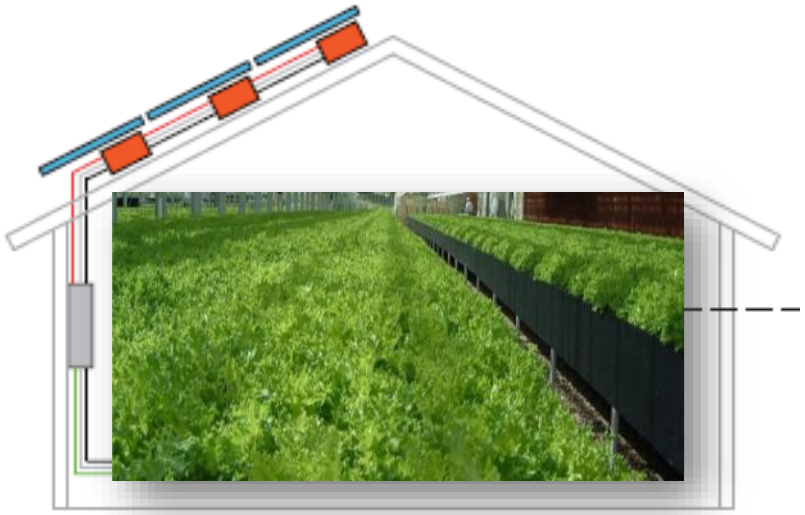
草莓

蕃茄

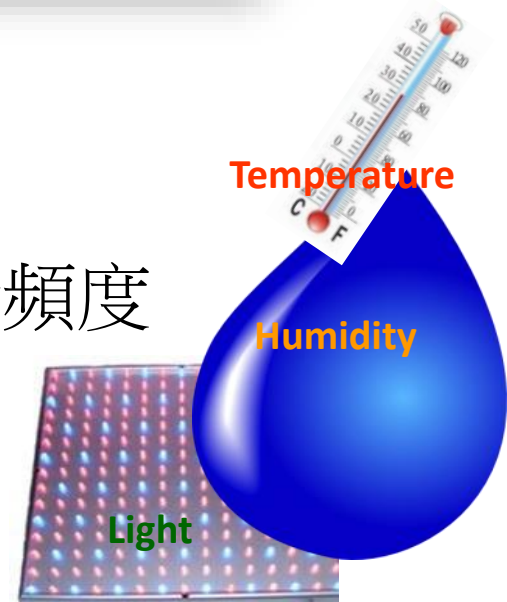
盆菊、粗肋草、火鶴花、蘭花種苗、水稻苗



Environment

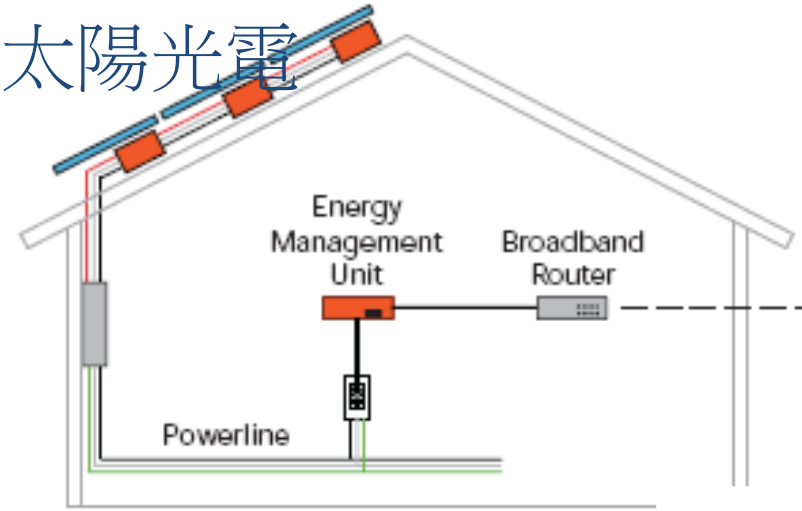


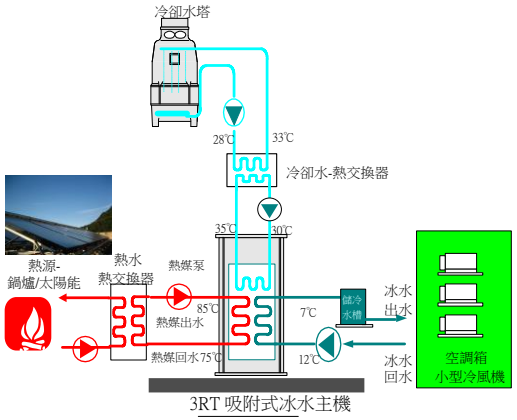
風：空氣溫、濕度、內循環風速
光：光量、光質、光週、均勻度
水：供給方式、供給時機、供給頻度
養：營養、供給方式/時機/頻度
氣：二氧化碳

