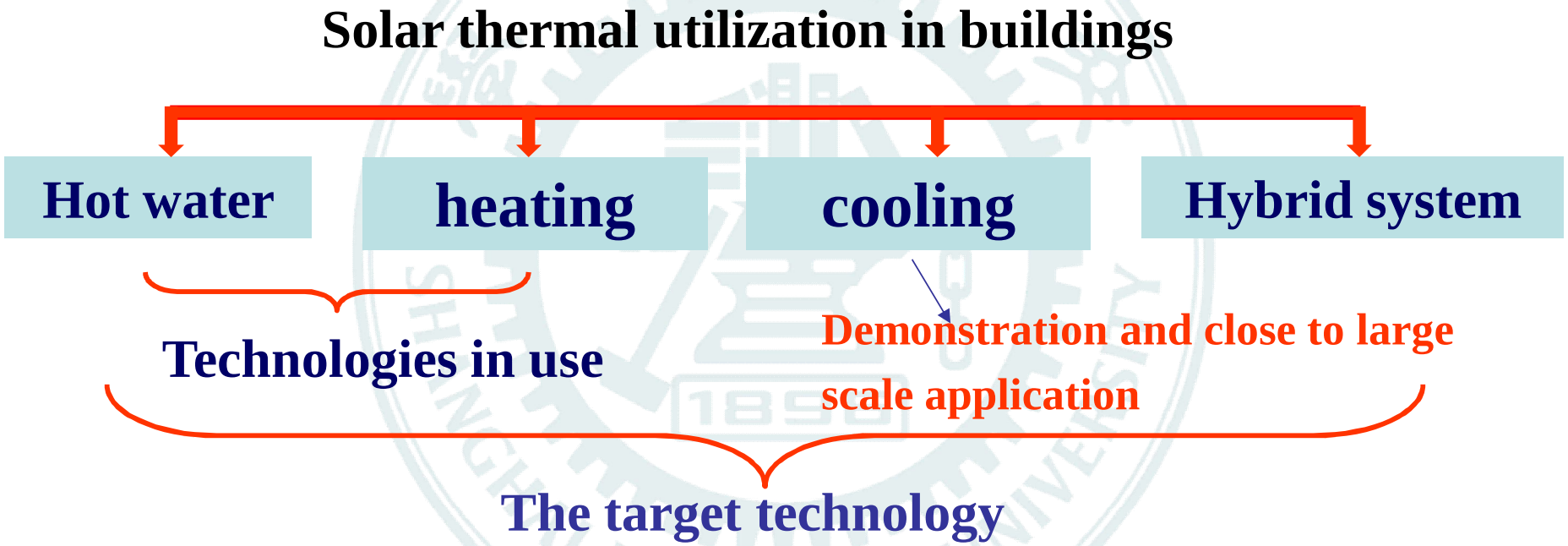
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Solar driven Air Conditioning & Refrigeration Systems corresponding to various heating source temperatures

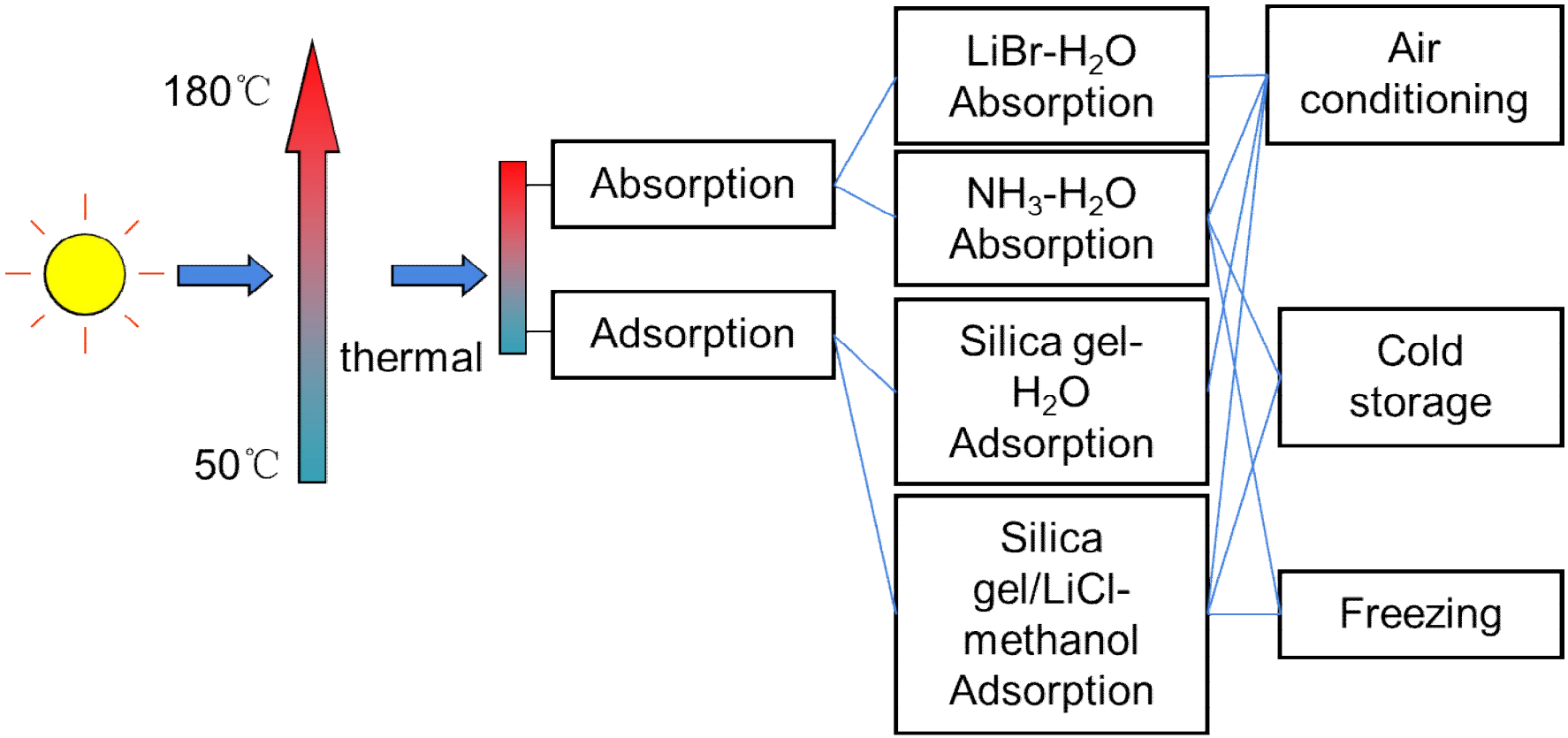
Ruzhu Wang

Institute of Refrigeration and Cryogenics
Shanghai Jiao Tong University

Solar thermal application in buildings



Backgrounds



Major technologies in SJTU

Adsorption chiller(2004)

Adsorption ice maker(2008)

Single effect LiBr-water absorption(2009)

Rotary desiccant cooling(2007)

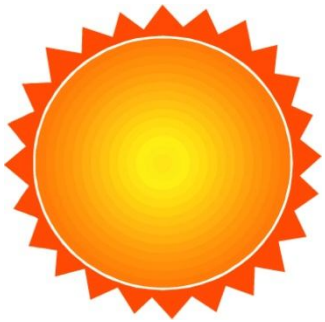
Two stage desiccant cooling(2009)

Single/Double effect LiBr-water(2012)

New R&D Progresses in 2013-2014

1.Modular silica gel-water adsorption chiller (55°C -90°C)

5.Ammonia water absorption ice maker with perfect internal heat recovery (140°C -170°C)



2.Single /double effect LiBr-water absorption chiller (80°C-95°C for solar cooling with fossil fuel as backup)

4.$CaCl_2$/AC-ammonia adsorption refrigerator (100°C -140°C)

3.The 1.n effect LiBr-water absorption chiller (90 °C-135°C)

1. Modular silica gel-water adsorption chiller

1.Modular silica gel-water adsorption chiller (55°C -90°C)

1.1. Appearance

Cooling power: 50kW

Size: 2.7m×2.1m×2m

Design COP: 0.4~0.6

Designed by

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Manufactured by

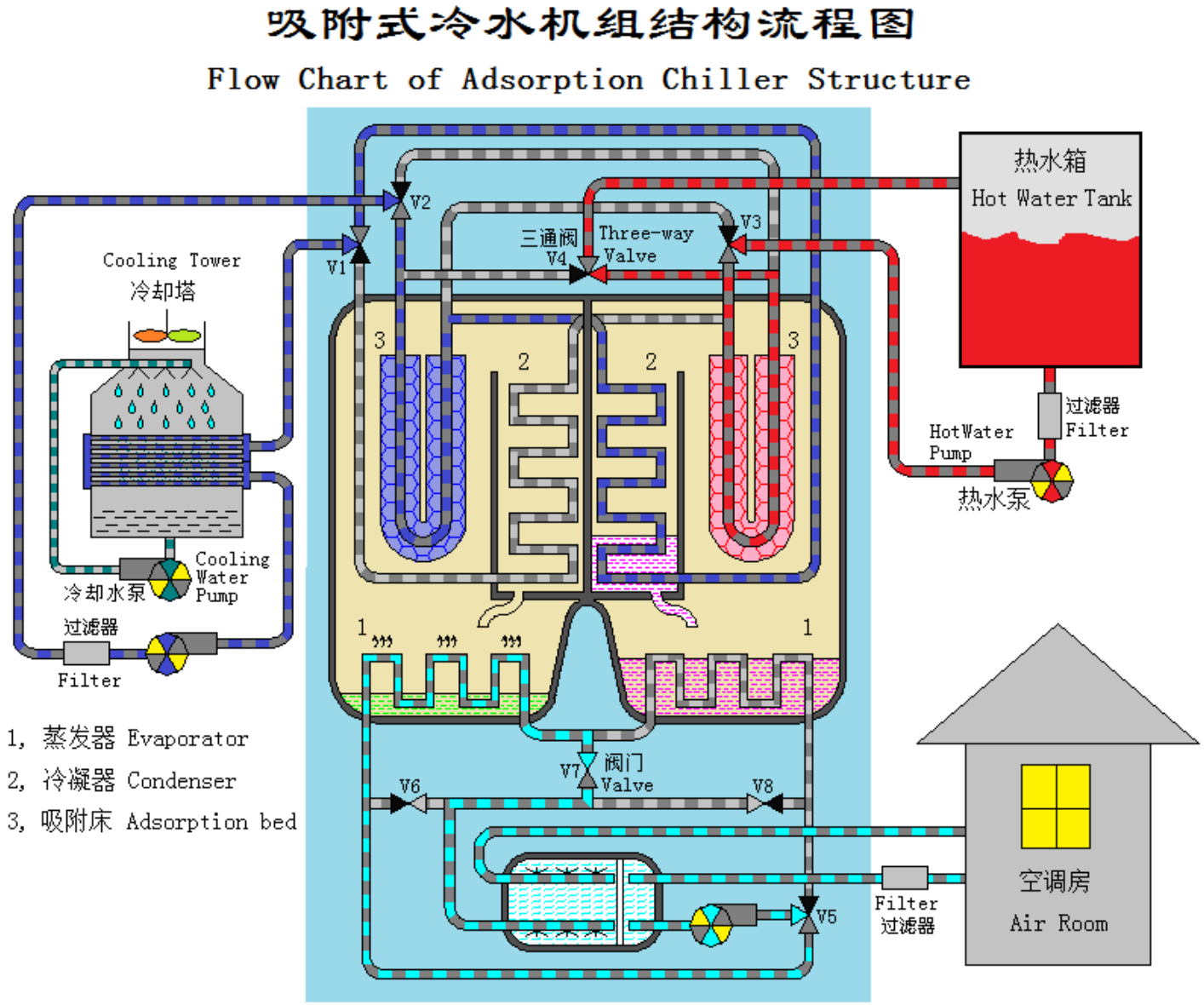
禄禧新能源科技
Lucy New Energy Technology

No.1

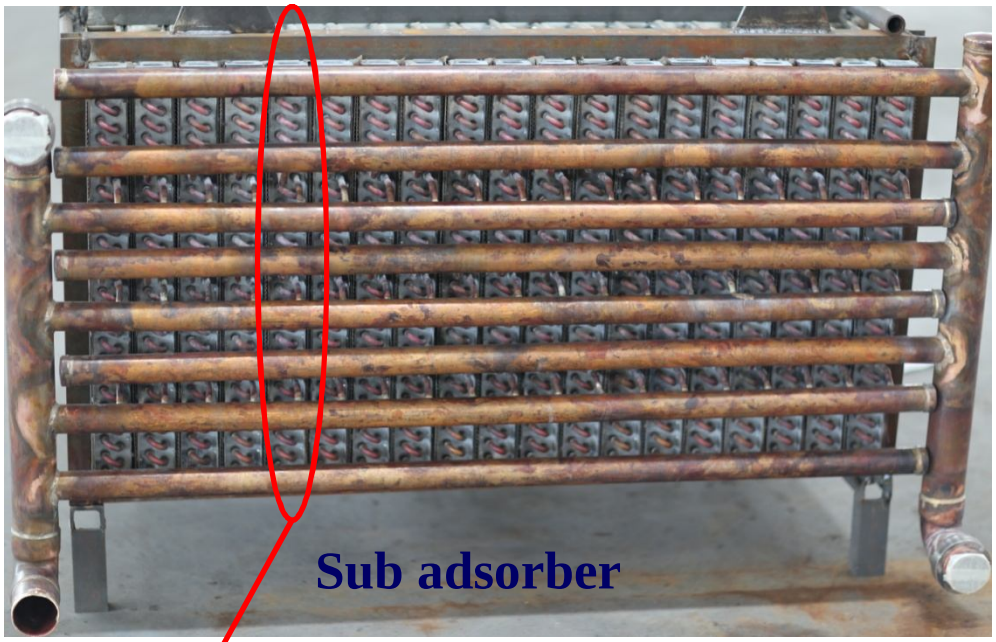
No.2

1.2. System Schematic

- 2 adsorbers
- 2 condensers
- 2 evaporators
- 8 valves
- 1 chiller water pump
- 1 chiller water tank



