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Refrigeration technology about solar adsorption, absorption and Photovoltaic

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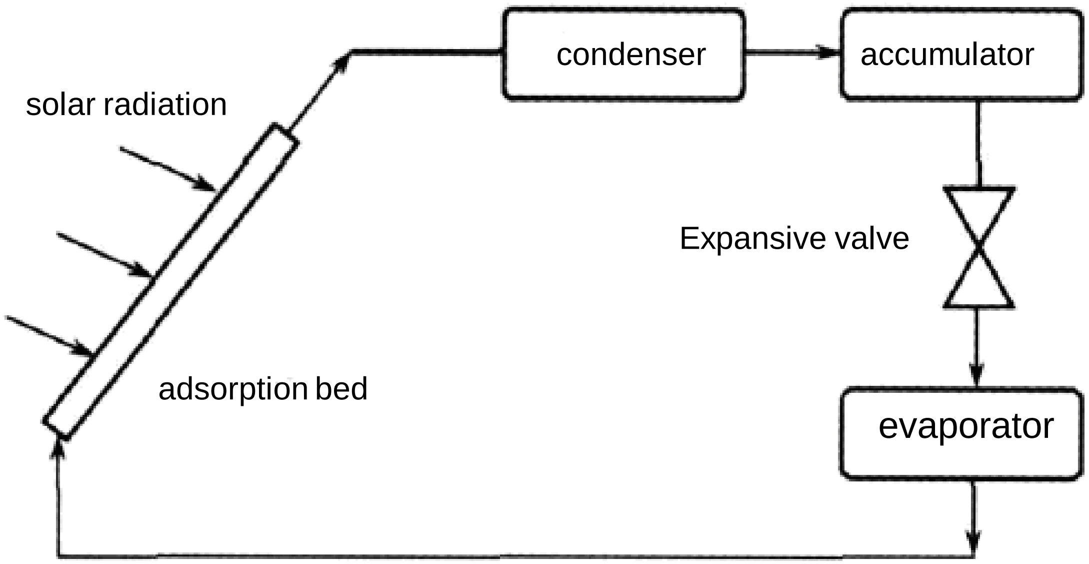
Contents

1. Solar Heating Adsorption Refrigeration

1.1 Working principle

- Working principle ：

  Energy is transferred through phase-change processes (evaporation heat)



Solar adsorption

•Working Pairs

activated carbon -methanol ；molecular sieve -water ； silica gel -water ； activated carbon -ammonia and so on.

form ：

Single bed 、 multiple-bed

The most important research work of solar heating adsorption refrigeration is:

How do we improve the efficiency?

There are two ways adopted to improve the efficiency of solar heating adsorption.

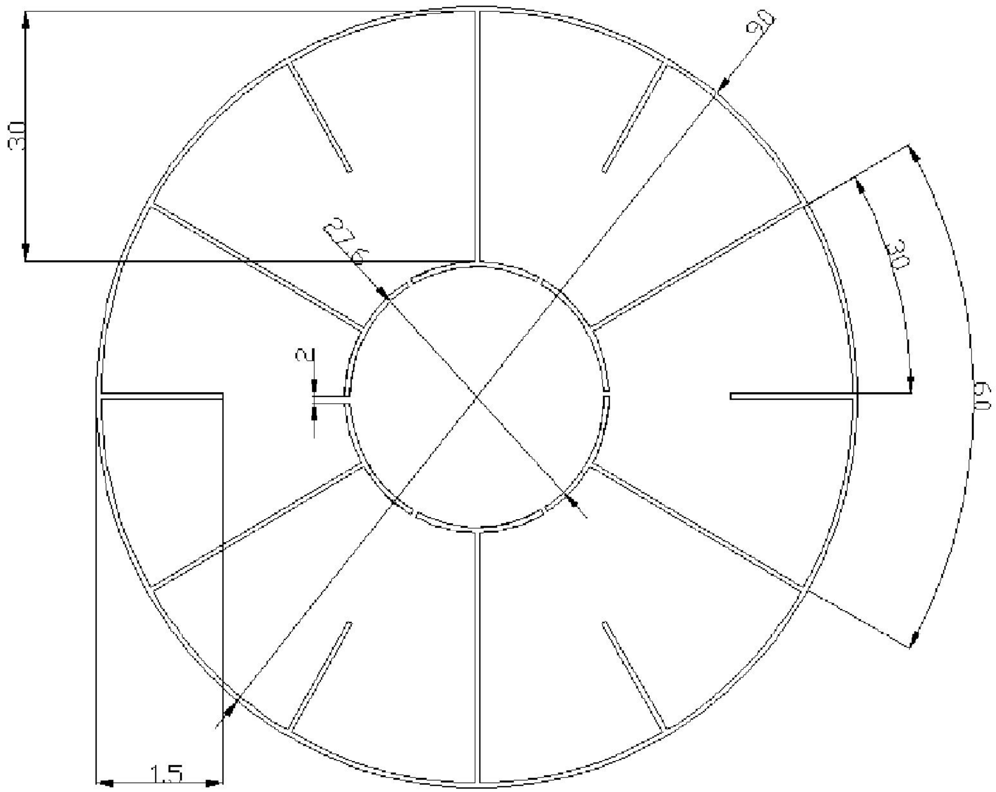
a. Enhancing heat transfer

b. Enhancing mass transfer

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.1 Optimization of adsorption bed

Designing a fin-tube adsorption collecting bed



Sectional view
Material: pure Aluminum or Aluminium alloy
Outer tube diameter: 90mm
Inter tube diameter: 27.4mm
Fin angle: 60°
Disconnect width of the inner tube: 2mm
Fin length: 15mm
Pipe wall thickness: 1.2mm

Advantages:

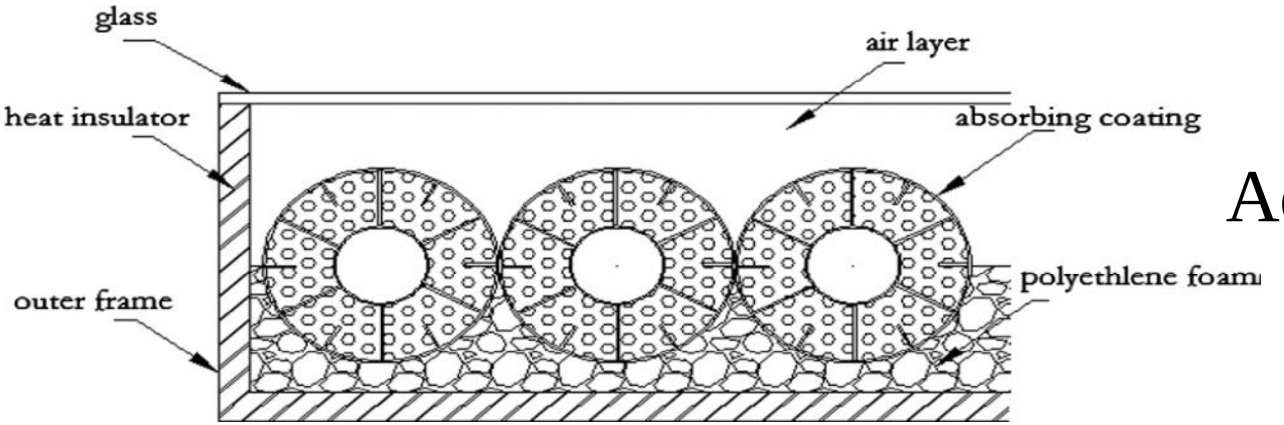
1. enhancing heat transfer
2. improving adsorption tube resistance
3. improving sealing performance

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.1 Optimization of adsorption bed