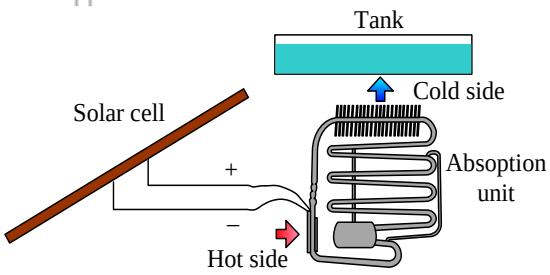


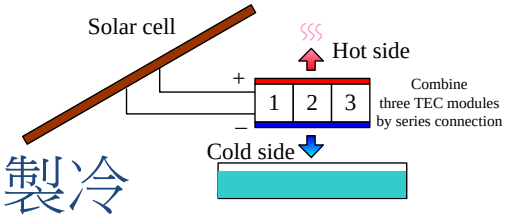
Energy

太陽光電

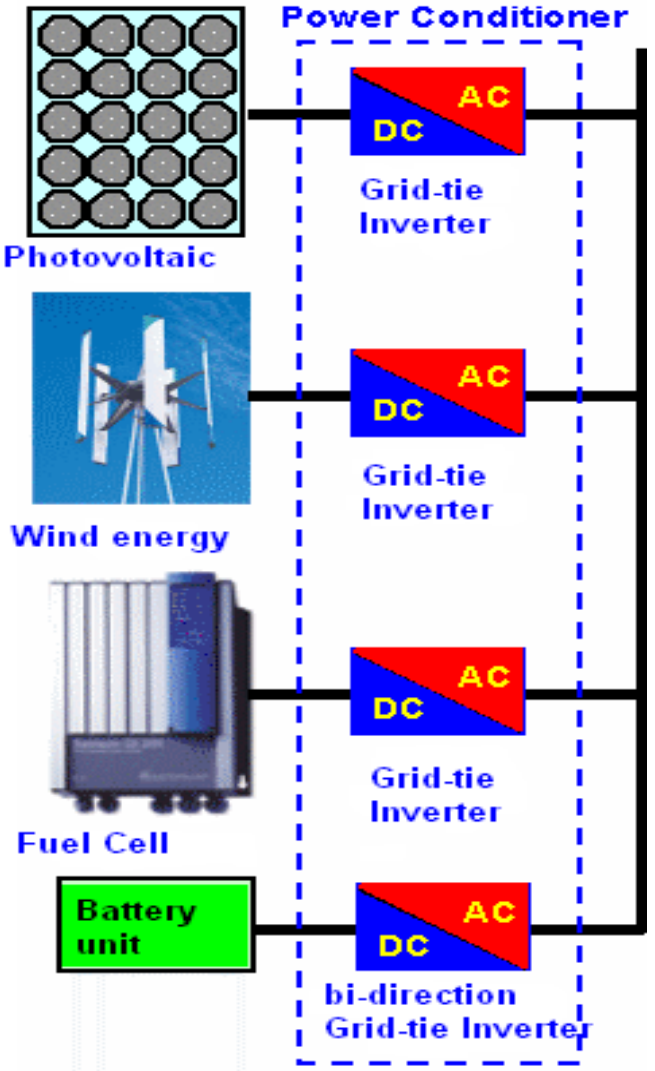








太陽電能製冷

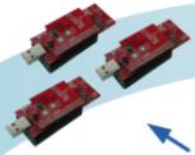


System

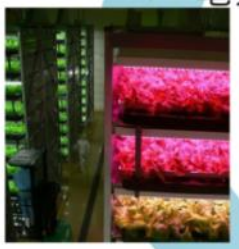
經營、管理
決策支援
行銷、市場

WSN環境監控系統
- 低功耗環控系統開發
- 植物工廠環境監控

作物栽植履歷資料庫
- 作物生長鑑別模型建立
- 植物工廠管理資料記錄

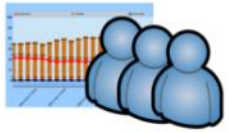


電力轉換系統



太陽能供電系統

電力儲存系統



管理人員監控系統
暨專家知識庫平臺
- 作物生長效率及產量分析
- 太陽能供電設備節能減碳分析
- 無線自動化設備控制
- 精緻農業－生產履歷建立
- 示範型集約植物工廠建立

植物工廠
- 節能式LED照明設施設計
- 高效能空調熱泵系統整合開發
- 水耕養液自動供給系統
- 立體化栽培系統發展