1.3. Modular design of adsorber



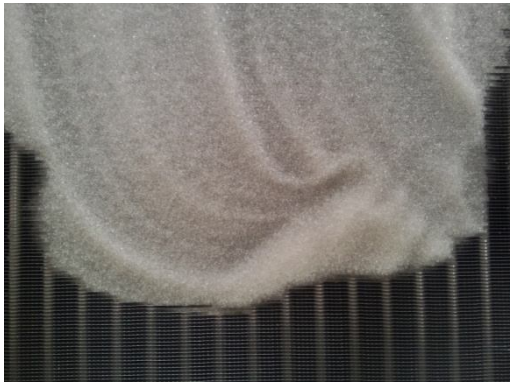
Fin-tube type

19 independent sub adsorbers

Adsorbent: 342kg

Heat transfer area: 22 m^2

Fin-tube unit

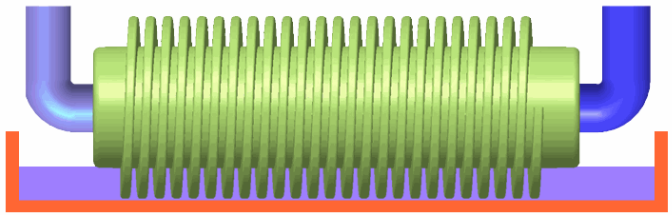


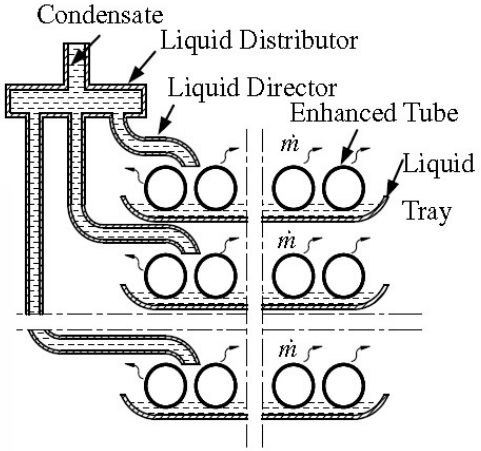
Packing adsorbent

Assembly

1.4. Condenser & Evaporator

- **Condenser**
  - **Shell-tube type**





- **Evaporator**
  - **Shell-tube type**
  - **Capillary-assisted evaporation**

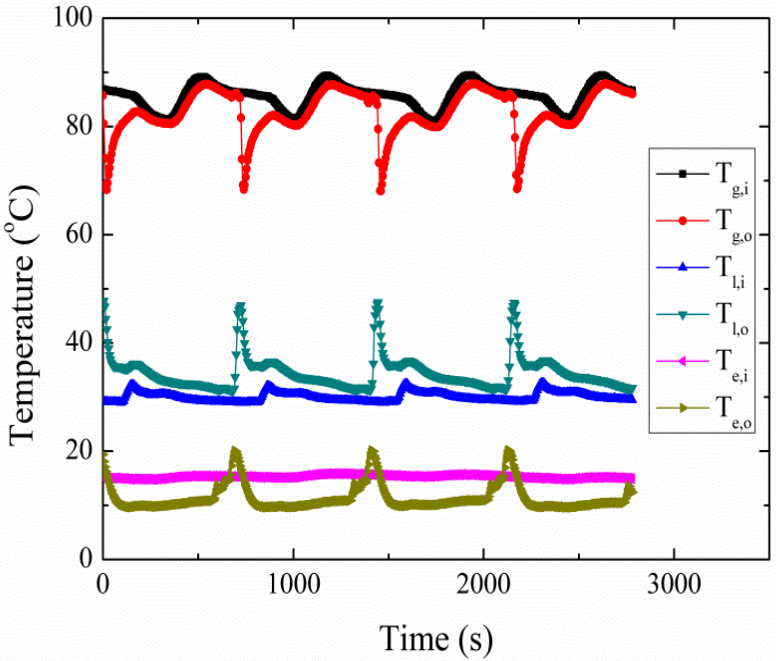
Capillary-assisted evaporation

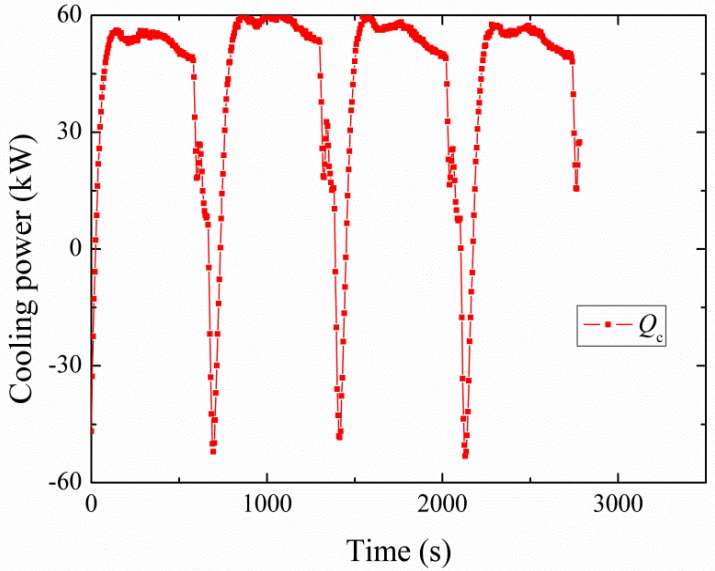
Condenser

Evaporator

[WRT]应该按照一个吸附床吸附剂质量计算

System performances Tests

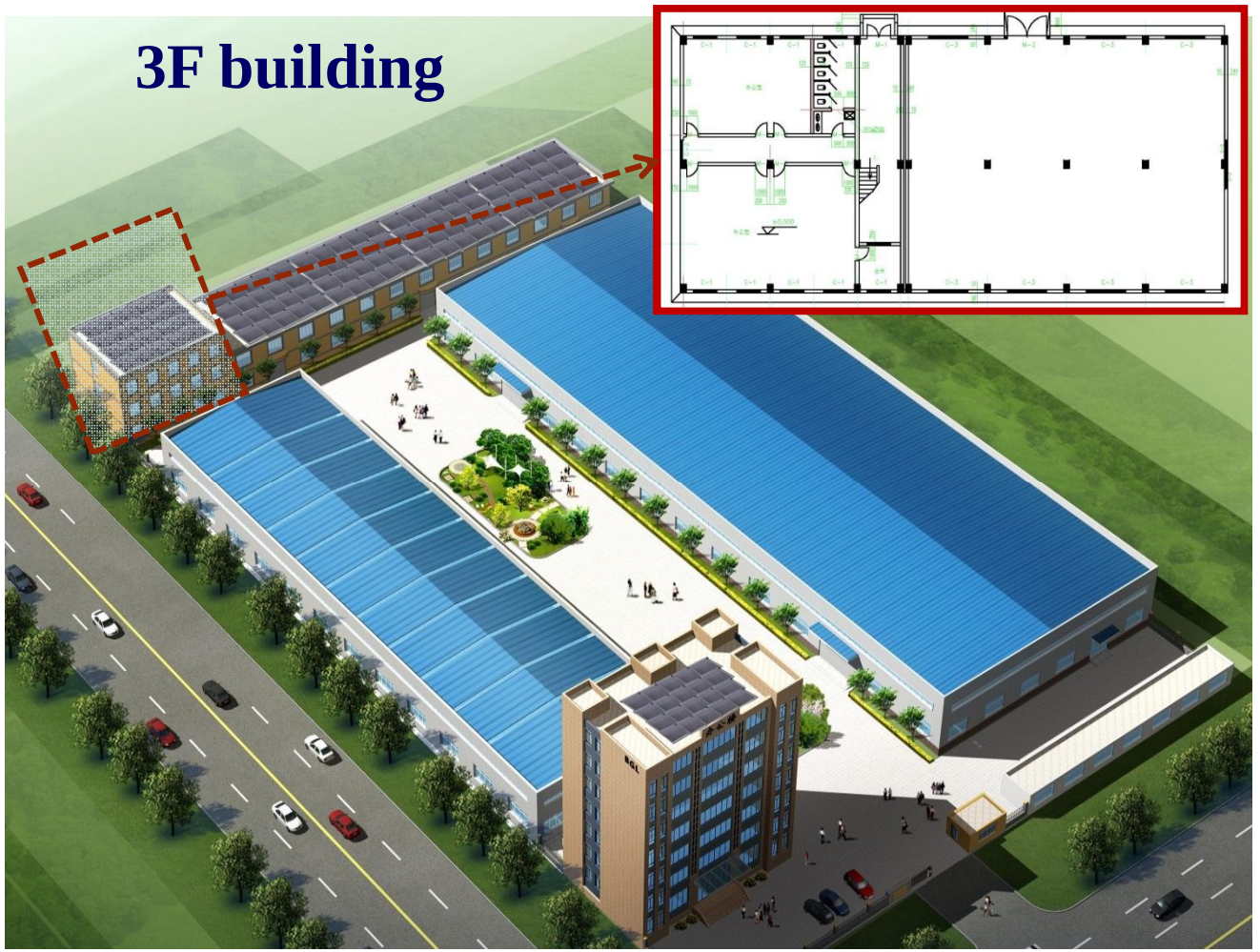




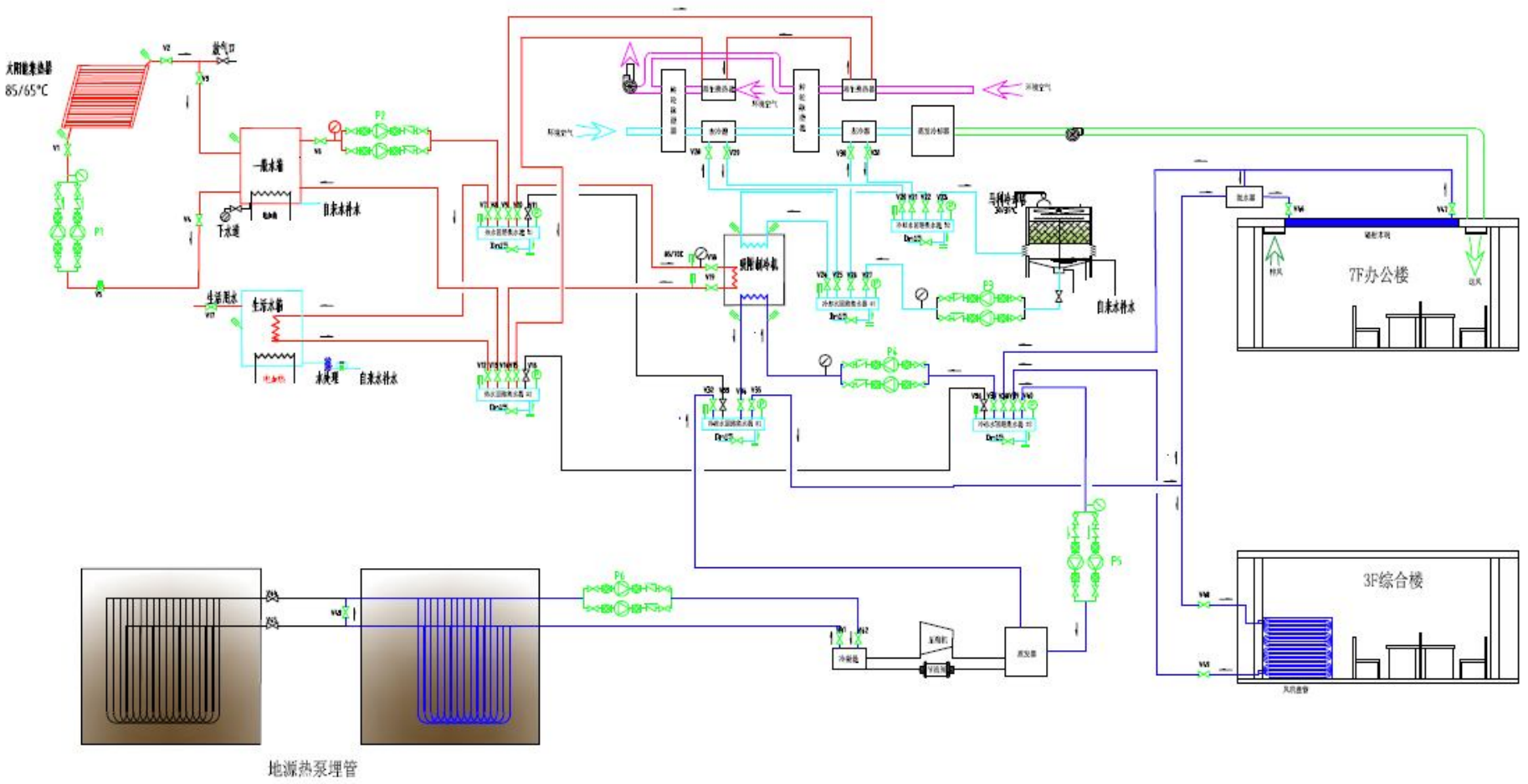
No.	$T_{g,I}$ oC	$T_{l,I}$ oC	$T_{e,o}$ oC	Q_e ,*kW*	*COP*	*SCP* (W/kg)
1	85.87	29.84	11.19	41.1	0.515	120
2	85.41	30.28	9.13	29.6	0.344	86
3	82.17	32.14	14.74	50.1	0.627	140
4	61.82	29.42	13.16	17.1	0.358	50
5	85.77	29.97	11.50	40.9	0.431	120

1.5. Application

- Solar heating and cooling system in Shandong Auhua New Energy Co., Ltd.



System design (Sino – Denmark joint Project)



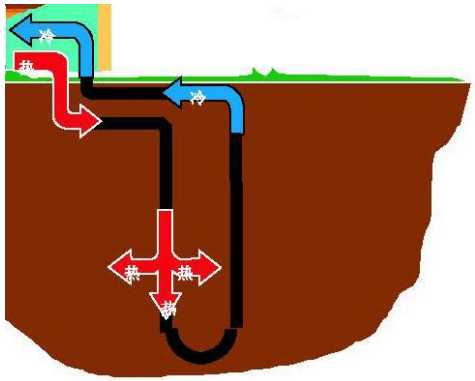
Systems involved

- Solar heating and cooling system in Shandong Auhua New Energy Co., Ltd.