Finned tube

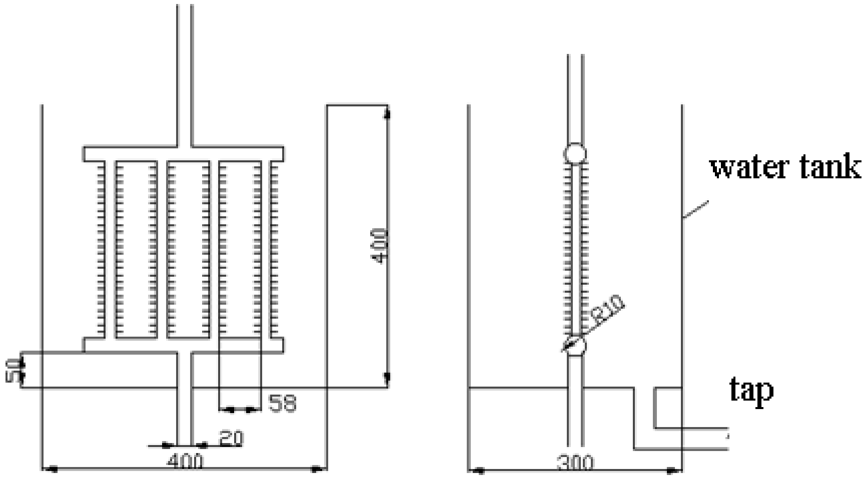
Activated carbon adsorbent



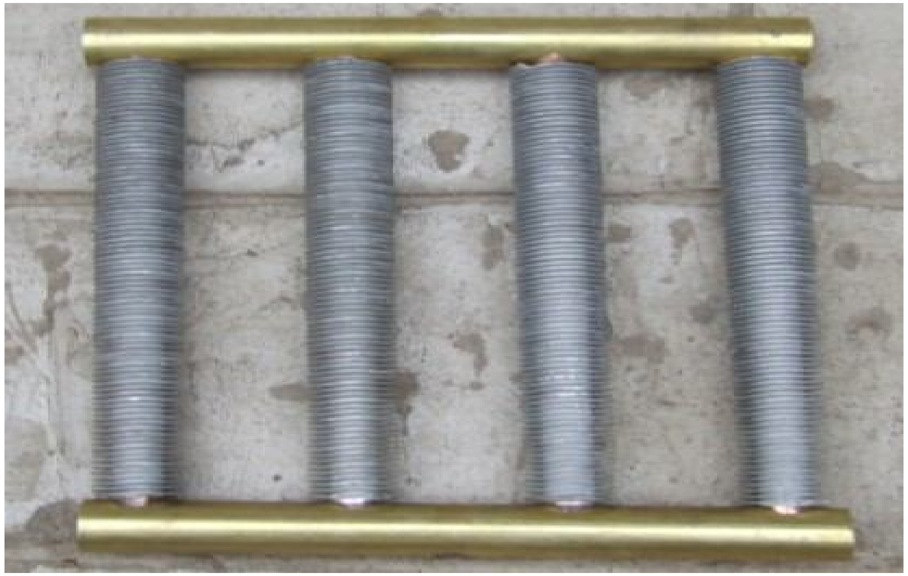
Adsorption bed

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.2 Optimization of condenser



Outer material: pure Aluminum
Inter material: pure copper
Fin outer diameter: 32.5mm
Fin inter diameter: 15.5mm
Fin spacing: 2.5mm

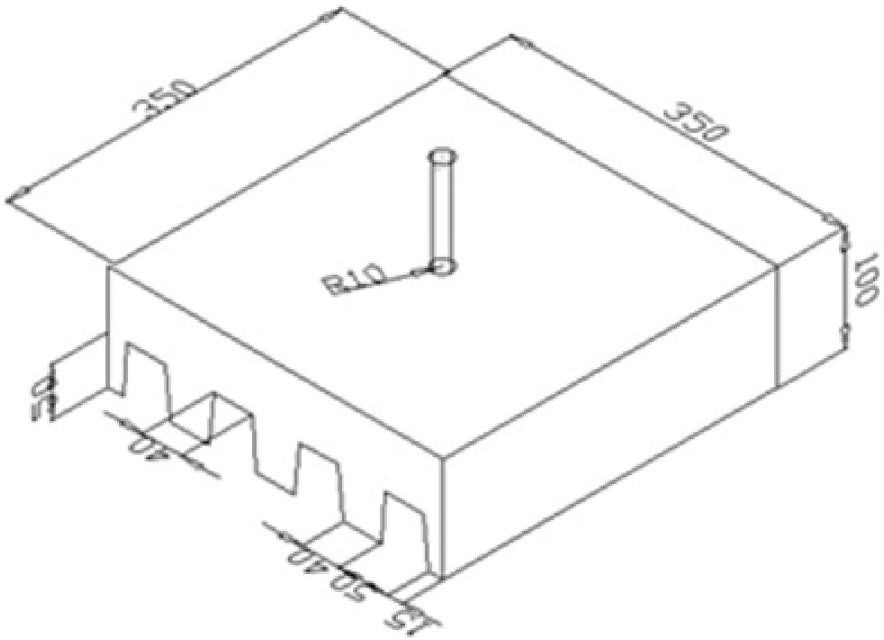


Advantages:

1. Increasing heat exchange area
2. enhancing heat transfer
3. improving cooling uniformity

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.3 Optimization of evaporator

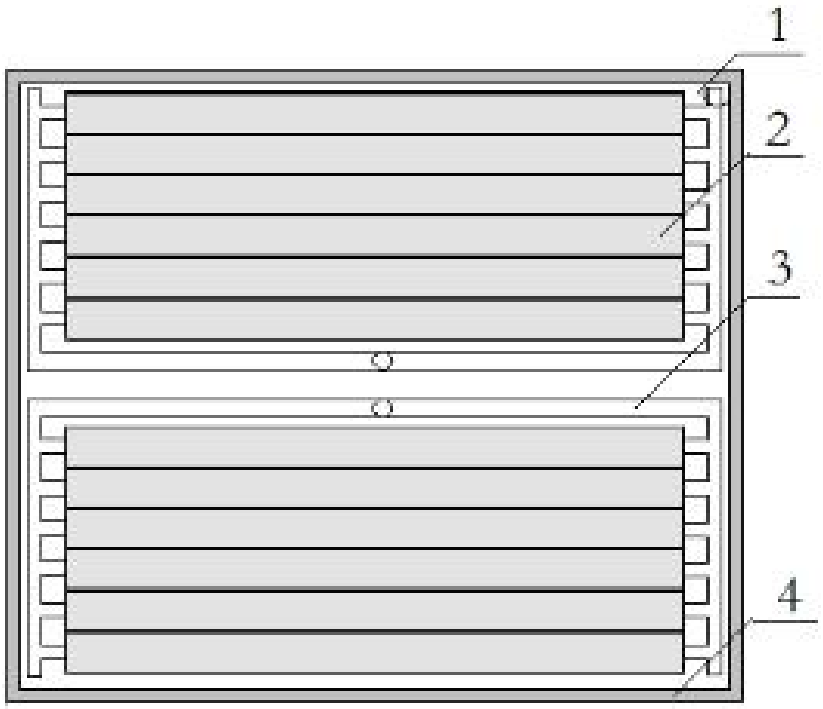


Parameter
Shell size: 350mm*350mm*100mm
Effective evaporation area: 0.46m^2
Volume: 7.8L

Advantages:
1. Increasing contact area
2. enhancing ice making rate
3. Alleviating super cooling phenomenon

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.4 Parameters of adsorption bed



1 glass cover 2 finned adsorption tube
3 draft tube 4 Thermal insulating layer

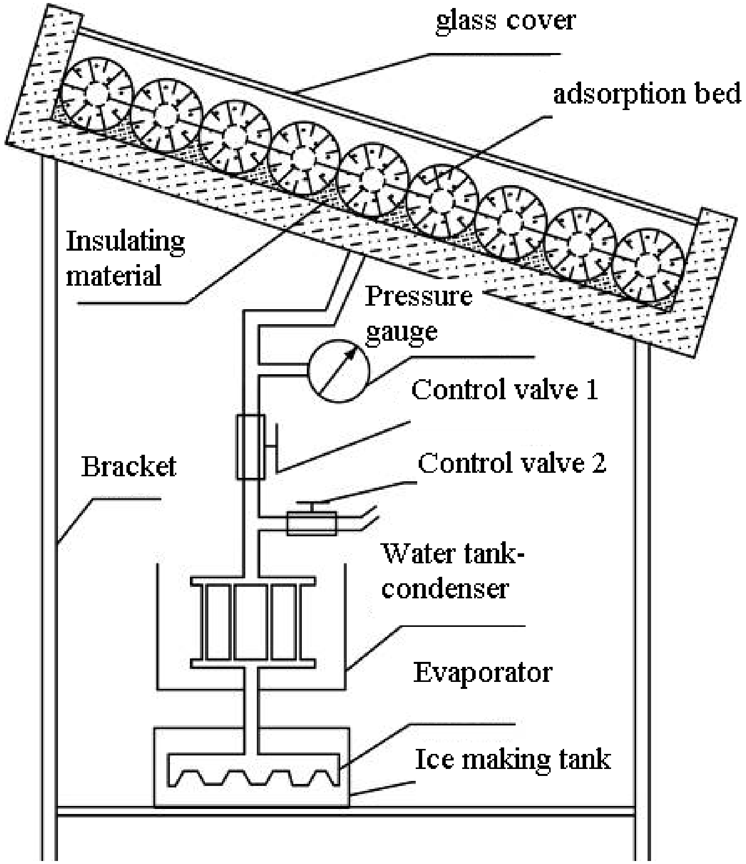
Structure diagram of adsorption bed

Structure parameters

Name	Parameters
Size（ L*W*H ）	1560mm*1320mm*150mm
absorbing area	$1.1m^2$
Quality of activated carbon	29kg
Quality of adsorption tube	29kg
Adsorption bed area	$10.8m^2$