植物生長監控系統
- CCD影像監控系統開發
- 近紅外光檢測技術研究
- 植物生長模式建立與軟體設計

目標

- 節能最大化
- 節水最大化
- 減排最大化

- 產能最大化
- 品質最佳化
- 行銷最大化
- 利潤最大化
- ….

$$\text{Value} = \frac{\text{Capability}}{\text{Problem x Cost}}$$

電腦輔助系統工程

Computer Aided Systems Engineering C.A.S.E.

思考

- 如何建立一個電腦軟體，讓不同專業領域的人，都可以用此工具來建立簡報？

- 範例：想想 MS Powerpoint 軟體的架構

思考

- 如何建立一個電腦軟體，讓不同專業領域的人，都可以用此工具來激發創意，進而創造發明 ？
- 如何濃縮整理既有的專利發明，物理、化學、數學等定律、法則與公式?
- 如何濃縮整理前人的經驗，演化的法則，進步的軌跡，歷史的規律?
- 範例：Triz、AskNature、ChatGPT

Triz (week6)

發明創造相關的

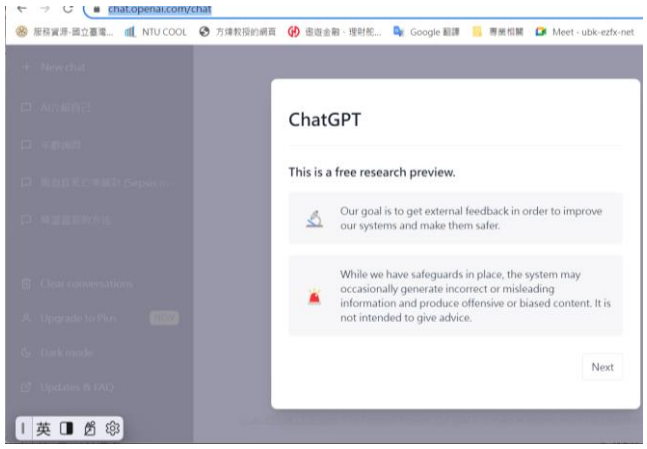
- 靈感來源
- 專利與文獻資料的彙整

AskNature (week9)