Solar heating system
1300 m2

Adsorption chiller

Office
3000 m2



Ground source system

2. Single /double effect LiBr-water absorption chiller

2.Single /double effect LiBr-water absorption chiller (80°C-95°C for solar cooling with fossil fuel as backup)

2.1. System schematic

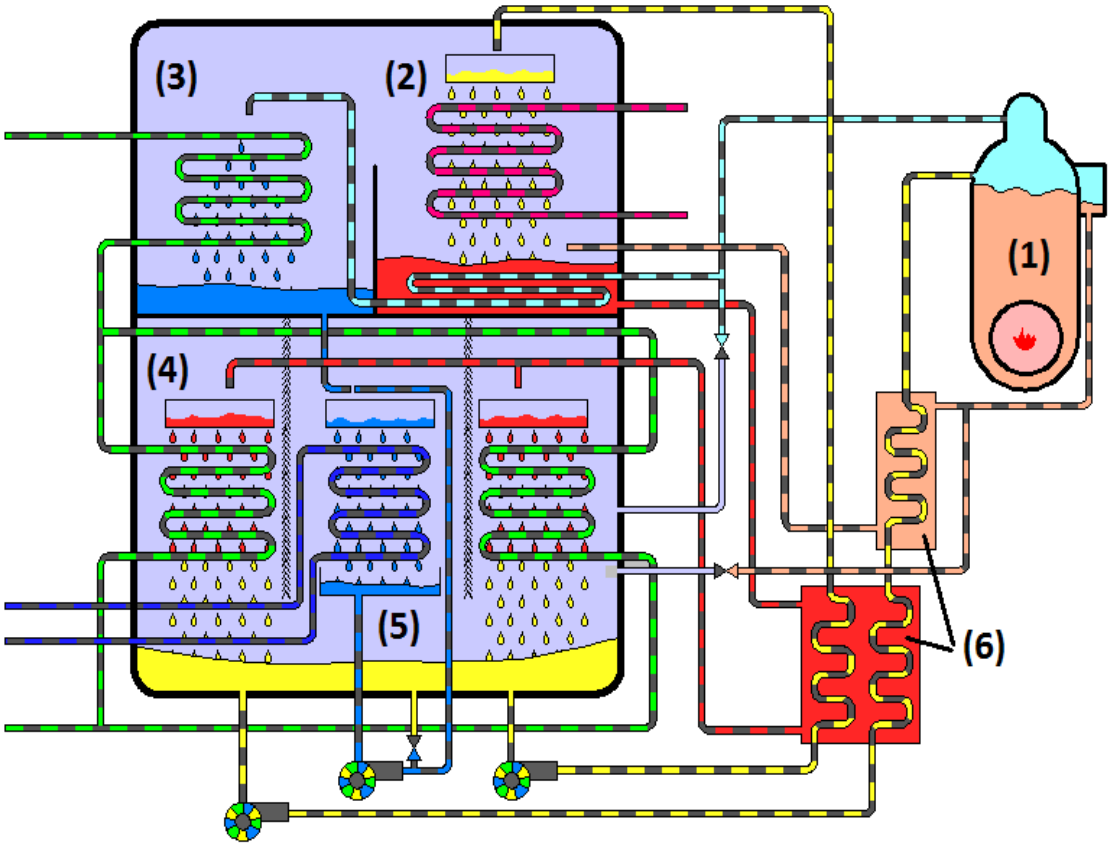
(1) High pressure generator

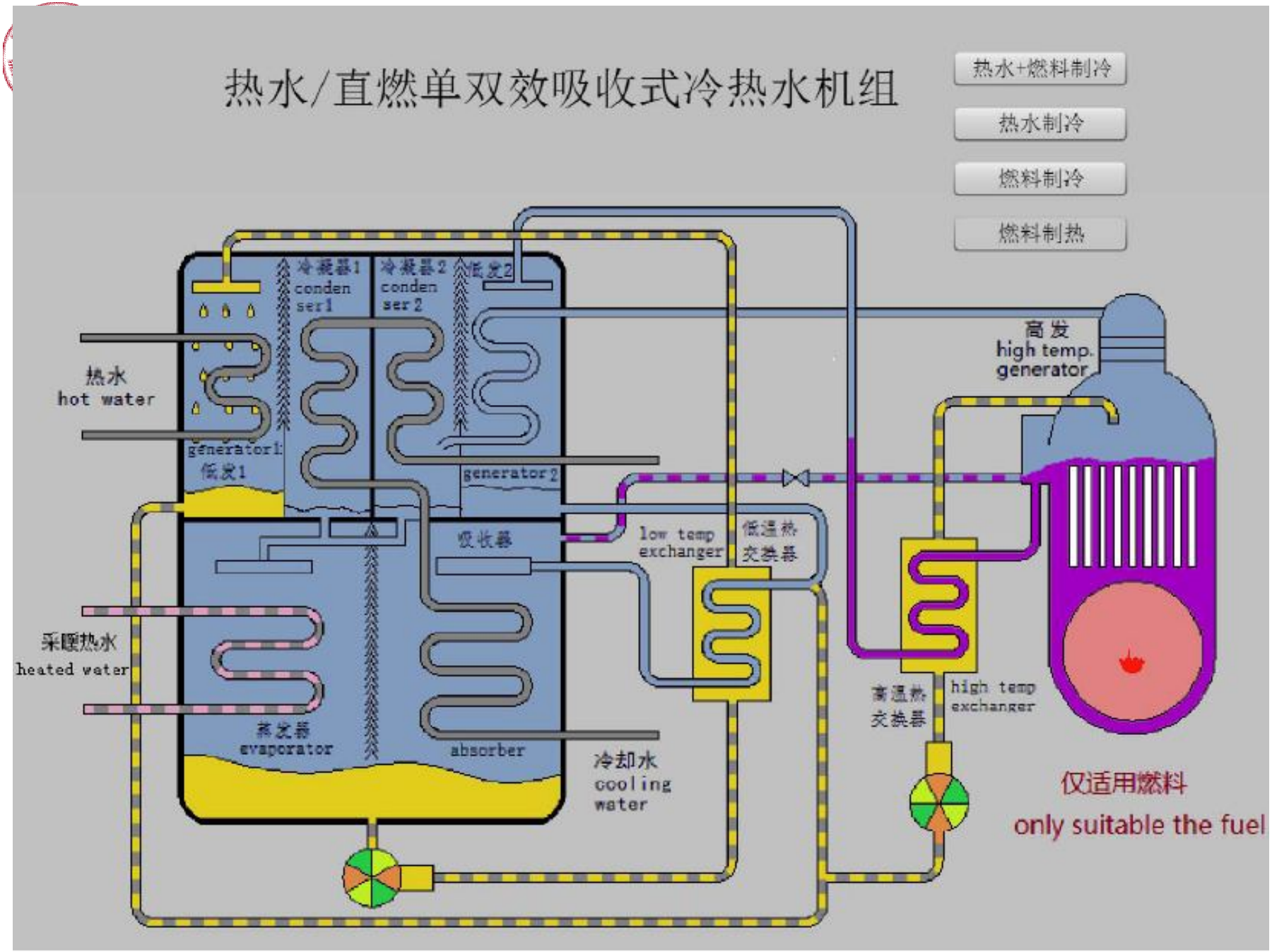
(2) Low pressure generators
(falling film-single effect
pool boiling-double effect

(3) Condenser

(4) Absorber

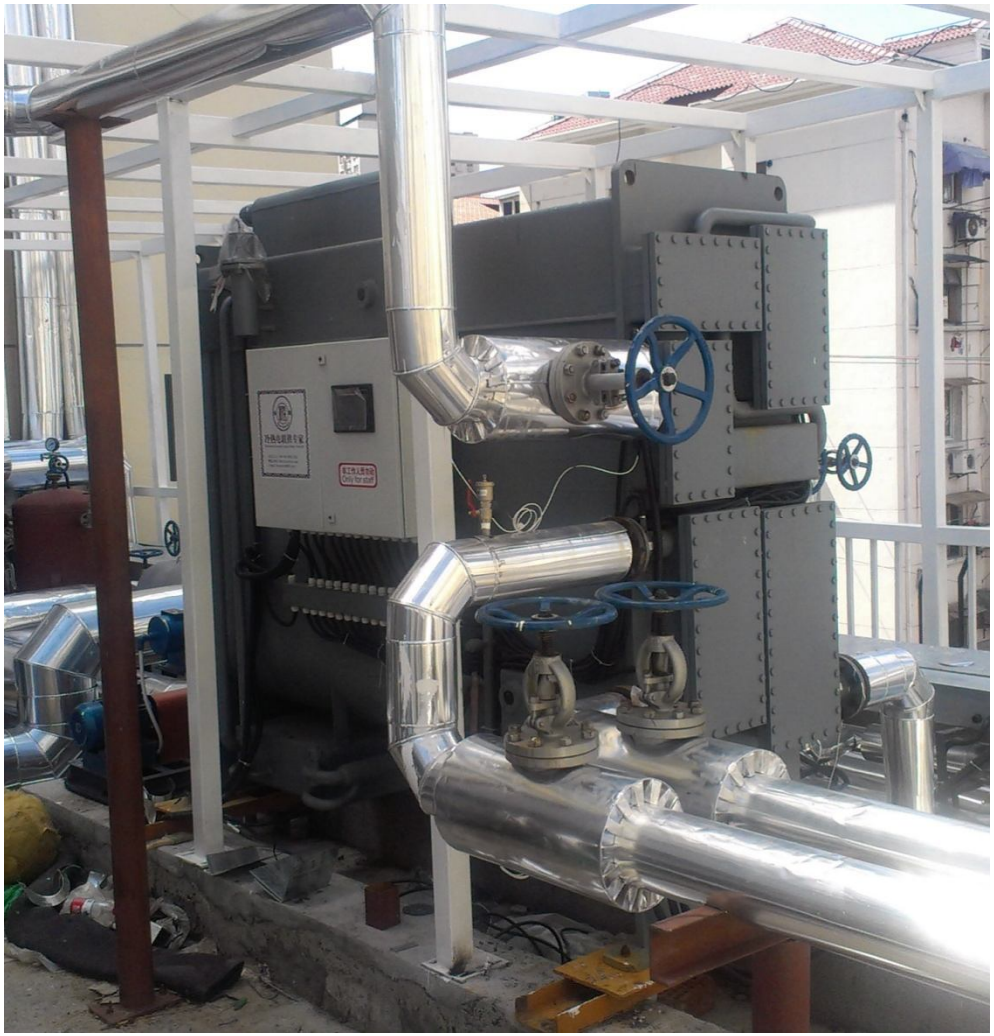
(5) Evaporator




热水/直燃单双效吸收式冷热水机组
热水+燃料制冷
热水制冷
燃料制冷
燃料制热
冷凝器1
conden
ser1
冷凝器2
conden
ser2
低发2
高发
high temp.
generator
热水
hot water
generator1
低发1
generator2
吸收器
low temp
exchanger
低温热
交换器
采暖热水
heated water
蒸发器
evaporator
absorber
冷却水
cooling
water
高温热
交换器
high temp
exchanger
仅适用燃料
only suitable the fuel

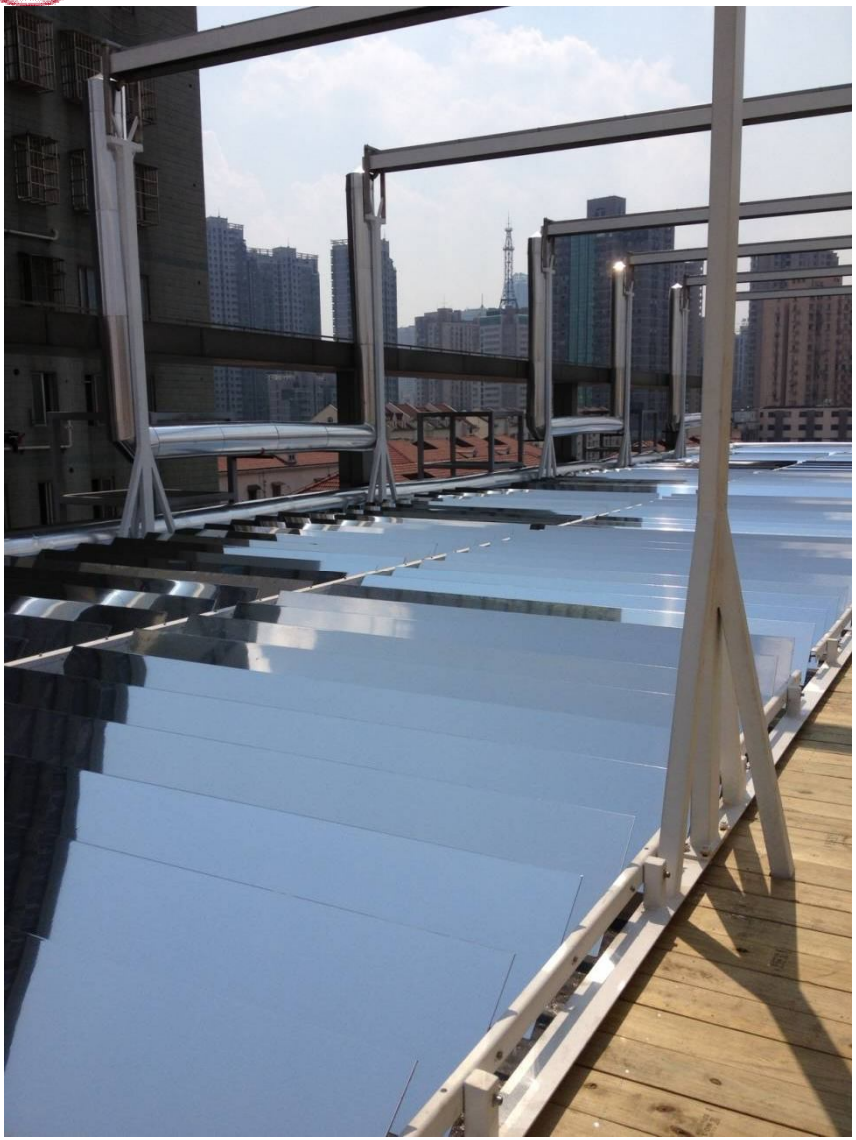
Example 1: Solar driven single/double effect absorption cooling system with Fresnel collector

pipings



Single / double effect absorption cooling

Fresnel solar collector

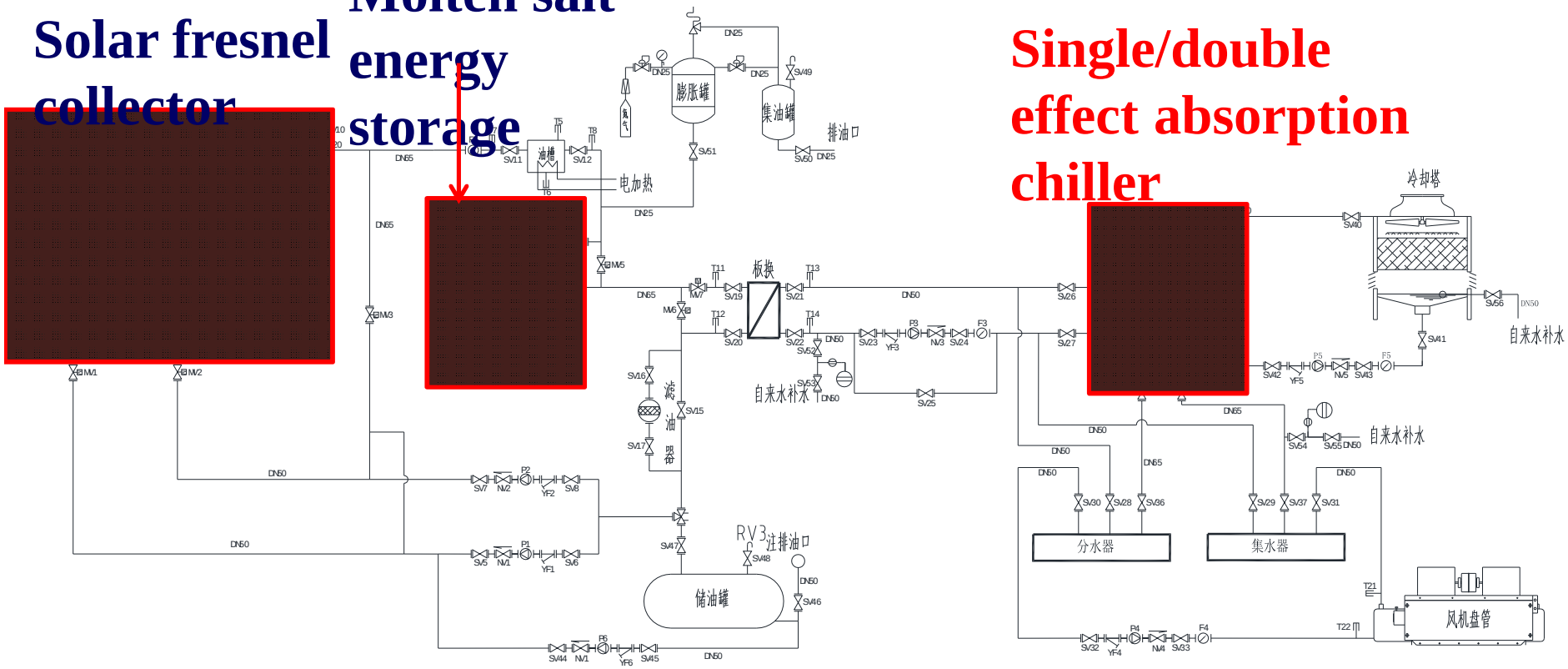


Solar cooling in Shanghai Electric Co.