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.5 Experimental platform

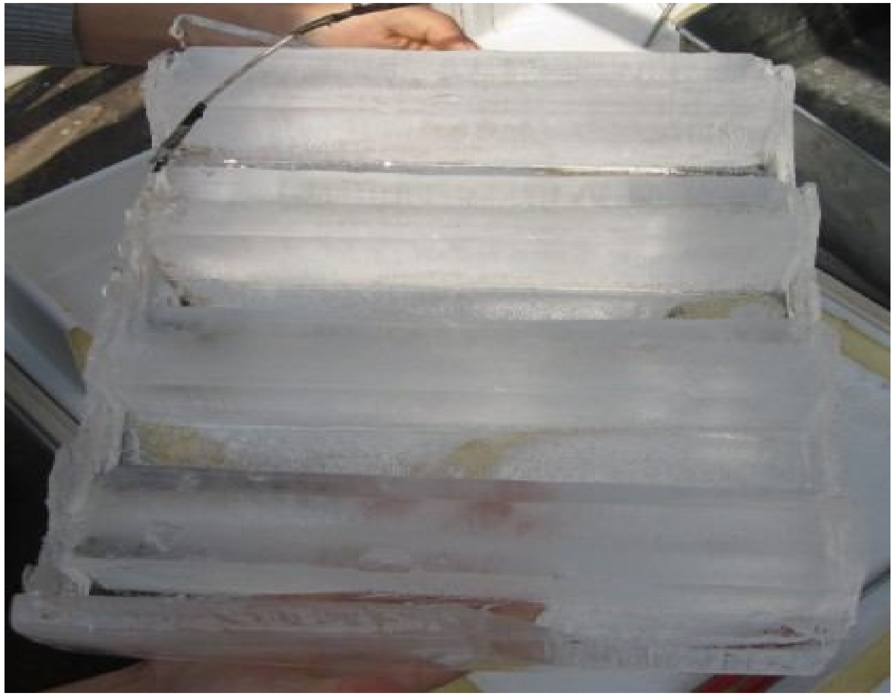


Structure diagram

Photos of the system

1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.7 Ice making

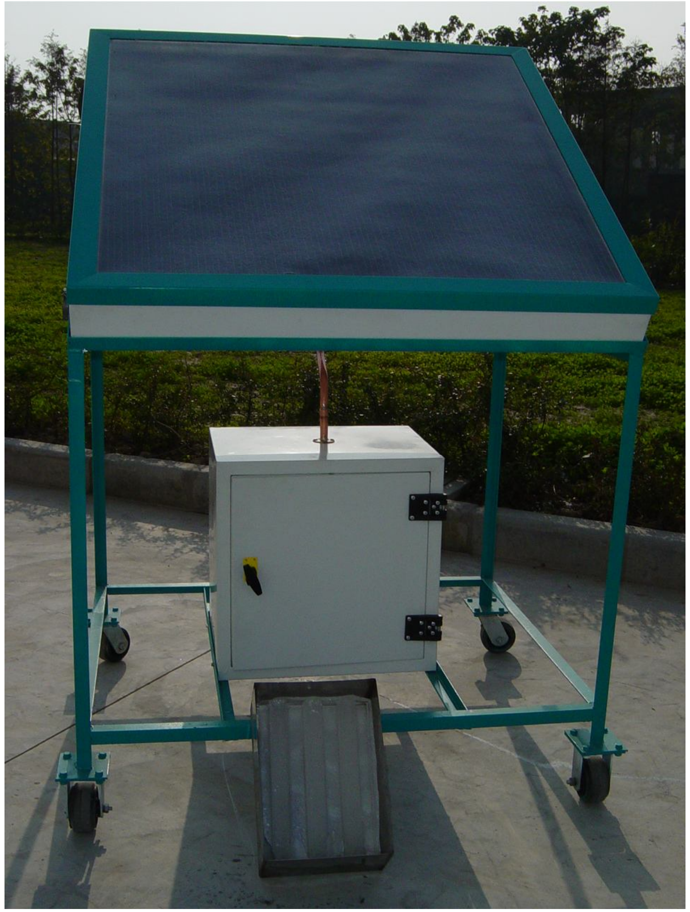


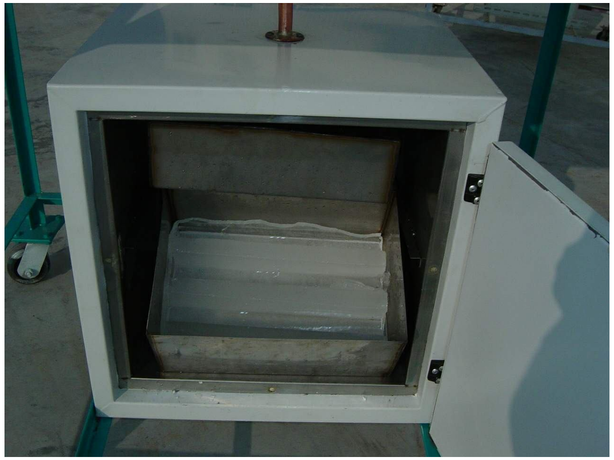
Ice making process

8-10kg ice/Per $m^2 \cdot d$

Compared with the Solar ice maker developed in 2002

- 5-7 kg ice/day per square meter collector





1.2 solar heating adsorption refrigeration——Enhancing heat transfer

1.2.8 Test results

The highest adesorption temperature and the time of closing valve (cloudless day)

	March 19	March 23	March 24
Time of closing valve	15:00	14:40	15:30
Radiation (MJ)	20.5	18.2	18.2
Highest temperature(℃)	91.5	90.1	83.5
Time	13:45	14:20	15:15
COP_{solar}	**0.122**	**0.129**	**0.112**
Note	Cloudless	Cloudless before 14:40	Cloudless

the highest adesorption temperature and the time of closing valve (cloudy day)

	March 20	March 21	March 22
Time of closing valve	15:00	15:00	15:00
Radiation (MJ)	21.5	20.8	15.0
Highest temperature(℃)	93.4	89.8	81.5
Time	14:22	14:15	12:35
COP_{solar}	**0.094**	**0.094**	**0.079**
Note	cloudy day	cloudy day	cloudy day

1.2 solar heating adsorption refrigeration——Enhancing heat transf

1.2.9 Accomplishments

National Fund:

The mass and energy transmission and coupling energy research about solar heating adsorption refrigeration driven by medium temperature energy based on trough concentrating ， 51366014

patent：

A fin tube type solar adsorption refrigeration system, CN 202209810 U

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.1 We have found Some problems during the experiment:

a. **The refrigerant gas mass transfer resistance was very high. Therefore, the desorption time was very long in desorbing process and the outer wall of pipeline was very hot as well as the number of vacuum pressure was high.**

b. The desorption process was not complete. Some refrigerant heated in collector can not flow into condenser on time. Subsequently, they absorbed in absorption bed at low temperature.

c. methanol adsorption refrigerant did not vaporize indirectly but atomized at first and then vaporized slowly.

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.2 Analysis and solution

The reason is that desorbed gas blocked in mass transfer process, which resulted in refrigerant circulating rate and energy utilizing rate were not improved in refrigerating process.

To solve the problem, the pipeline pump should be installed in mass transfer pipeline to accelerate the adsorption gas transferring and refrigerant desorbing in absorption bed.