台灣仿生協會

ai.com

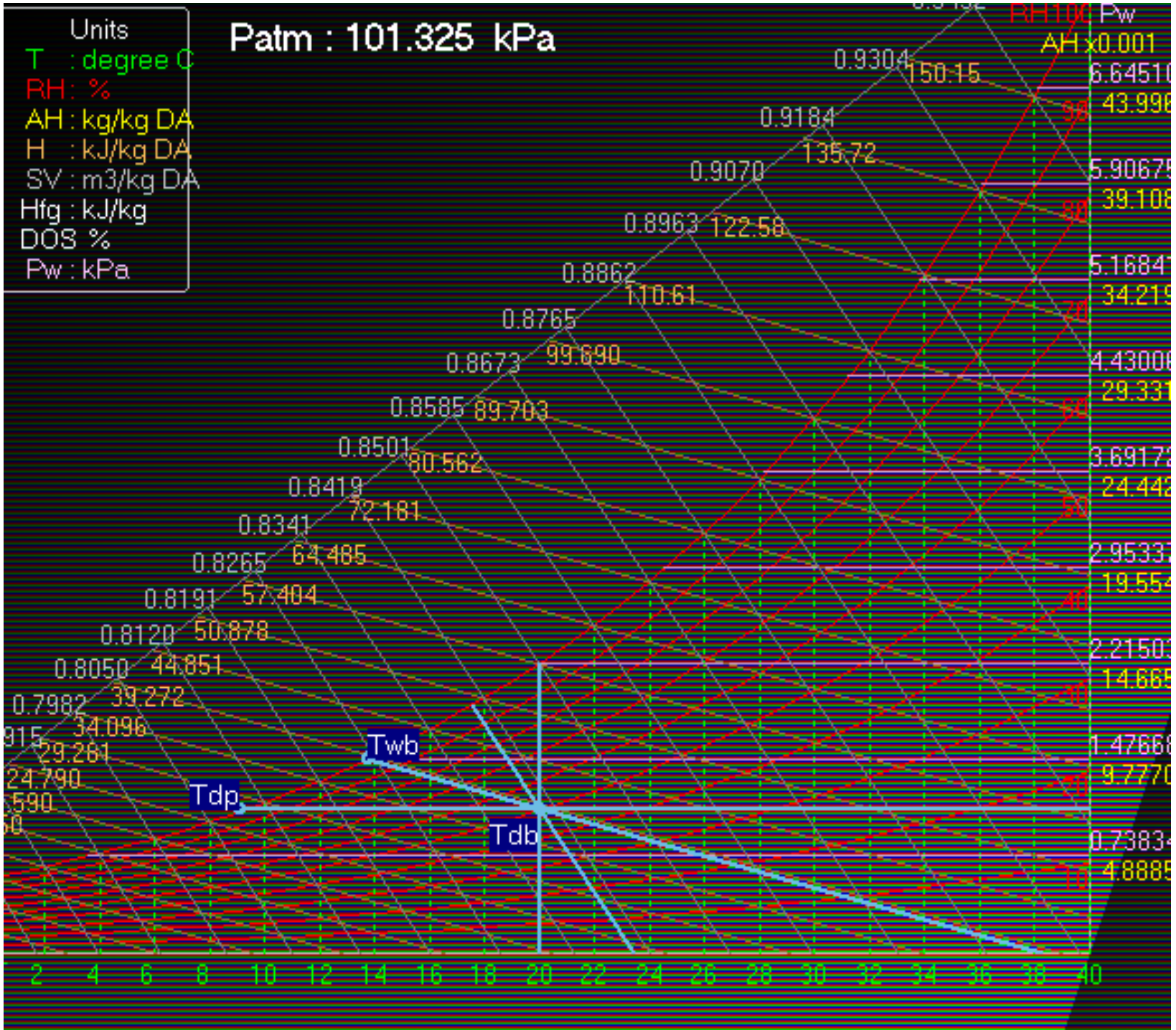
ChatGPT

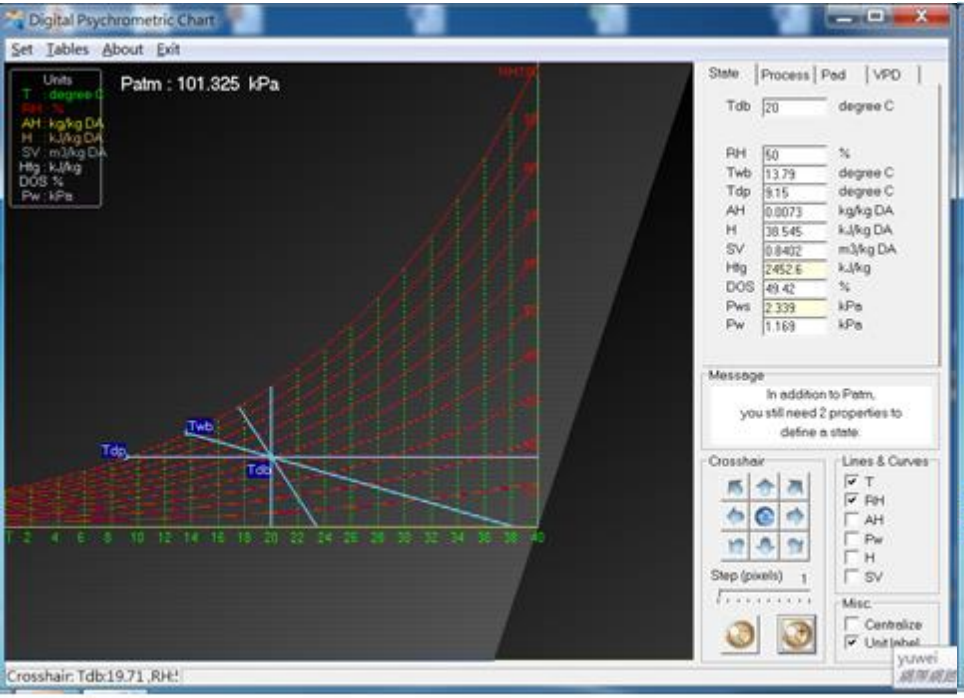


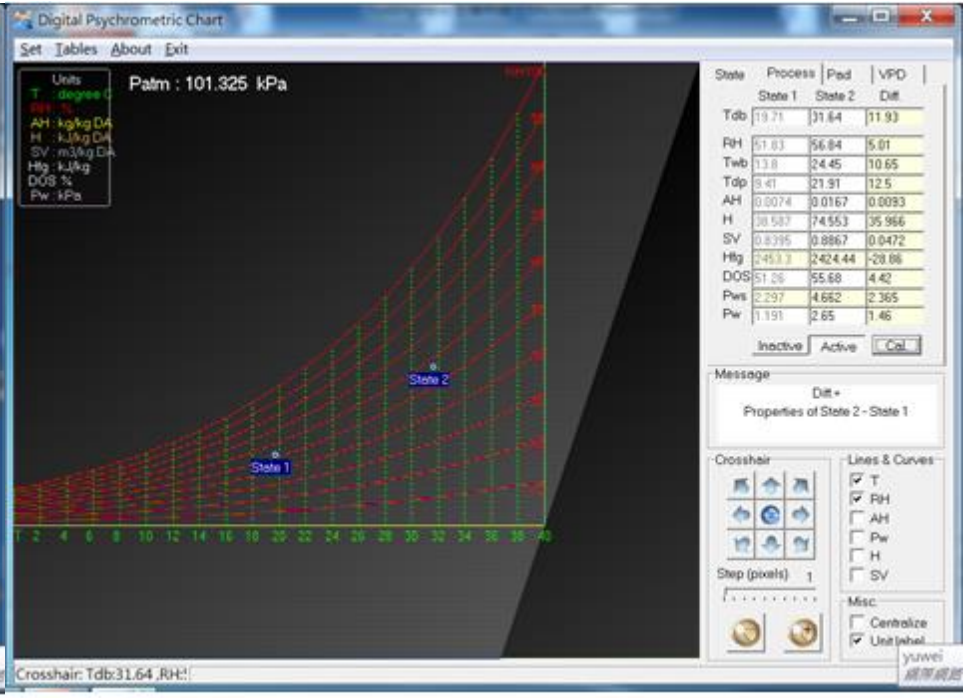
思考

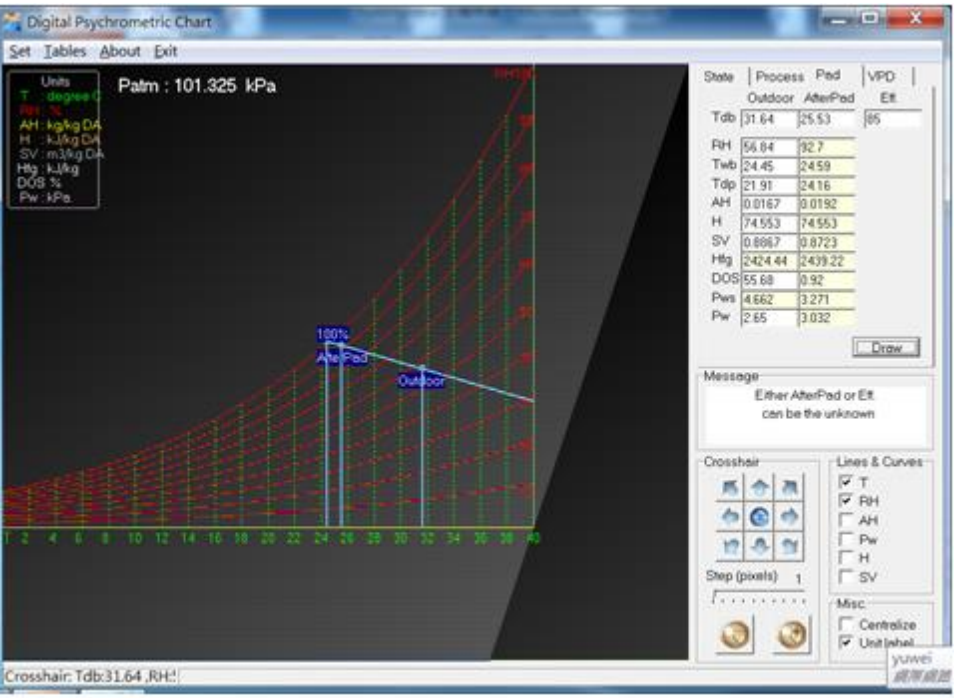
- 如何彙整所有的空氣熱力學性質?
- 如何才能方便查詢? 方便使用?