Solar fresnel collector

Molten salt energy storage

Single/double effect absorption chiller

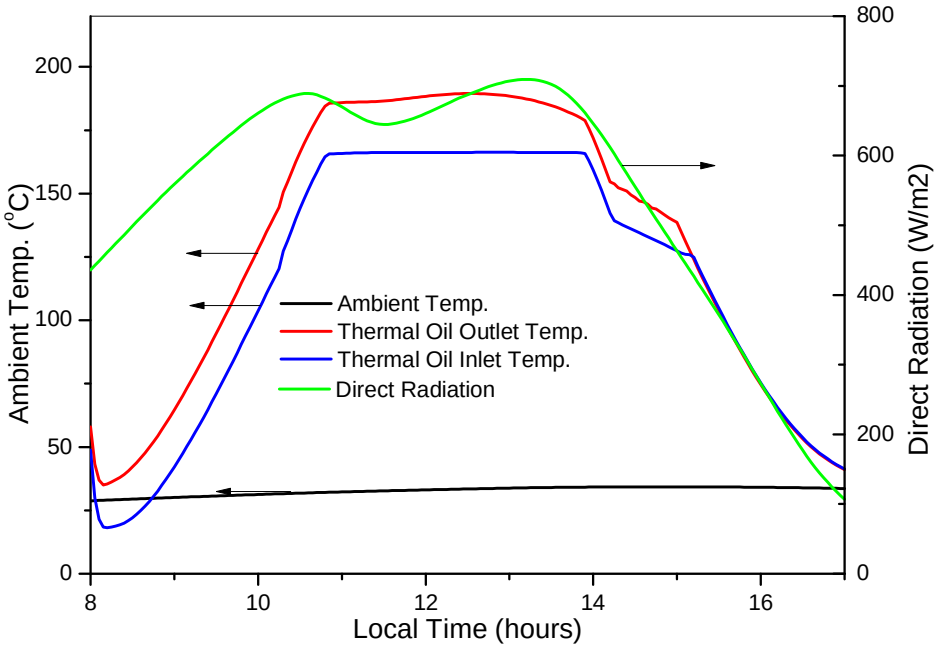


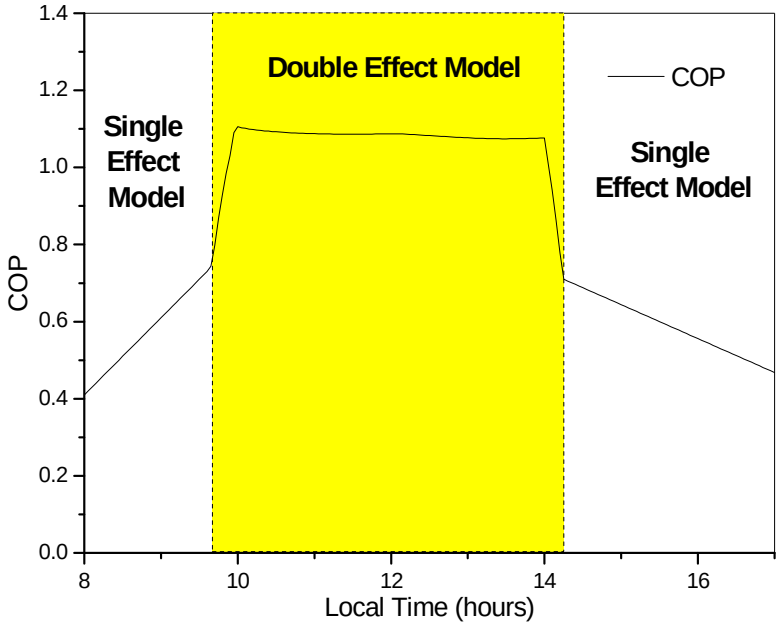
- 550 m2 Fresnel solar collector; (150 ~ 200℃
- Salt thermal energy storage (PCM, 146℃)
- Double/Single effect absorption chiller(100kW)

Single/double LiBr-water chiller

		double effect	Single effect
Cooling capacity		134 kW	91 kW
Hot water	Flow rate	11.0 m^3/h	
	Inlet/Outlet Temp.	150 /140 ^oC	105/95 ^oC
Cold water	Flow rate	23.0 m^3/h	
	Inlet/Outlet Temp.	12/7 ^oC	12/8.4 ^oC
Cooling water	Flow rate	44 m^3/h	
	Inlet/Outlet Temp.	31/36 ^oC	31/35.3 ^oC

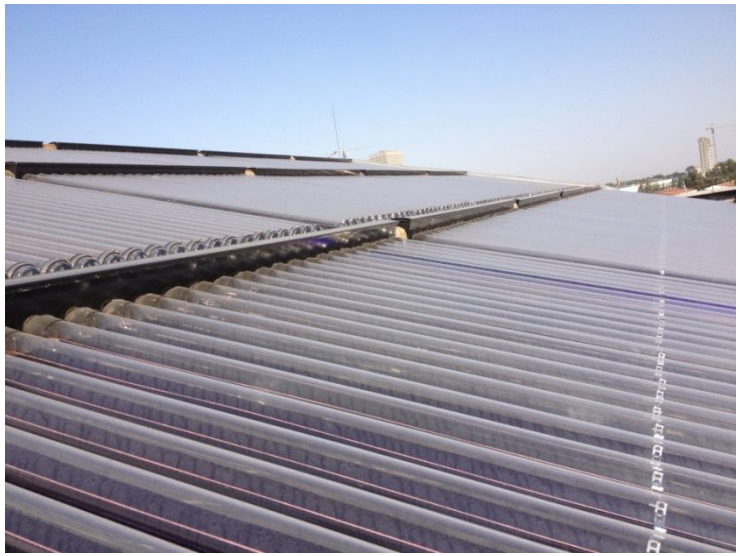
Performance analysis

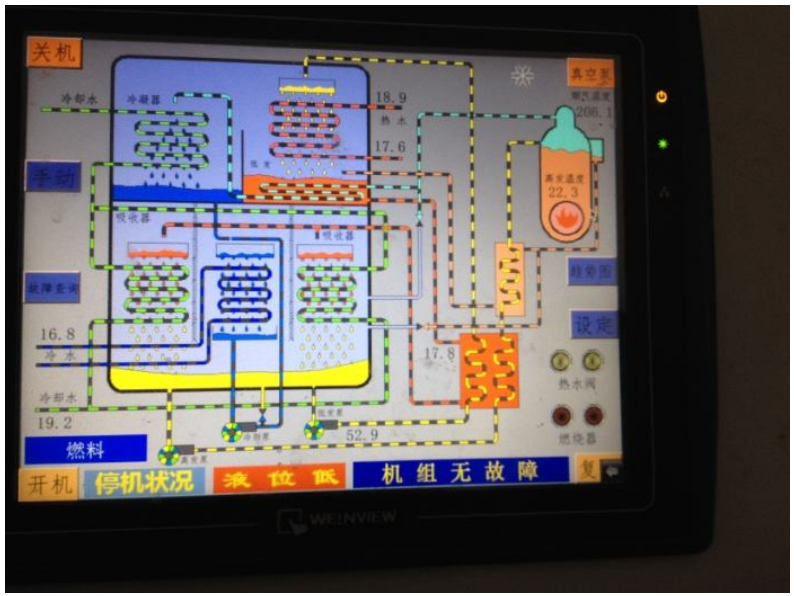




- **Under sunny days，double effect mode from 10am -14 pm**
- **Single effect mode for the other time.**
- **Daily average COP is about 0.8**
- **Cooling production for 6-8 hours**

Example 2: Single/double effect LiBr-water Chiller （ Changle hotel, Shandong ）





Chiller Parameters

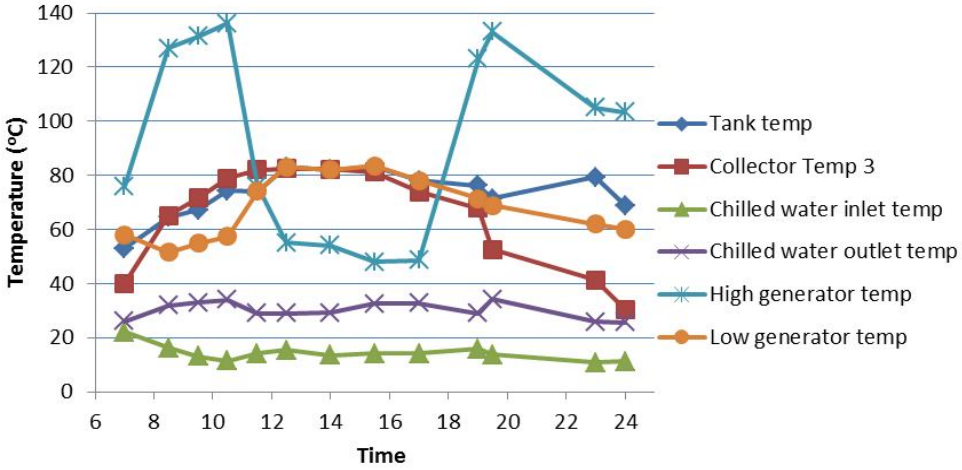
Gas firing driven cooling power	1280 kW	**Solar driven cooling power**	320 kW
Gas firing driven heating capacity	1066 kW	**Temperature for heating output**	55-60^{o}C
Chilled water temperature (in-out)	12 -7^{o}C	**Chilled water flow rate (in-out)**	220 t/h
Chilled water pressure drop	90 Pa	**Cooling water temperature**	32-37^{o}C
Cooling water flow rate	343 t/h	**Cooling water pressure drop**	69 Pa
Hot water temperature (in-out)	90 -84^{o}C	**Hot water flow rate**	61 t/h
Hot water pressure drop	70 Pa	**Power of refrigerant pump**	0.75kW
Low pressure generating pump power	0.75 kW	**High pressure generating pump power**	3.7 kW

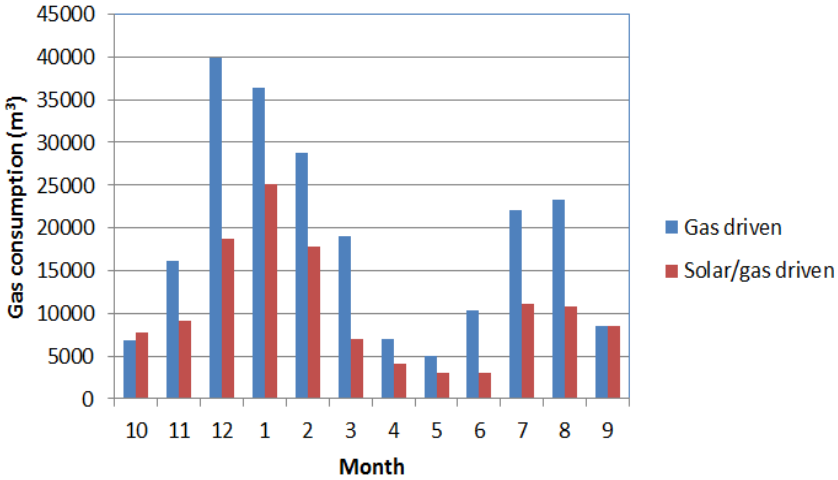
Operation of the system

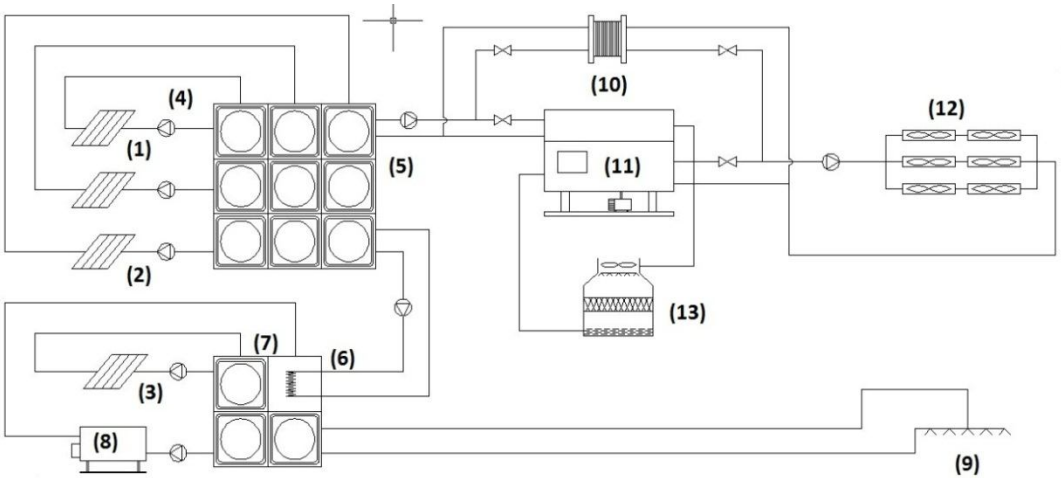
Location:
Changle, Shandong 36.69°N , 118.83°E