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

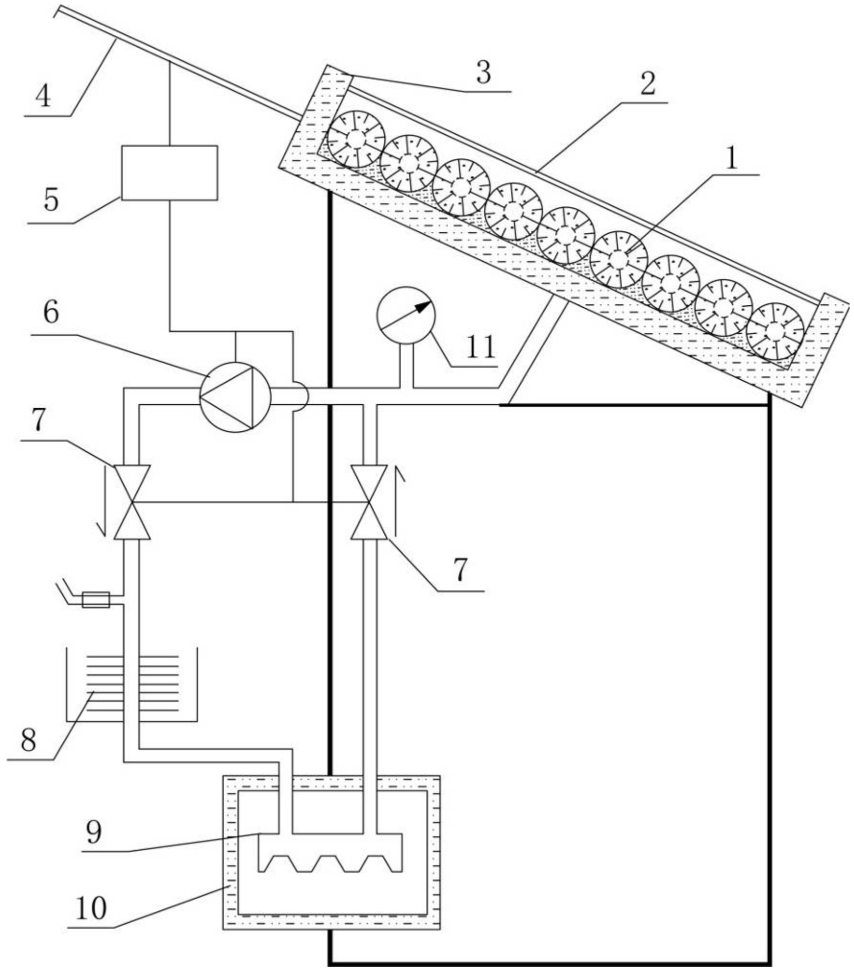
1.3.3 Enhancing mass transfer assisted with Photovoltaic

Considering that working time is synchronous among pipeline pump, solar collector and adsorption bed. The Photovoltaic will be adopted to provide power for pipeline pump.

Refrigeration efficiency and energy utilization rate can be improved. Furthermore, comprehensive utilization performance of solar photovoltaic and solar Thermal system can be enhanced.

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

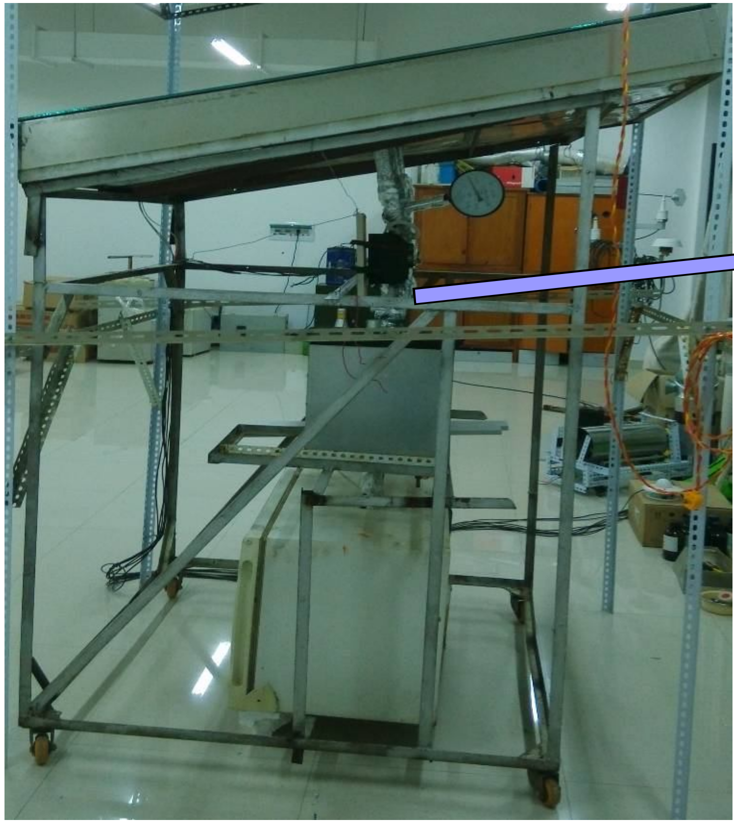
1.3.4 Photovoltaic together with strengthen mass transfer and solar adsorption refrigeration system



1. The finned tube collector/adsorption bed
2. Glass cover
3. The thermal insulation material
4. Solar panels
5. The controller
6. Pipeline pump
7. Check valve
8. The condenser
9. The evaporator
10. Heat insulation water tank
11. The pressure gauge

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.4 Photovoltaic together with strengthen mass transfer and solar adsorption refrigeration system



Photovoltaic strengthen adsorption refrigeration real figure

Dc pipe pump
(micro vacuum pump)

The solar panels

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.5 System performance contrast test results in the two modes of mass transfer

The refrigeration system performance under the mode of natural mass transfer

Project	September 5	September 8	September 11	September 14	September 17
The heating time（h）	8.5	8.0	7.5	7.0	6.5
Receive the total radiation（MJ）	19.278	18.144	17.010	15.876	14.742
The amount of ice/cold wate（kg）	**4.8/2.2**	3.7/4.3	3.0/4.0	2.3/4.7	2.0/5.0
Direct refrigerating capacity（MJ）	2.201	1.809	1.602	1.180	1.023
COP	**0.114**	0.100	0.094	0.074	0.069

The refrigeration system performance under the mode of strengthen mass transfer

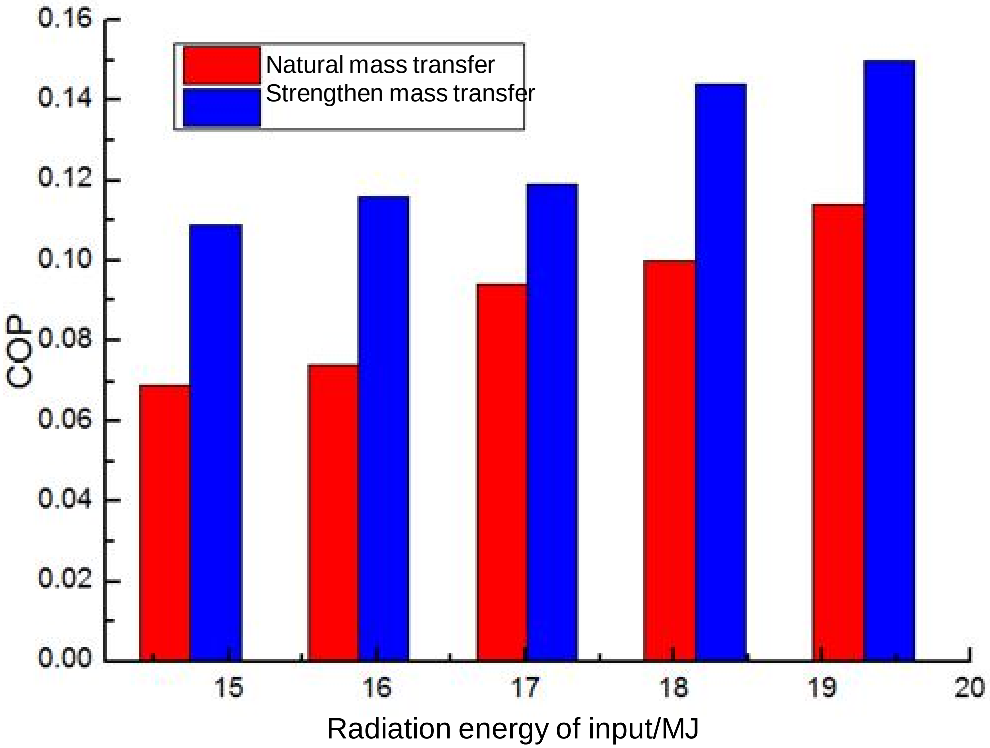
Project	September 6	September 7	September 12	September 13	September 16
The heating time（h）	8.5	8.0	7.5	7.0	6.5
Receive the total radiation（MJ）	19.278	18.144	17.010	15.876	14.742
The amount of ice/cold wate（kg）	**7.0/0**	5.8/2.2	5.0/2.0	4.2/2.8	2.8/4.2
Direct refrigerating capacity（MJ）	2.896	2.609	2.019	1.856	1.600
COP	**0.150**	0.144	0.119	0.116	0.109

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.6 Interpretation of results

Under the same conditions the COP was higher than 58.0%, 56.8%, 26.6%, 44.0% respectively and ranged from 58.0%, to 44.5% in the average.