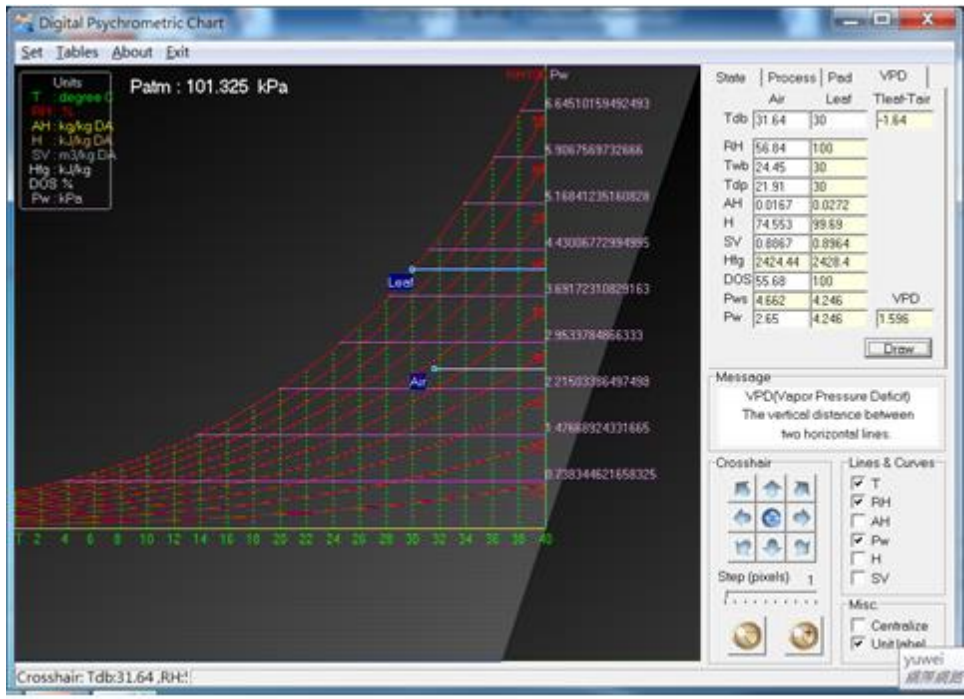
- 範例：
  - 濕空氣熱力特性圖 (熱力學教科書)
  - Psychart 軟體 (方，1996)


Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS %
Pw : kPa
Patm : 101.325 kPa
RH 10
Pw
AH x0.001
0.9304
150.15
0.9184
135.72
0.9070
0.8963
122.58
0.8862
110.61
0.8765
99.690
0.8673
0.8585
89.703
0.8501
80.562
0.8419
72.181
0.8341
64.485
0.8265
57.404
0.8191
50.878
0.8120
44.851
0.8050
39.272
0.7982
34.096
29.261
24.790
Twb
Tdp
Tdb
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40