Application:
Heating, cooling and hot water supply for a 5 star hotel

Operating data of the system



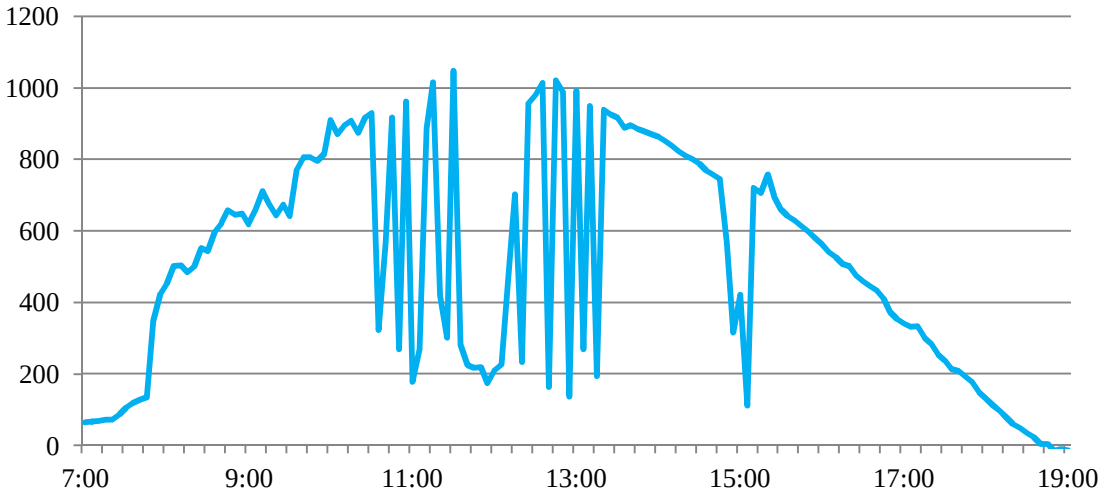




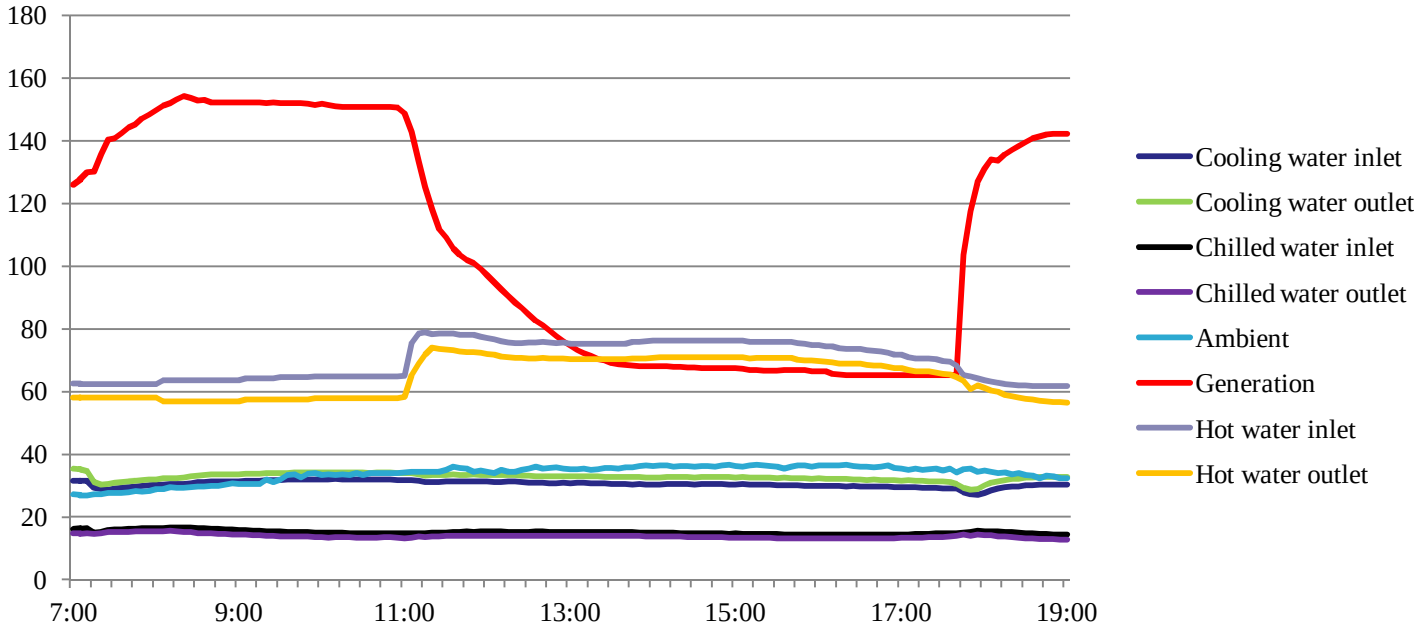
Energy saving:

The hybrid energy system saved **50.3%** of the gas consumption for the whole year operation (2012.10 ~2013.9).

Daily performance taken recently



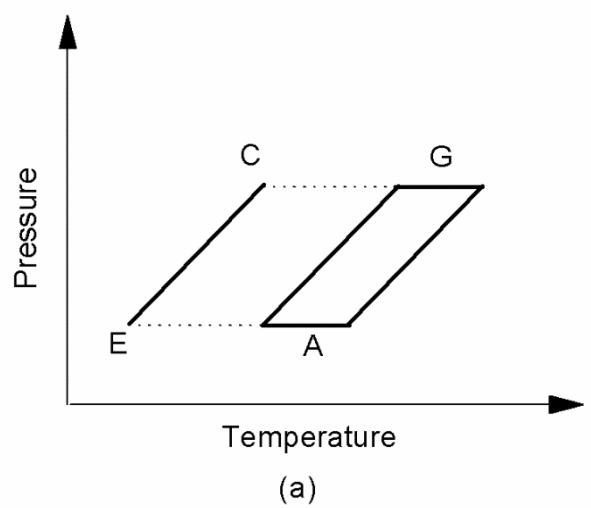
COP for solar cooling range from 0.5 to 0.6



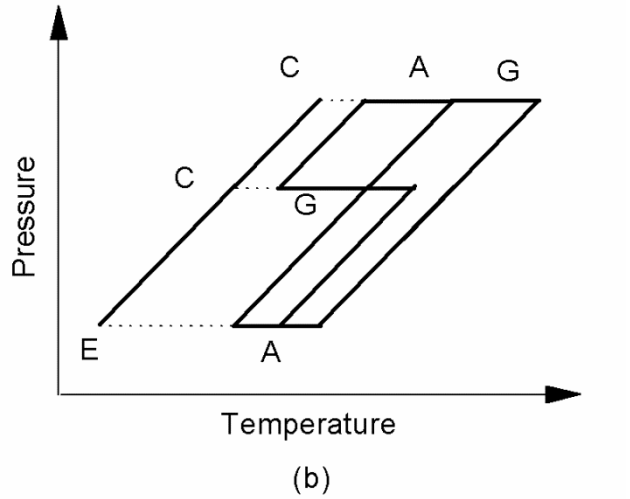
3. The 1.n effect LiBr-water absorption chiller

3.The 1.n effect LiBr-water absorption chiller (90 ºC-135ºC)

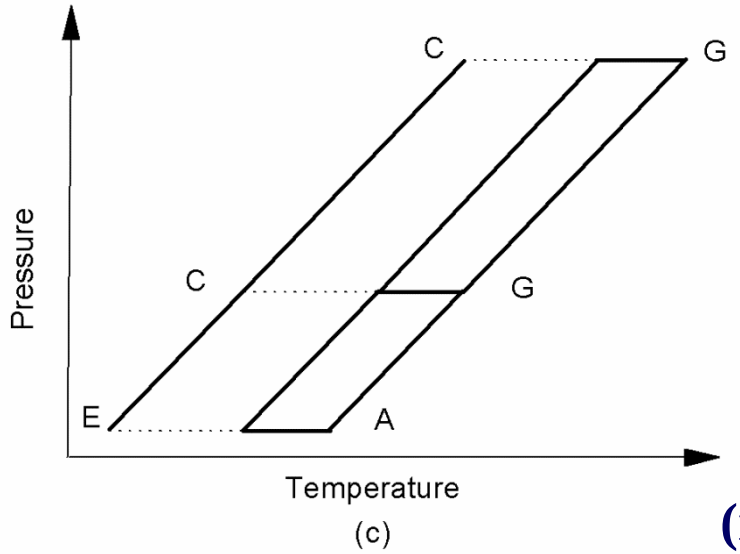
3.1. The 1.n effect absorption cycle



(i) Single effect

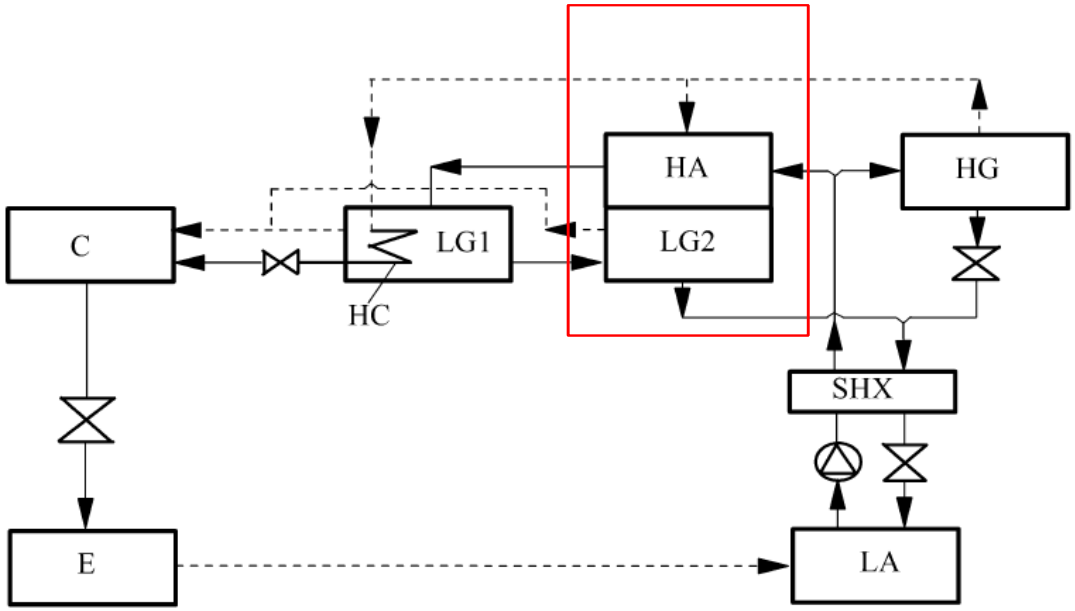


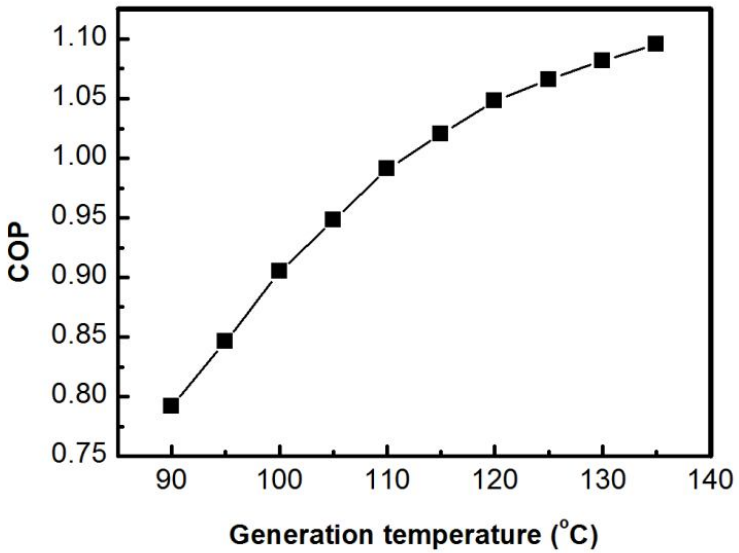
(ii) 1.n effect



(iii) Double effect

3.2. Schematic of 1.n effect cycle





(i) Schematic of the cycle

(ii) Thermodynamic calculation

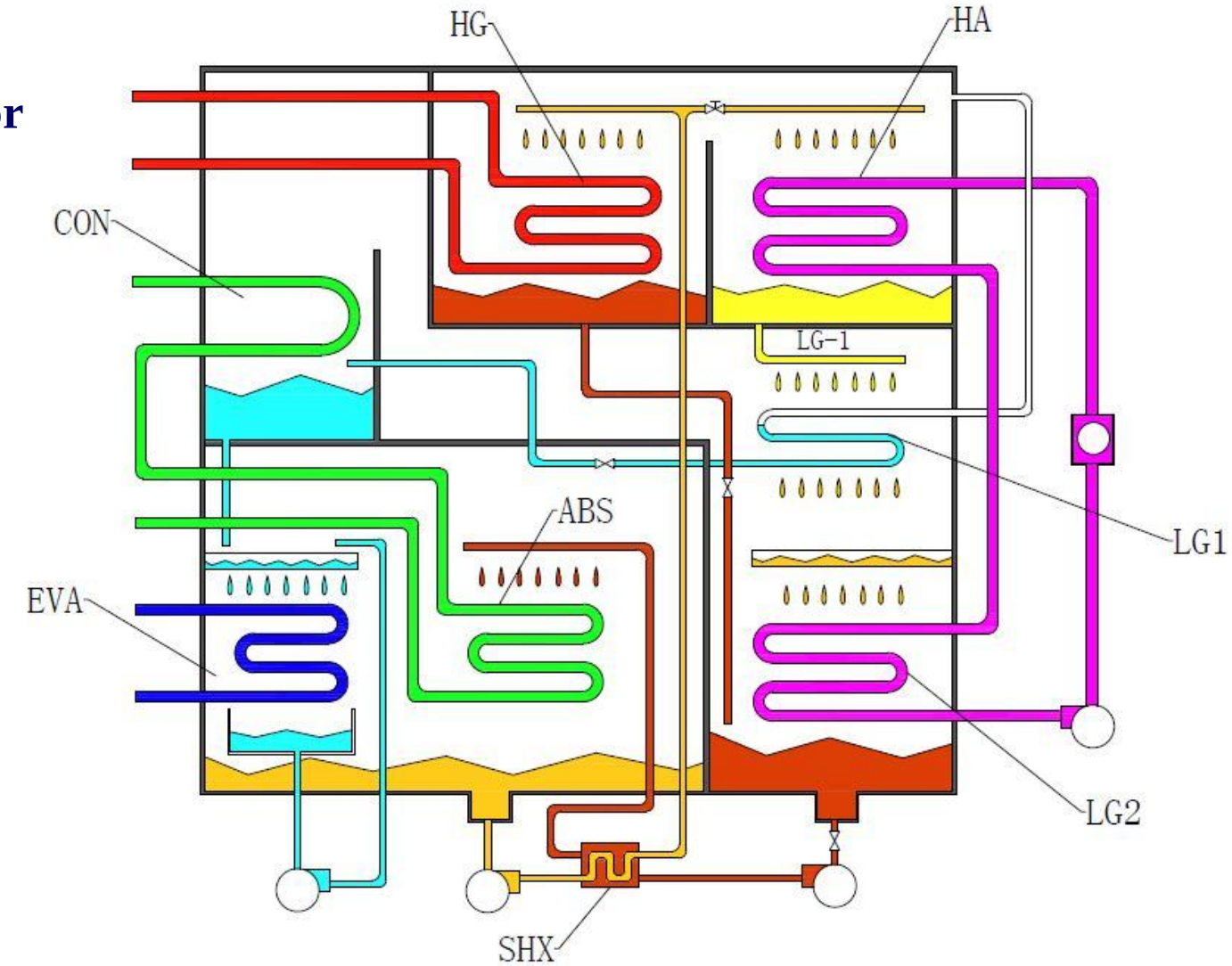
3.3. Schematic of chiller

Rated condition for design:

T_{gen}=125°C
T_{con}=40°C
T_{abs}=35°C
T_{eva}=5°C

Concentration distribution:

X_{HA}=45.73%
X_{ABS}=55.28%
X_{HG}=60.10%

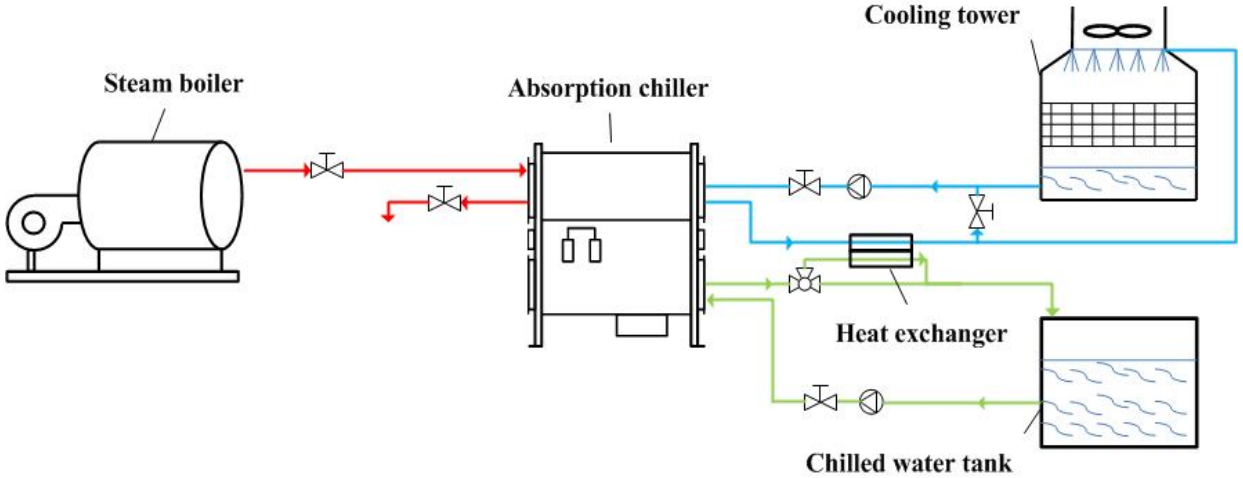


3.4. Design of the chiller

	Heat exchanger form	Calculated power(kW)	Heat transfer area (m^2)
HG	Falling film generation	50.8	7.84
HA	Falling film absorption	22.7	5.52
LG2	Falling film generation	22.7	6.68
LG1	Falling film generation	15.1	4.65
CON	Falling film condensation	38.2	4.61
ABS	Falling film absorption	62.9	14.24
EVA	Falling film evaporation	50.0	9.59
SHX	Flat plate heat exchange	29.6	4.25

Cooling power: 50 kW

3.5. Performance testing



T_{gen}	T_{ch1} (°C)	T_{ch2} (°C)	T_{c1} (°C)	T_{c2} (°C)	Cooling power(kW)	COP
95.01	12.46	9.38	31.17	34.94	35.90	0.69
100.17	10.19	7.45	32.53	35.85	31.97	0.71
102.71	12.71	9.35	28.13	32.10	39.12	0.73
104.45	16.35	13.23	29.78	34.22	45.53	0.78
110.89	15.04	10.69	32.45	37.19	43.53	0.85
115.77	14.65	10.45	30.88	35.08	49.03	1.01
119.88	13.46	9.00	27.55	31.85	52.06	1.08

4. $CaCl_2$/AC-ammonia adsorption refrigerator

4.$CaCl_2$/AC-ammonia adsorption refrigerator (100°C -140°C)

4.1. System schematic

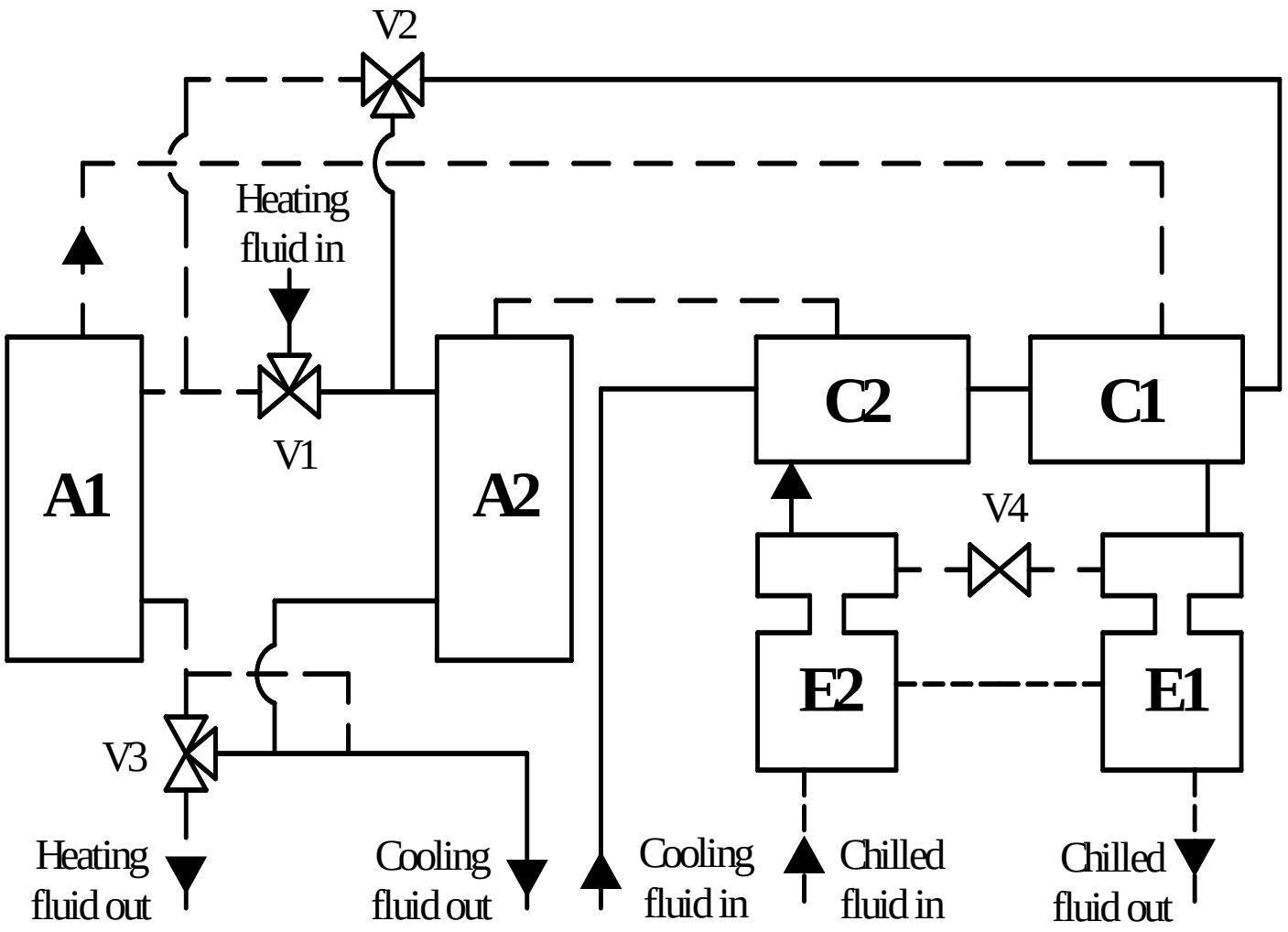
$CaCl_2$/AC-ammonia

2 adsorbers

2 condensers

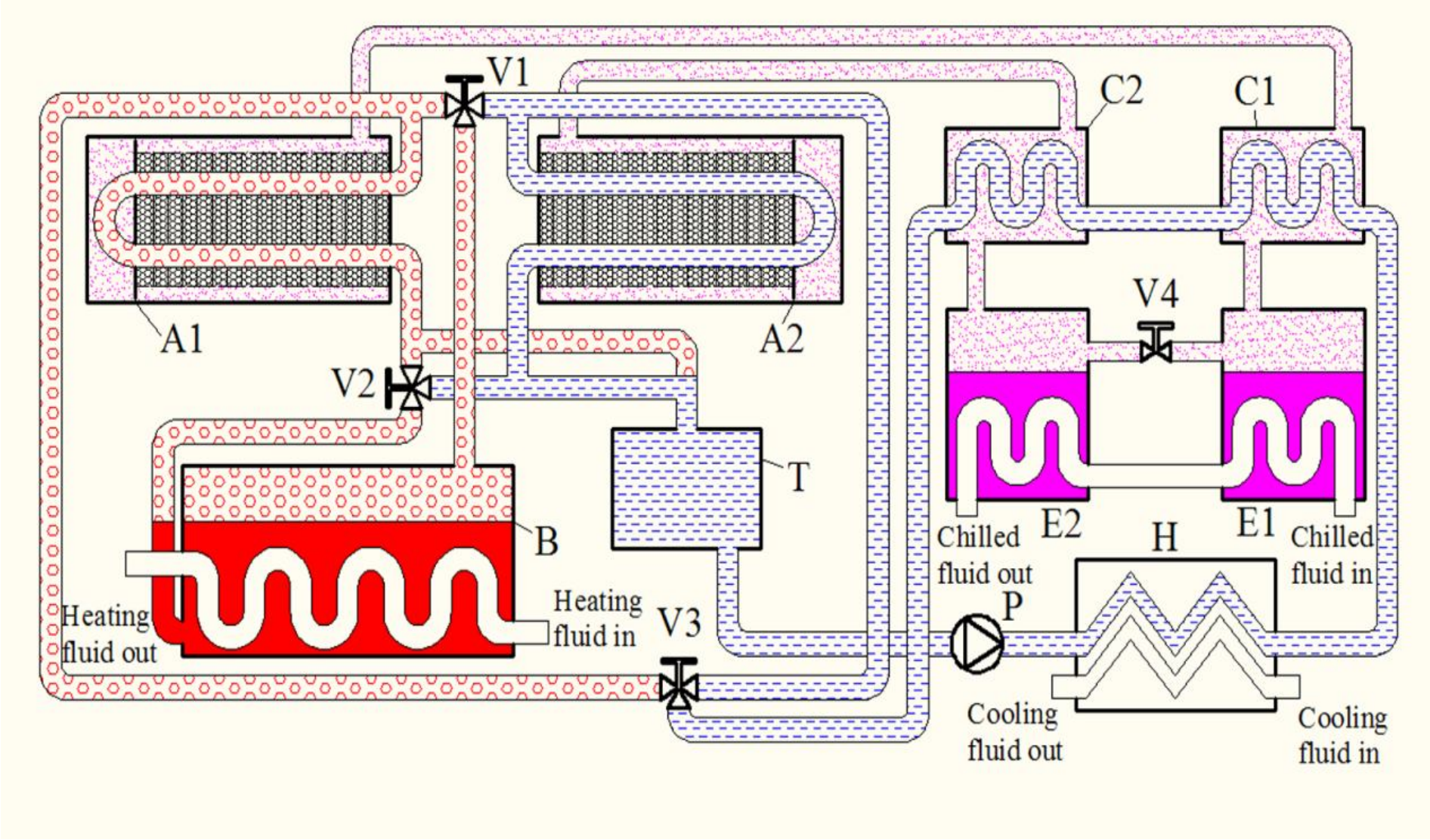
2 evaporators

4 valves

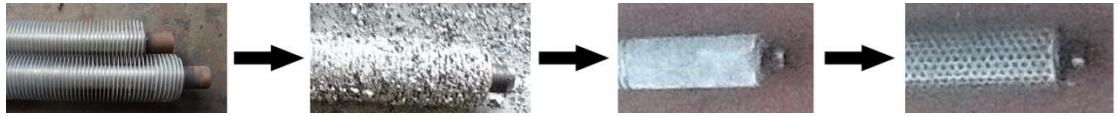


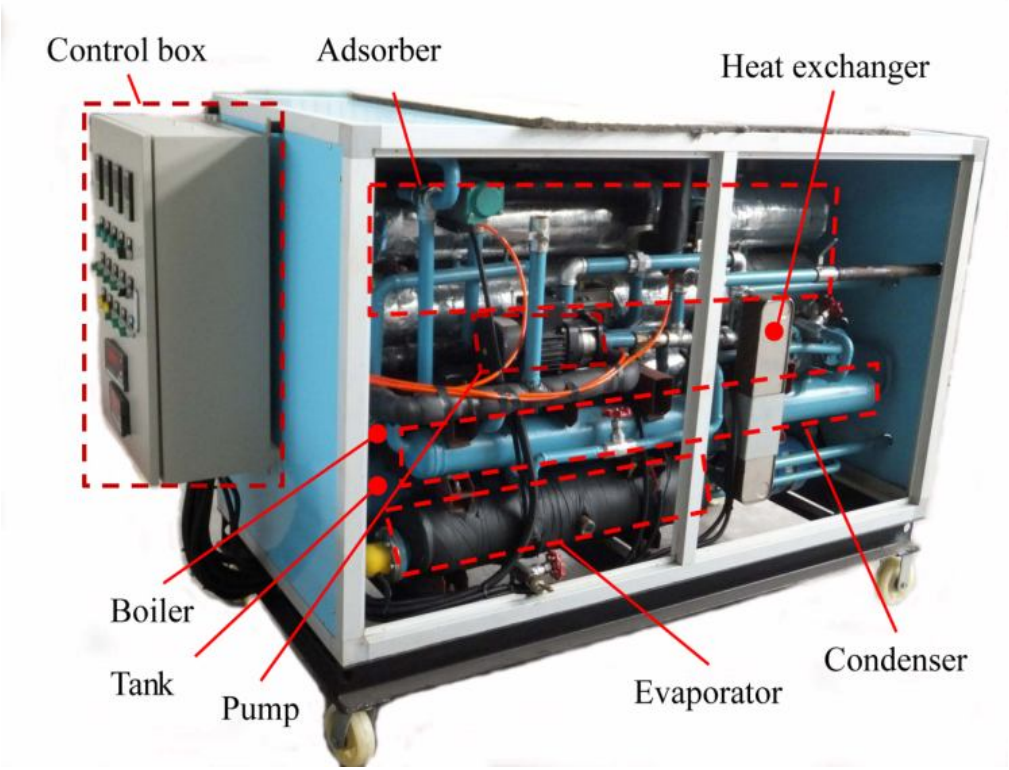
A: Adsorber
C: Condenser
E: Evaporator
V: Valve