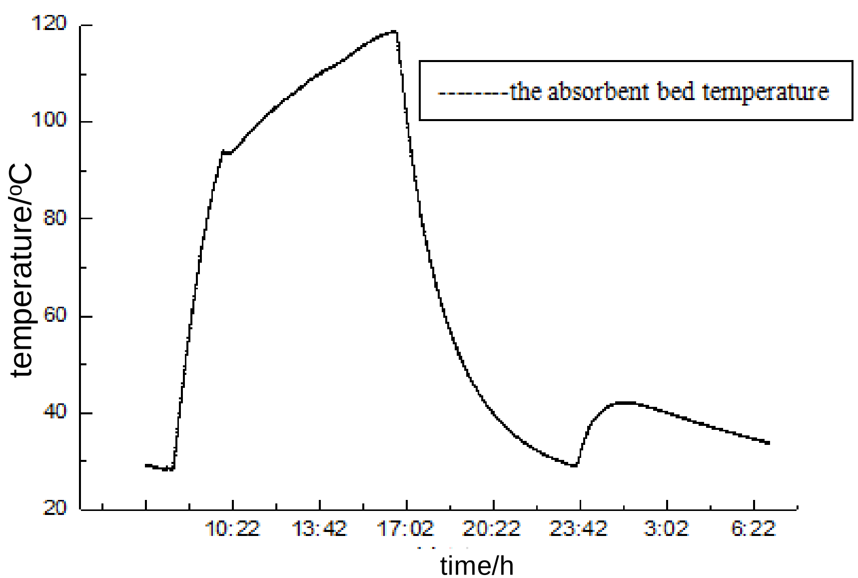
It is clear that this system under the mode of strengthening mass transfer has a high cooling efficiency, and the cooling performance was more stable, Therefore, strengthening mass transfer has obvious advantages than the mode of the natural mass transfer.



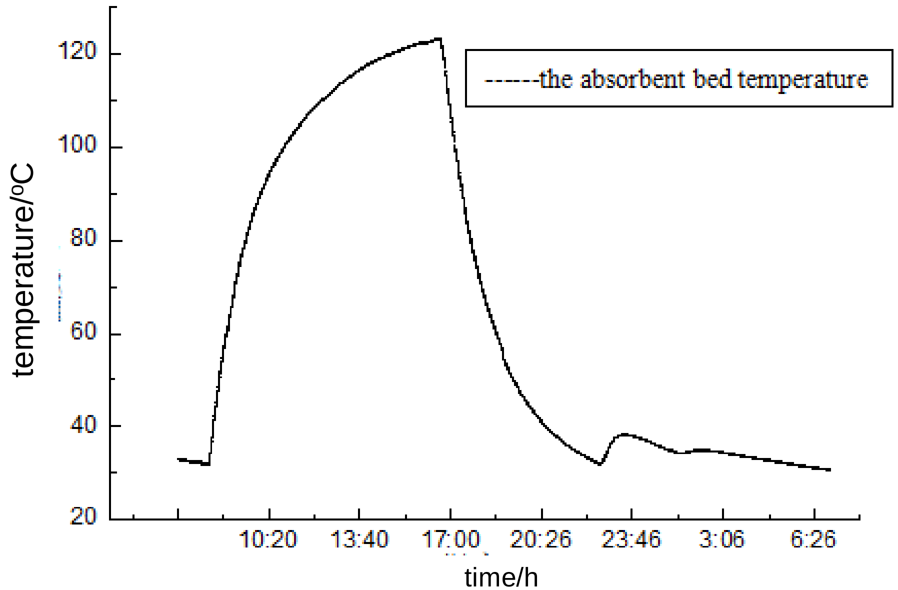
System COP contrast under the mode of natural/strengthen mass transfer

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.7 Adsorbent bed temperature changes in two modes



Mass transfer enhancement

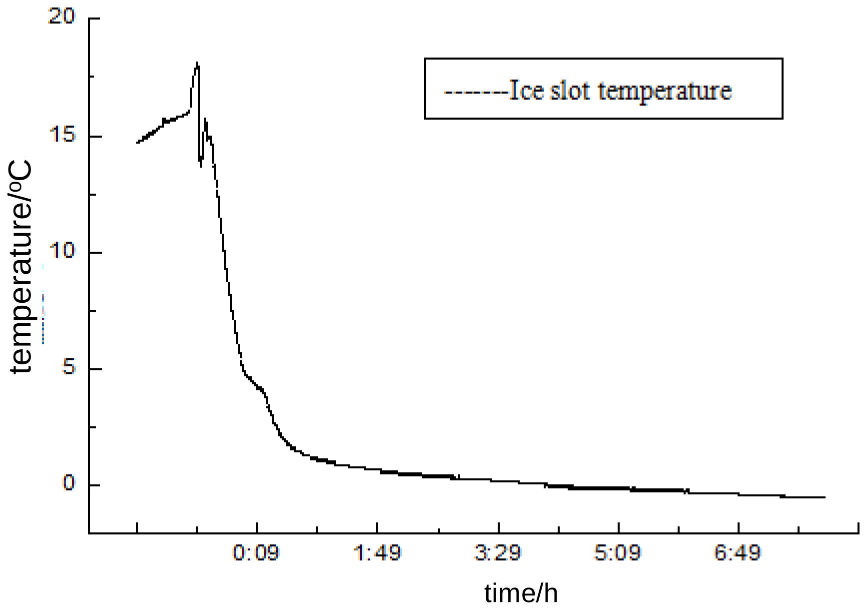


Natural mass transfer

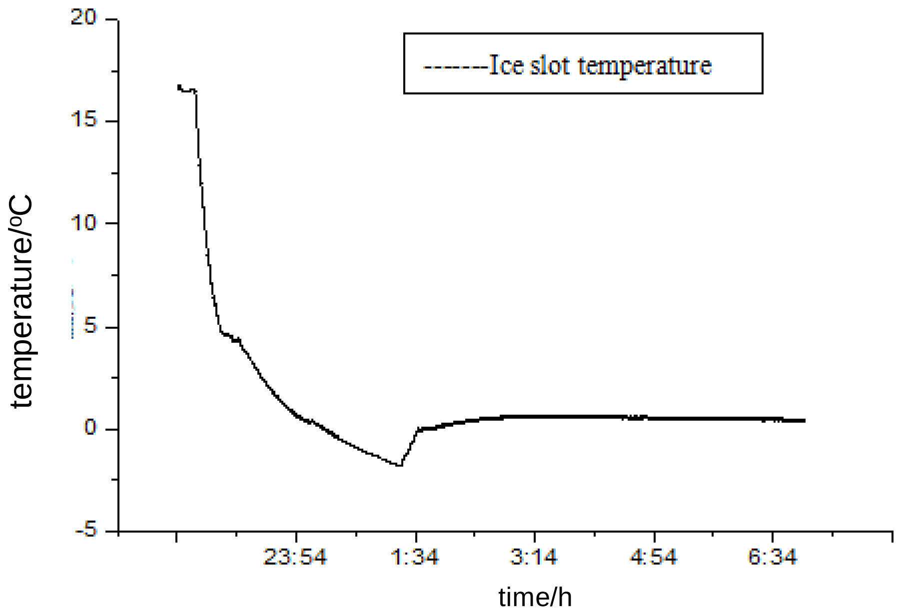
The adsorption heat under enhancing mass transfer was significantly higher than it under the natural mass transfer in the adsorption stage.