Digital Psychrometric Chart
Set Tables About Exit
Patm : 101.325 kPa
Twb
Tdp
Tdb
State Process Pad VPD
Tdb 20 degree C
RH 50 %
Twb 13.79 degree C
Tdp 9.15 degree C
AH 0.0073 kg/kg DA
H 38.545 kJ/kg DA
SV 0.8402 m3/kg DA
Htg 2452.6 kJ/kg
DOS 49.42 %
Pws 2.339 kPa
Pw 1.169 kPa
Message
In addition to Patm,
you still need 2 properties to
define a state
Crosshair
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 1
Misc.
Centralize
Crosshair: Tdb:19.71 ,RH:


Digital Psychrometric Chart
Set Tables About Exit
Patm : 101.325 kPa
State 1
State 2
State Process Pad VPD
State 1 State 2 Diff
Tdb 19.71 31.64 11.93
RH 51.83 56.84 5.01
Twb 13.8 24.45 10.65
Tdp 9.41 21.91 12.5
AH 0.0074 0.0167 0.0093
H 38.587 74.553 35.966
SV 0.8395 0.8867 0.0472
Htg 2453.3 2424.44 -28.86
DOS 51.26 55.68 4.42
Pws 2.297 4.662 2.365
Pw 1.191 2.65 1.46
Inactive Active Cal
Message
Diff =
Properties of State 2 - State 1
Crosshair
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 1
Misc.
Centralize
Crosshair: Tdb:31.64 ,RH:


Digital Psychrometric Chart
Set Tables About Exit
Patm : 101.325 kPa
100%
AfterPad
Outdoor
State Process Pad VPD
Outdoor AfterPad Eff
Tdb 31.64 25.53 85
RH 56.84 92.7
Twb 24.45 24.59
Tdp 21.91 24.16
AH 0.0167 0.0192
H 74.553 74.553
SV 0.8867 0.8723
Htg 2424.44 2439.22
DOS 55.68 0.92
Pws 4.662 3.271
Pw 2.65 3.032
Draw
Message
Either AfterPad or Eff
can be the unknown
Crosshair
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 1
Misc.
Centralize
Crosshair: Tdb:31.64 ,RH:


Digital Psychrometric Chart
Set Tables About Exit
Patm : 101.325 kPa
Leaf
Air
Pw
6.645101594924 93
5.906756973266 86
5.168412351608 28
4.430067729948 95
3.691723108291 63
2.953378486633 3
2.215033864974 98
1.476689243316 65
0.738344621658325
State Process Pad VPD
Air Leaf Tleaf-Tair
Tdb 31.64 30 -1.64
RH 56.84 100
Twb 24.45 30
Tdp 21.91 30
AH 0.0167 0.0272
H 74.553 99.69
SV 0.8867 0.8964
Htg 2424.44 2428.4
DOS 55.68 100
Pws 4.662 4.246
Pw 2.65 4.246
VPD
1.596
Draw
Message
VPD(Vapor Pressure Deficit)
The vertical distence between
two horizontal lines
Crosshair
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 1
Misc.
Centralize
Crosshair: Tdb:31.64 ,RH:

結論

- 不自我設限：觸類旁通、異中求同、同中求異
- 資源有限
- 最佳化利用
- 如何評估?
  - 工程經濟是基礎
  - 善用工具、善用資源
- Do more with less 才是專業
- 態度決定一切

課程大綱

- Mindset (態度)
- 工程經濟 (Engineering Economic)
- 最佳化 (optimization)
- Triz 簡介 (創造發明工具庫)
- 學與思
  - 學習如何學習：快速記憶的技巧，向大自然學習 (生物模擬)
  - 思考如何思考：了解你的思考模式
- 應用範例：
  - ACESys相關：農業、溫室產業、養殖業、植物工廠
  - 跨領域：LED在生物產業應用，水產業，空調熱泵與其在生物產業應用
  - MIT 校友 24 步驟創三萬家公司
- 另類系統工程：
  - 河圖、洛書、八卦與魔術方陣
  - 系統工程看中醫

生機系核心課程
每學年下學期開課
歡迎修課或旁聽