Heat pipe heating is used



4.2. Prototype





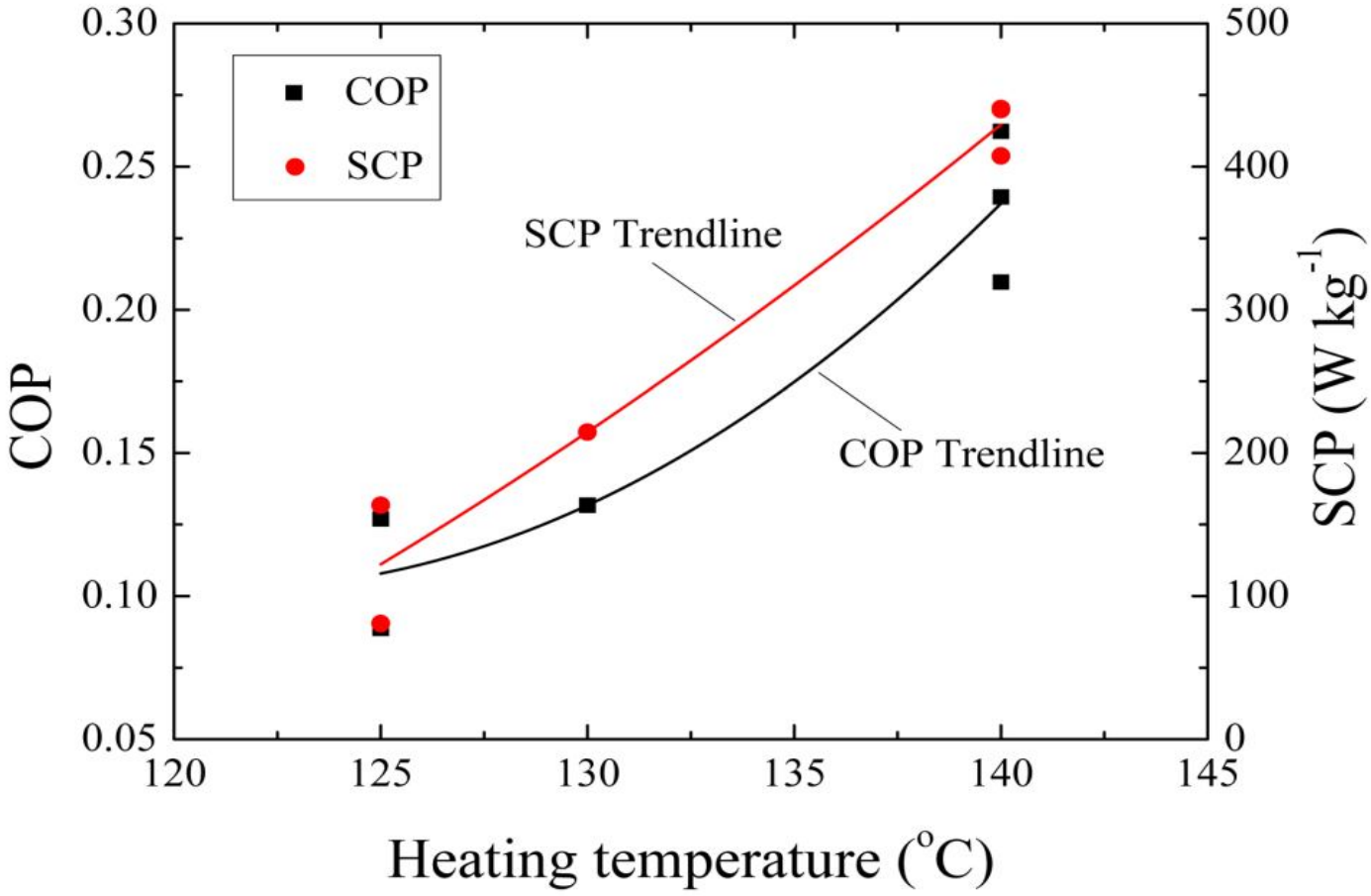
10.6 kg composite adsorbent ($CaCl_2$ 8.5kg)

140 °C heat source,
28 °C cooling source,
-12.5 °C evaporating temperature
Q_e=3.74 kW
COP=0.26
SCP=440.0 W kg^{-1}

Size: 1.85 × 0.85 × 1.05

4.3. Performance test

28 °C cooling source and -12.5 °C refrigeration temperature



5. Ammonia water absorption ice maker with perfect internal heat recovery

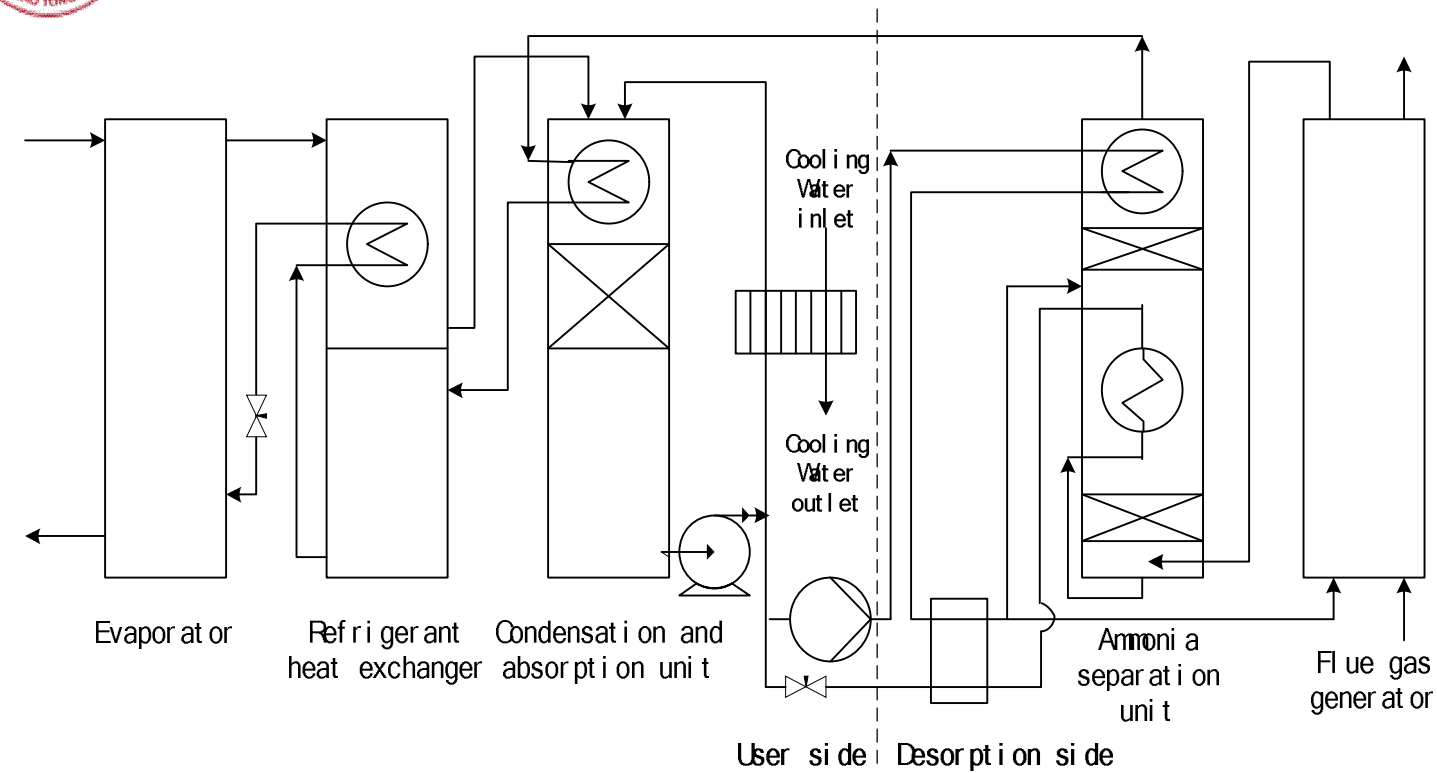
5.Ammonia water absorption ice maker with perfect internal heat recovery (140°C -170°C)

5.1. Problems and solutions

Ammonia water absorption ice-making system on fishing ship

Drawbacks:		Solutions
● Low COP (construction defect)	⇒	● Improve internal heat recovery (pinch analysis)
● Large bulk (large distillation column and heat exchangers)	⇒	● Compact heat exchangers (small scale heat and mass transfer)
● Requirement of anti-swaying (ship swaying leads to deterioration of absorption and purification processes)	⇒	● Heat and mass exchangers design without free liquid surface

5.2. Ice maker construction

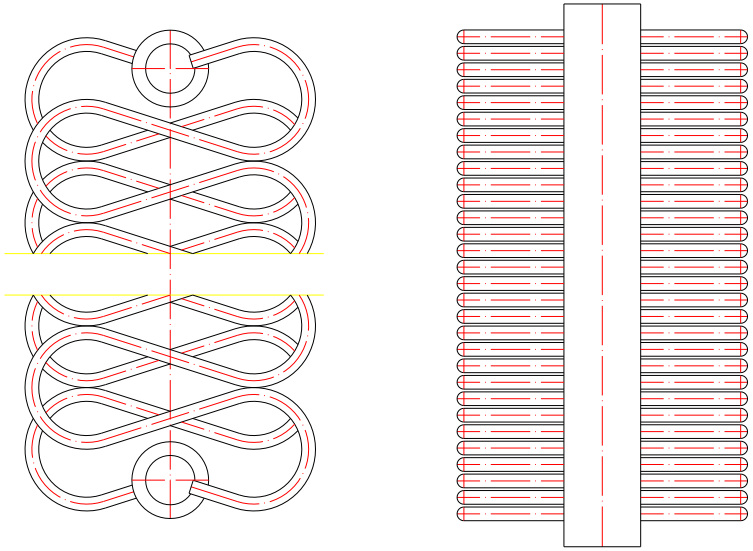


Design conditions:
T_g: 160 °C
T_a: 34 °C
T_c: 34 °C
T_e: -30 °C
Cooling capacity: 40kW

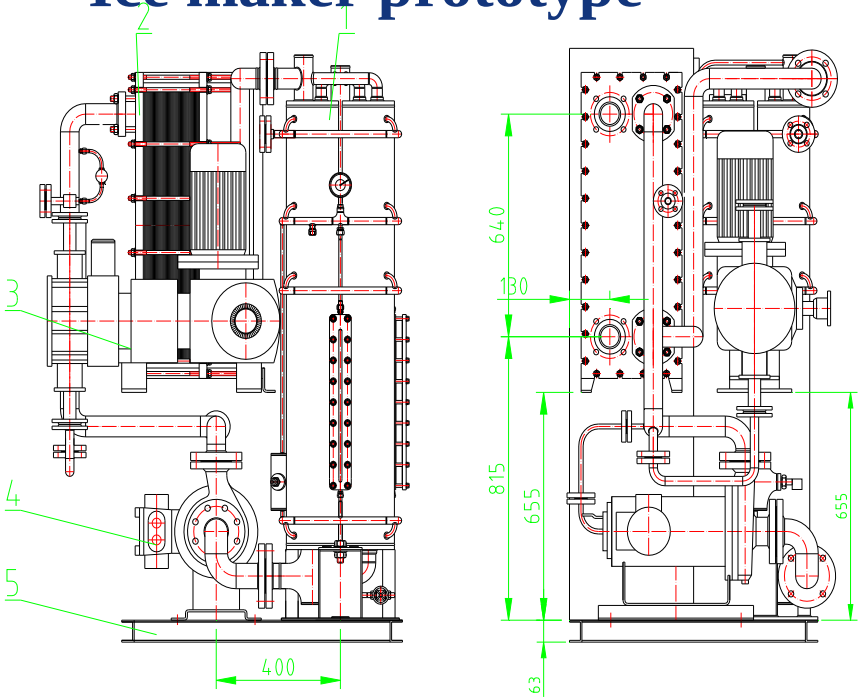
1. **Normal operating without effect of ship swaying**
2. **Compact and miniaturization**
3. **Better heat and mass recovery**
4. **Condensation and absorption cooling completed with the strong solution**
5. **Heat released in one plate heat exchanger**

5.3. Small scale heat exchanger

Small scale tube bundle



Ice maker prototype



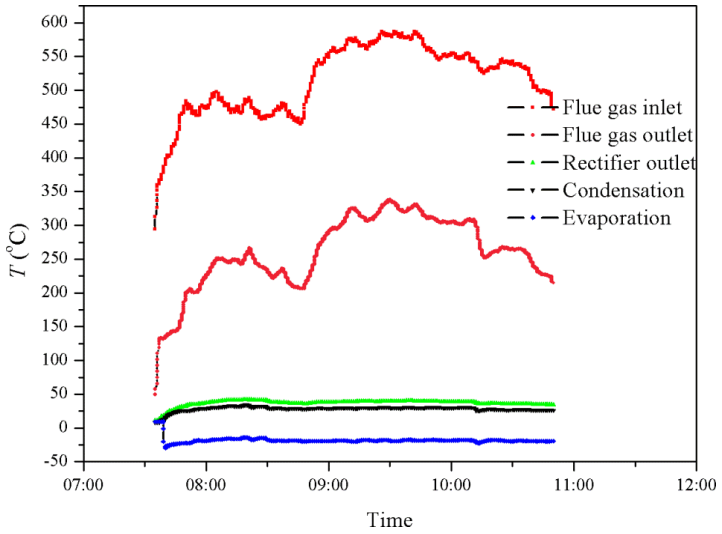
Outside Diameter:
2.5 mm
Inside Diameter:
1.7mm

User side size:
1.7m*1.1m*0.85m
Desorption side size:
1.6m*0.64m*0.56m

5.4. Photos and stable operation

User side

Desorption side



1. Stable operation for a long time
2. Flue gas temperature variation just has a little effect on generation

Table 5. The results of different operating conditions.

5.5. Results of different conditions

Parameters	1	2	3	4	5	6
Flue gas inlet (°C)	542	480	497	498	560	492
Flue gas outlet (°C)	265	208	226	237	308	245
Ammonia after rectification (°C)	36.8	34.8	36.1	38.5	39.3	39.4
Absorber (°C)	23.9	25.1	26.2	28.0	28.7	30.4
Evaporation (°C)	-21.7	-20.2	-19.4	-18.7	-18.5	-16.6
Condensation (°C)	24.3	26	26.9	29.0	29.9	31.1
Cooling capacity (kW)	29.6	30.2	27.6	26.6	30.5	26.8
COP	0.52	0.56	0.55	0.50	0.52	0.53

6. Conclusions

	Working pair	Driven temperature	Evaporation temperature	Advantages
Modular adsorption chiller	Silica gel- water	55 -90 °C	5°C	Modular design, cost saving
Single/double effect absorption chiller	LiBr-water	85 -95°C / 135-150°C	5°C	Continuously and steady operating
Adsorption refrigerator	$CaCl_2$/AC-ammonia	100 -140 °C	-5~-20 °C	High efficiency, stability
1.n effect absorption chiller	LiBr-water	90 -135°C	5°C	Variable effect, large working temperature range
Absorption ice maker	water- ammonia	140-170°C	-30°C	perfect internal heat recovery

Solar PV Powered HVAC & R?

Split room AC
VRV
Centrifugal chiller

Solar PV cooling

Lennox

PV air conditioning becomes more competitive with the PV cost goes down.