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.8 the cold water / ice temperature changes in two modes



Mass transfer enhancement

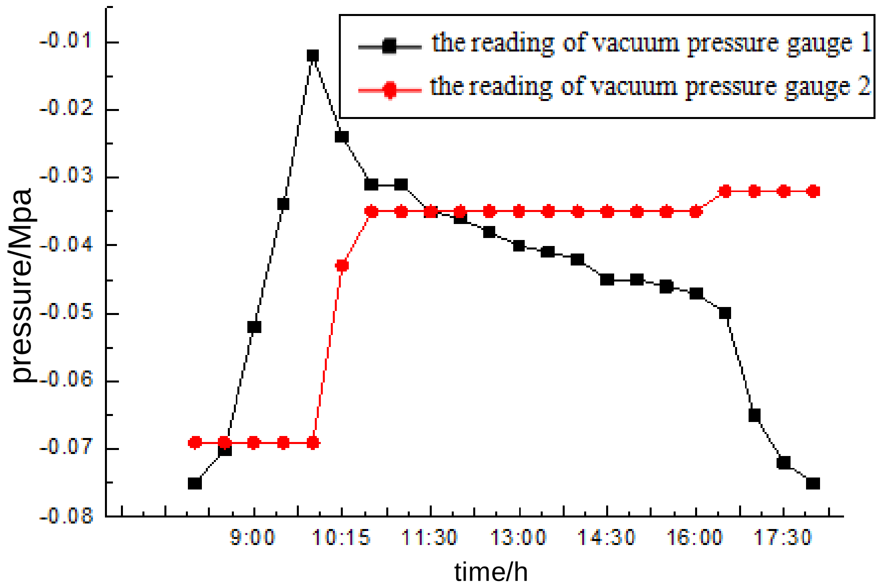


Natural mass transfer

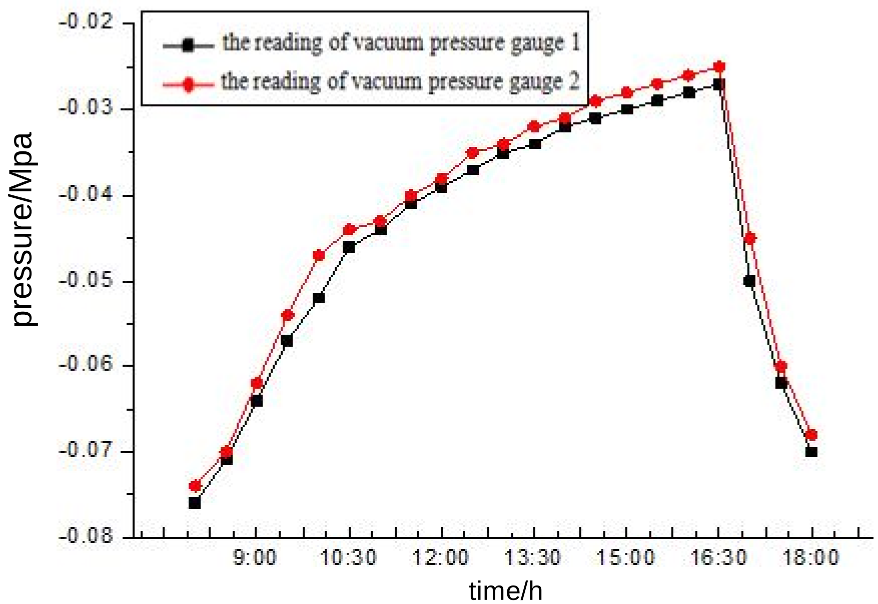
With the method of enhancing mass transfer , ice condensation rate was more faster !

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.9 Pressure changes in the system at two modes



The system vacuum gauge changes over time under enhancing mass transfer

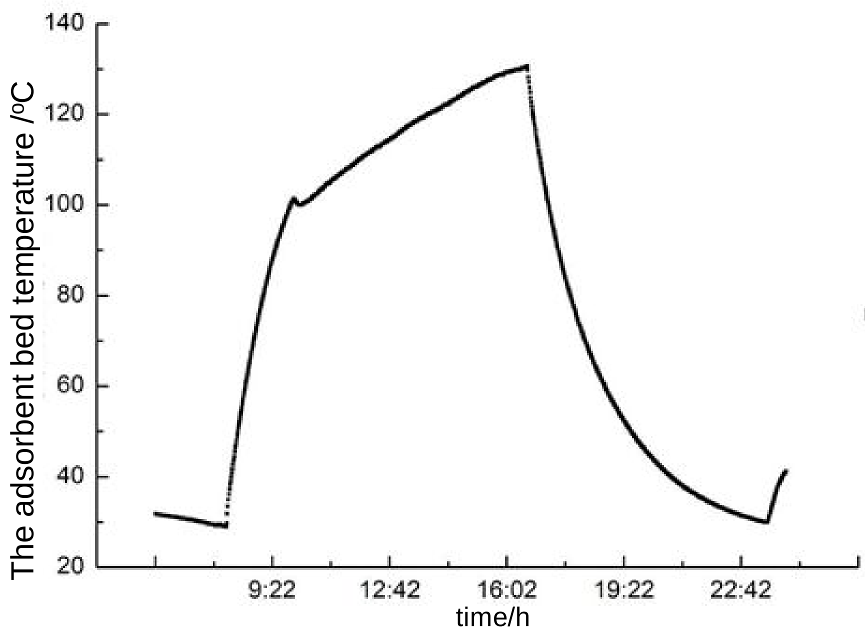


Vacuum gauge changes over time under natural mass transfer

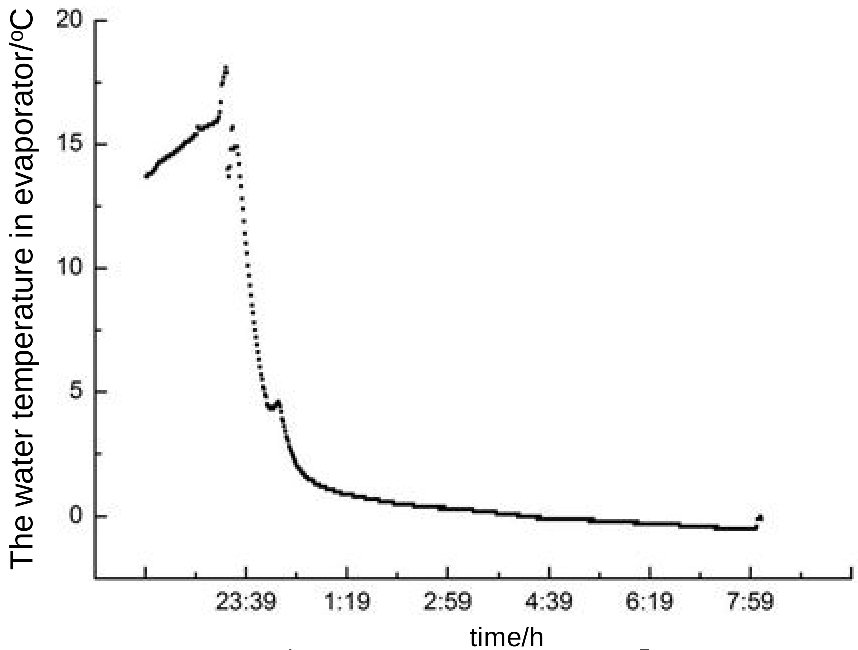
With pipeline pump，we can reduce the time of depriving vacuum，and maintain pressure stable between the condenser and the evaporator.

1.3 solar heating adsorption refrigeration——Enhancing mass transfer

1.3.10 The results analysis at enhancing mass transfer mode



the adsorbent bed temperature changes



water/ice temperature change curve in the evaporator

With the aid of the pipeline pump, water and ice temperature can effectively reduce in the evaporator and the entire adsorption refrigerator performance is effectively improved .

2 solar absorption refrigeration

Solar absorption refrigeration is based on solar energy as a driving source, thus we can get cold by relative changes occur of the refrigerant and absorbent concentration.

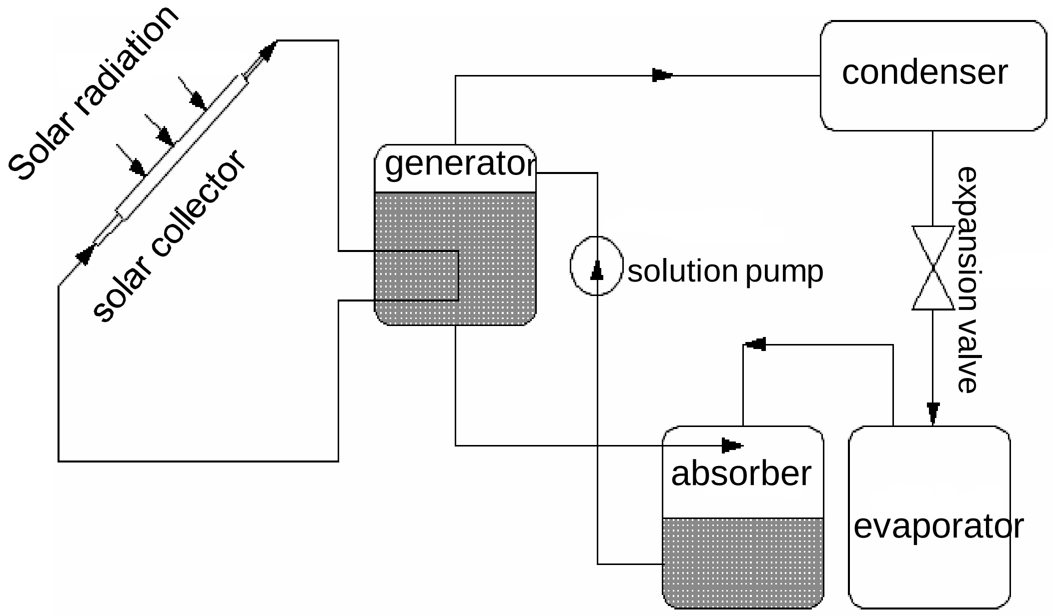
Absorption refrigeration technology is a mature technology ,which has entered the stage of commercial applications, mainly using LiBr/H_2O absorption chiller.