Solar PV DC powered Inverter centrifugal chiller
光伏直驱变频离心机

普通光伏空调

光伏组件

直流

光伏逆变器

交流

普通空调

格力光伏空调

光伏组件

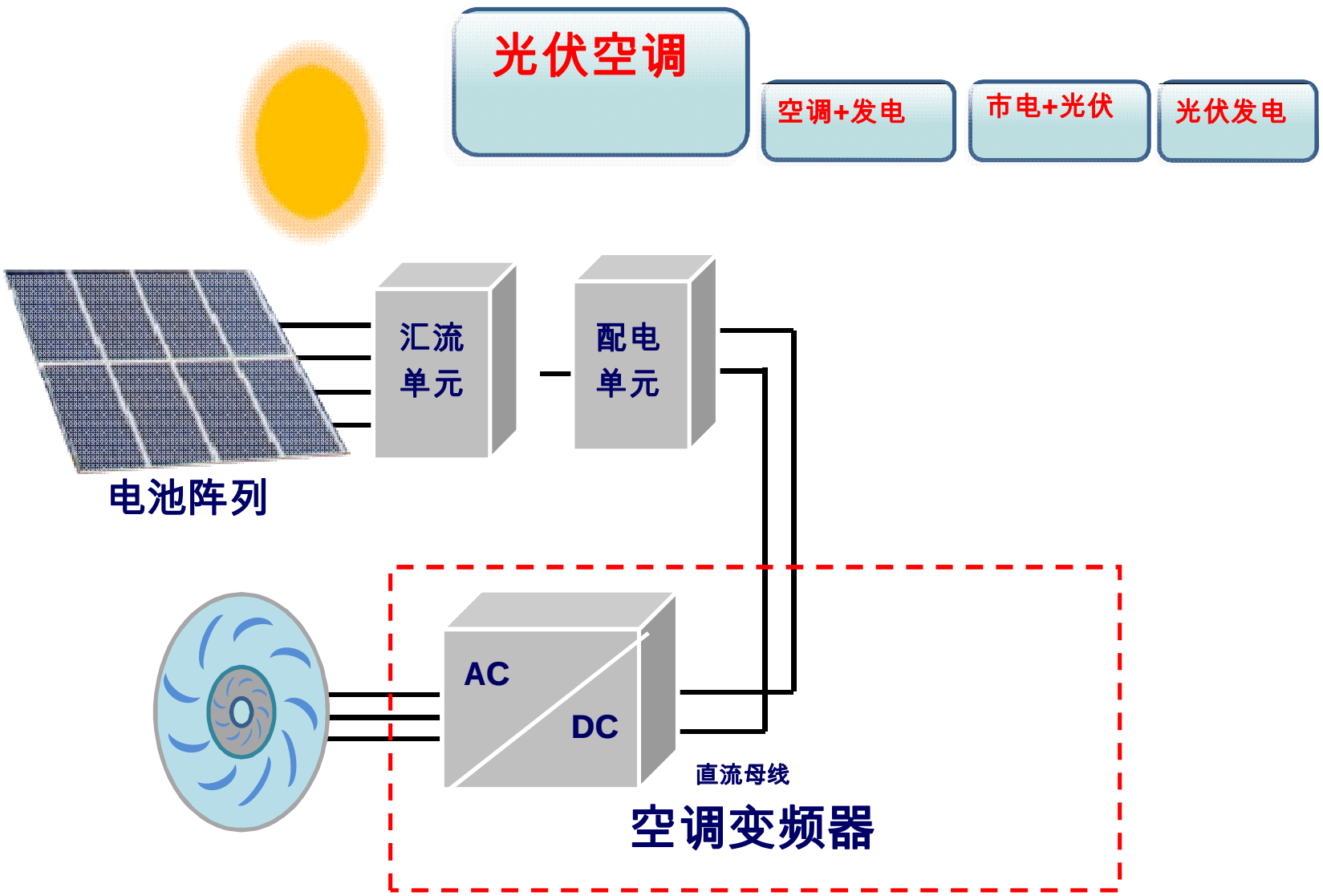
直流

省设备
省转换

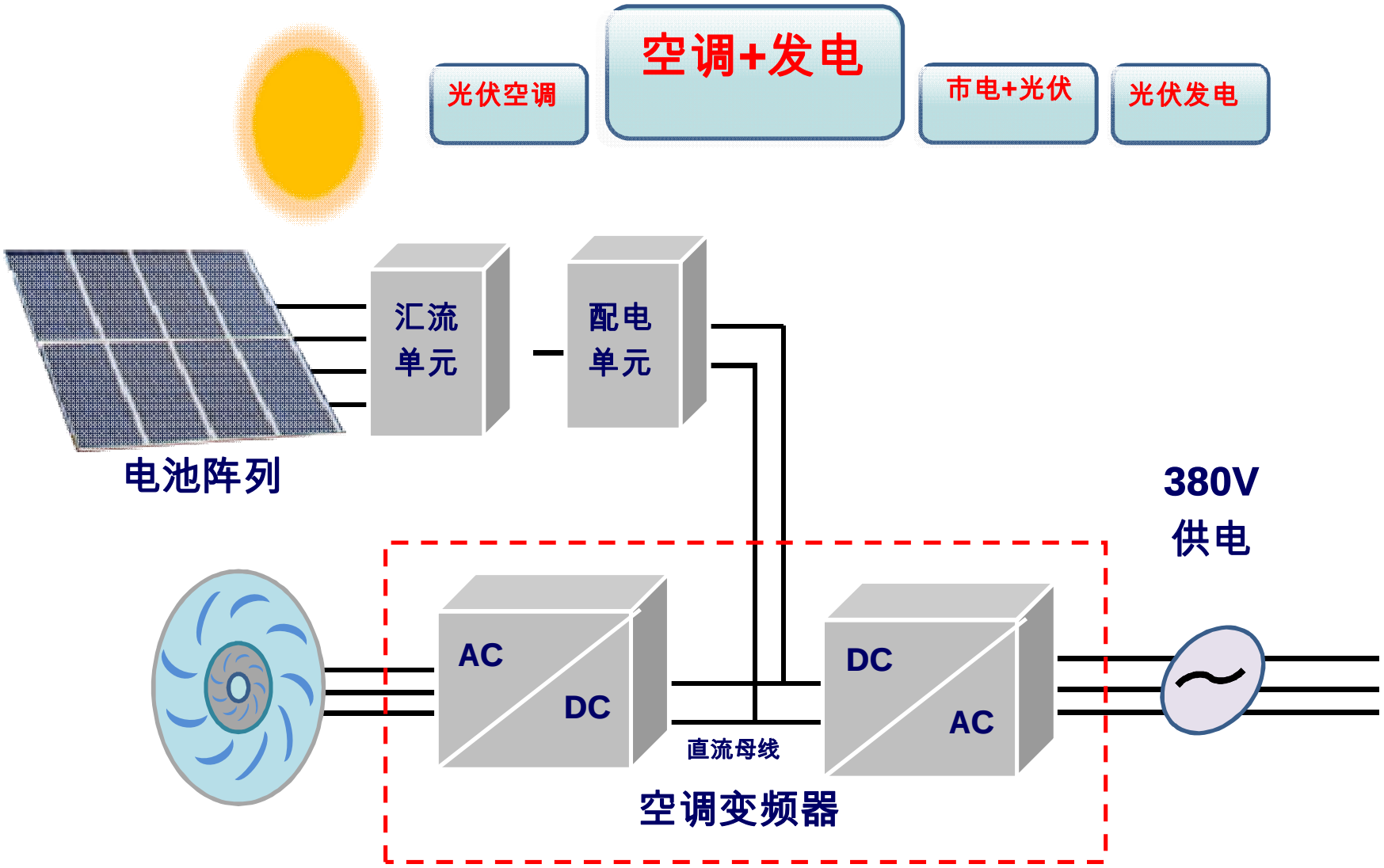
直流

格力光伏直驱变频离心机

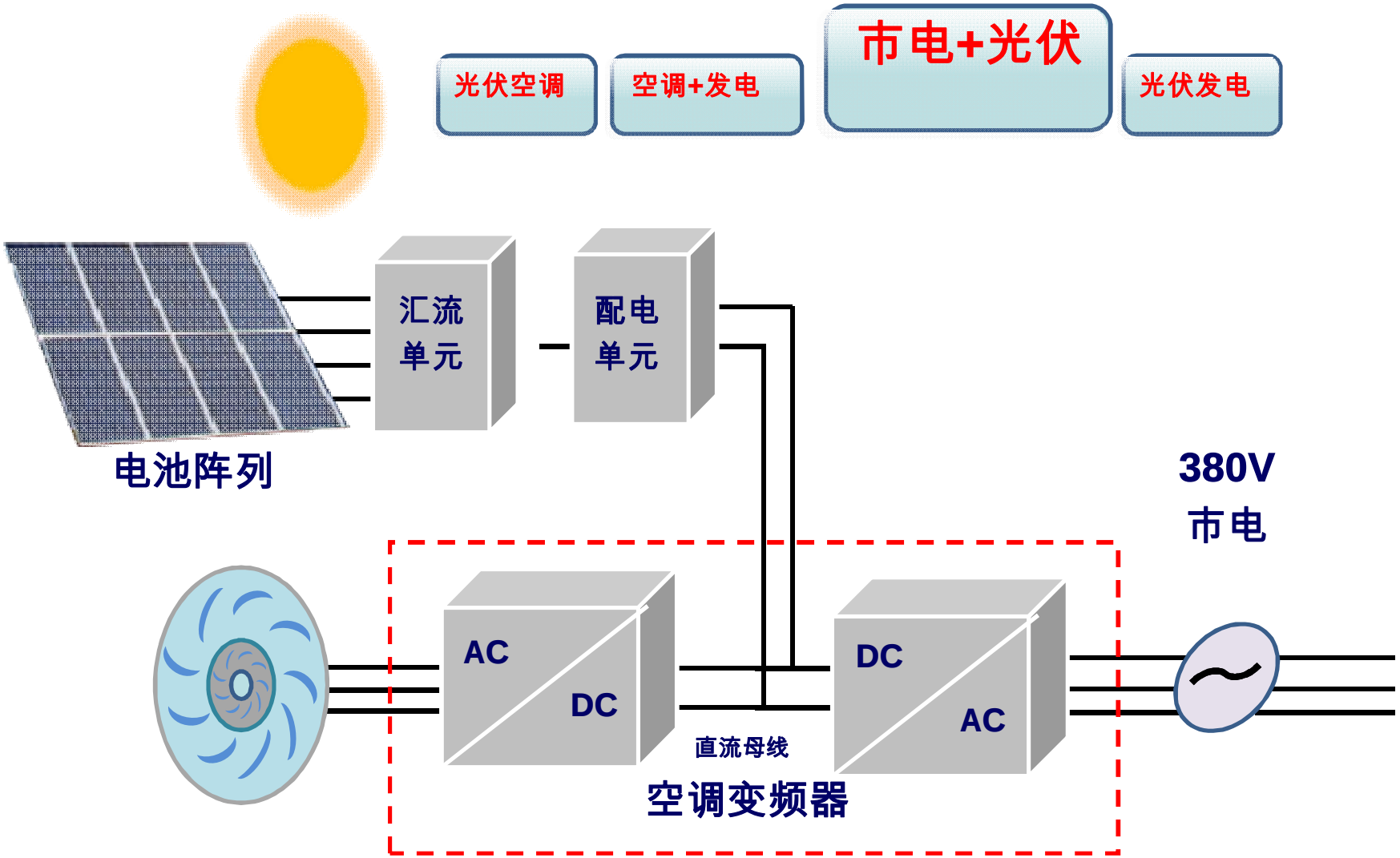
Solar PV DC powered Inverter centrifugal chiller
光伏直驱变频离心机



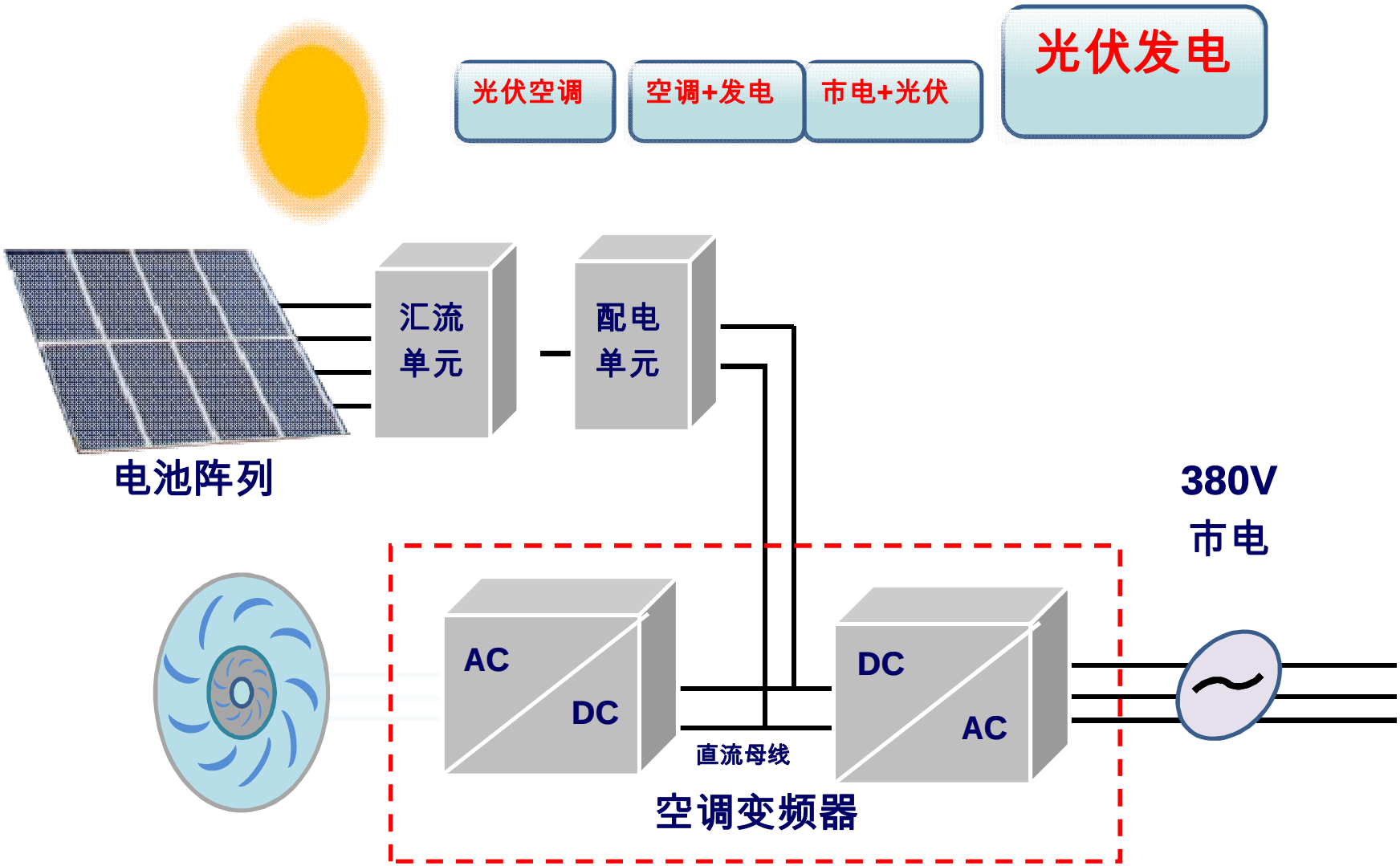
Solar PV DC powered Inverter centrifugal chiller
光伏直驱变频离心机



Solar PV DC powered Inverter centrifugal chiller
光伏直驱变频离心机



➢ 光伏直驱变频离心机


光伏空调
空调+发电
市电+光伏
光伏发电
汇流
单元
配电
单元
电池阵列
380V
市电
AC
DC
DC
AC
直流母线
空调变频器

Solar Energy

for the bright future of mankind!

Acknowledgements:

This work was supported by the key project of the Natural Science Foundation of China for international academic exchanges of Asia 3 under the contract No. 51020105010.