2 solar absorption refrigeration

2.1 Working principle

- **Working principle :**

Energy is transferred through phase-change processes (evaporation heat)

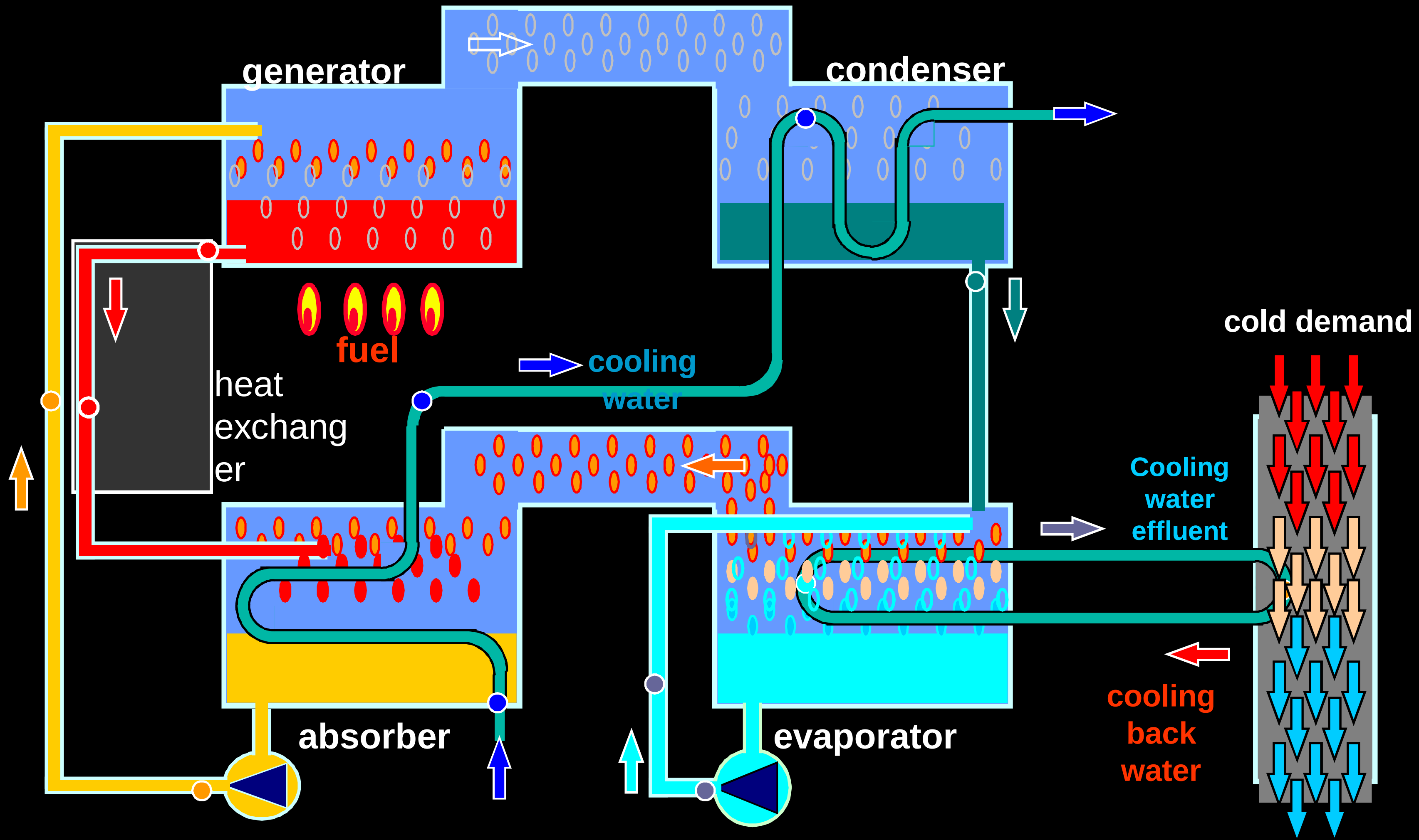


Solar absorption

•**Working Pairs**
lithium bromide -water ;
ammonia –water

•**form :**
single stage 、 multistage 、
single effect 、 multiple-effect

Dynamic principle diagram of absorption chiller



2 Solar absorption chilling

2.2 LiBr/H_2O absorption chilling

Single-effect

↓

simple structure, low cost, low driven temperature

↓

low efficiency

↓

Commercial promotion in centralized cooling buildings

Double-effect

↓

relative high efficiency, moderate driven temperature

↓

stability and durability to be improved

↓

Demonstrative projects, breakthroughs are expected

Multiple-effect

↓

high cooling efficiency

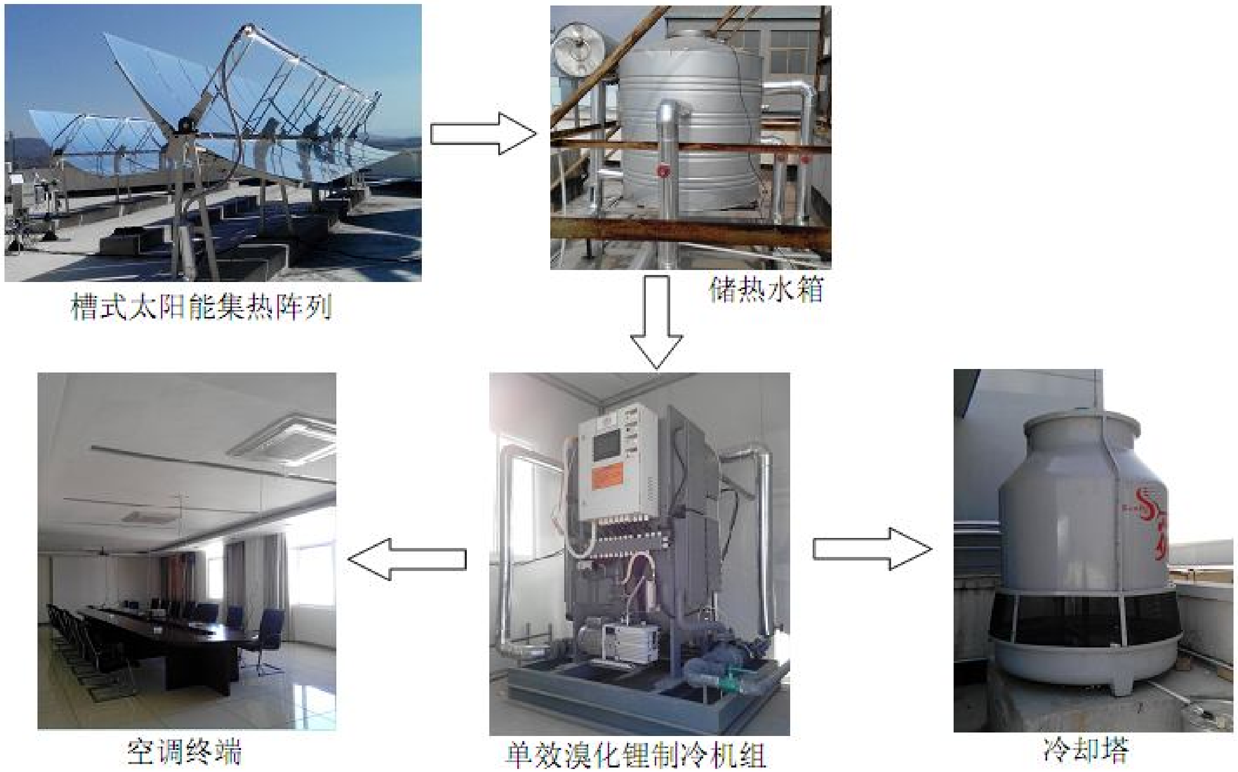
↓

complex structure, high driven temperature

↓

Scientific research stage

2.2 Single-effect LiBr/H_2O absorption chilling
2.2.1 23kW system construction



Pictures of refrigeration system

Parameters of PTC

项目	数值或说明
PTC 开口面积	56 m^2
轴向	南北向 (ψ = 0º)
集热管长度	26 m
开口宽度	2.5 m
焦距	1.1 m
工质	水
行数	2
集热管的内管直径	4 cm
集热管玻璃外径	11cm

System parameters

项目	数值
型号	TX-23
冷冻水出口	10.0 °C
空气温度	36.0 °C
热水进口温度	90.0 °C
制冷机容量	23 kW
冷冻水流量	4.0 m^3/h
热水流量	5.7 m^3/h
机组重量	1200 kg

Parameters of PTC

parameter	value	unit
Collector area	56	m^2
Rotation axial direction	North-south	-
Absorber tube length	26	m
Concentrator width	2.5	m
Focal length(f)	1.1	m
Operating temperature	50-93	°C
PTC row number	2	-
Diameter of inner tube	4	cm
Diameter of glass cover	11	cm

PTC arrays

Parameters of cooling tower

parameter	value	unit
MODEL	BLT-10	-
Air volume	10.5	km^3/h
Cooling water volume	10	m^3/h
Motor power	0.75	kW
Net weight	165	kg
Operating weight	330	kg

Parameters of refrigerating unit

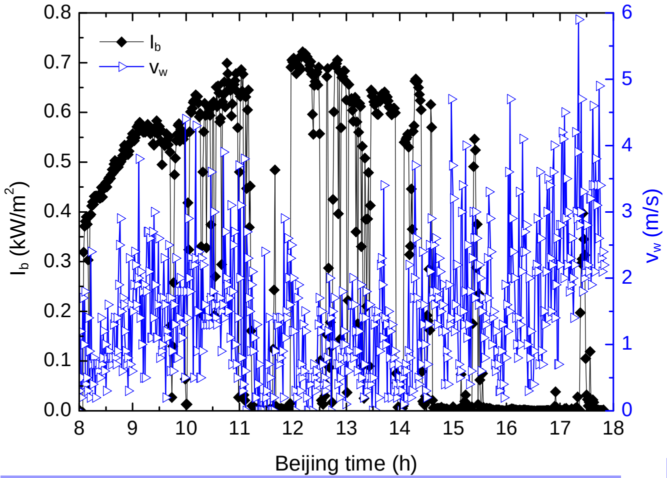
parameter	value	unit
MODEL	TX-23	-
Cooling water outlet temperature	10.0	°C
Hot water inlet temperature	90.0	°C
Power consumption	2.3	kW
Refrigeration capacity	23	kW
Flow of cooling water	3.24(0.9kg/s)	m^3/h
Flow of hot water	4.9(1.36kg/s)	m^3/h
Unit weight	1200	kg

Parameters of fan-coil EKCW800KT

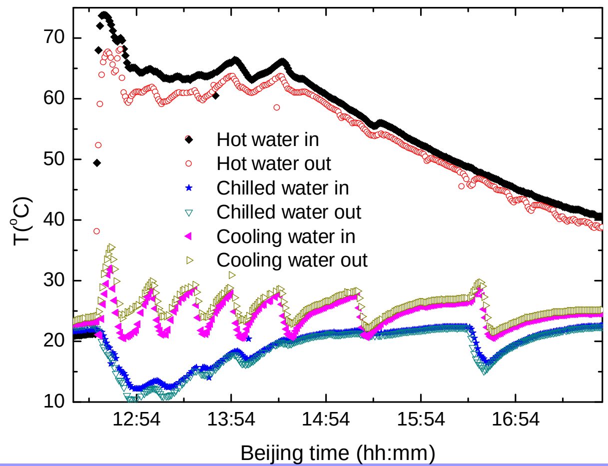
parameter	value	unit
MODEL	EKCW800KT	-
H	1360	m^3/h
M	1210	m^3/h
L	1100	m^3/h
Cooling capacity	7200	W
Heating capacity	10800	W
Input power	130	W

2.2 Double-effect LiBr/H_2O absorption chilling

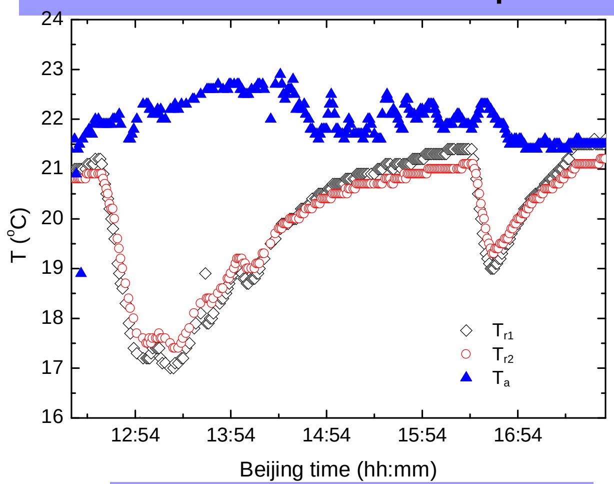
2.1.1 Experimental results



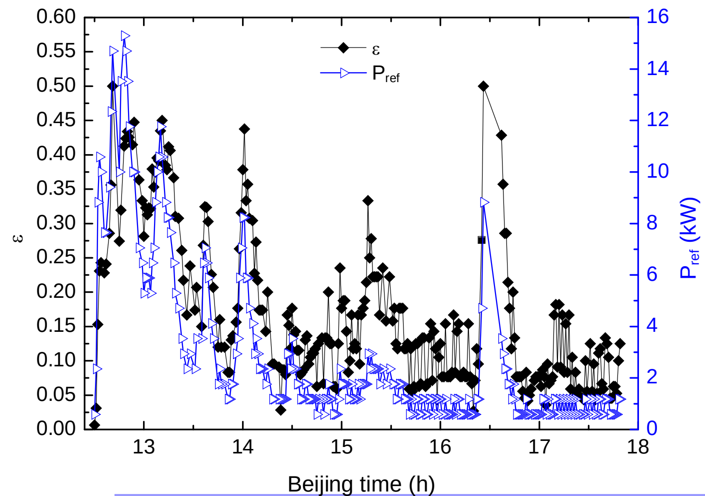
Irradiation and wind speed



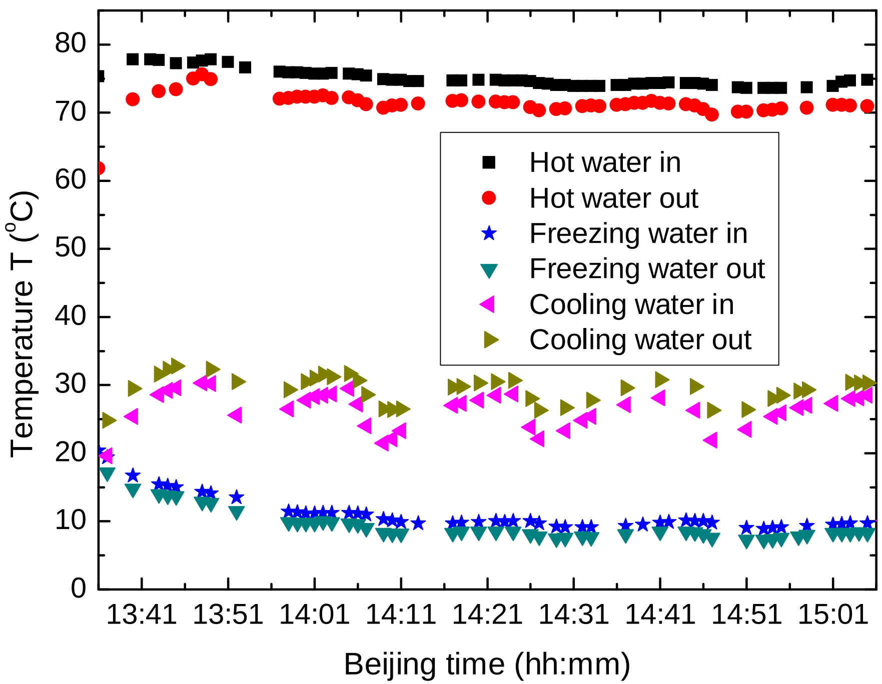
Temperatures of heating, refrigerating and cooling outputs



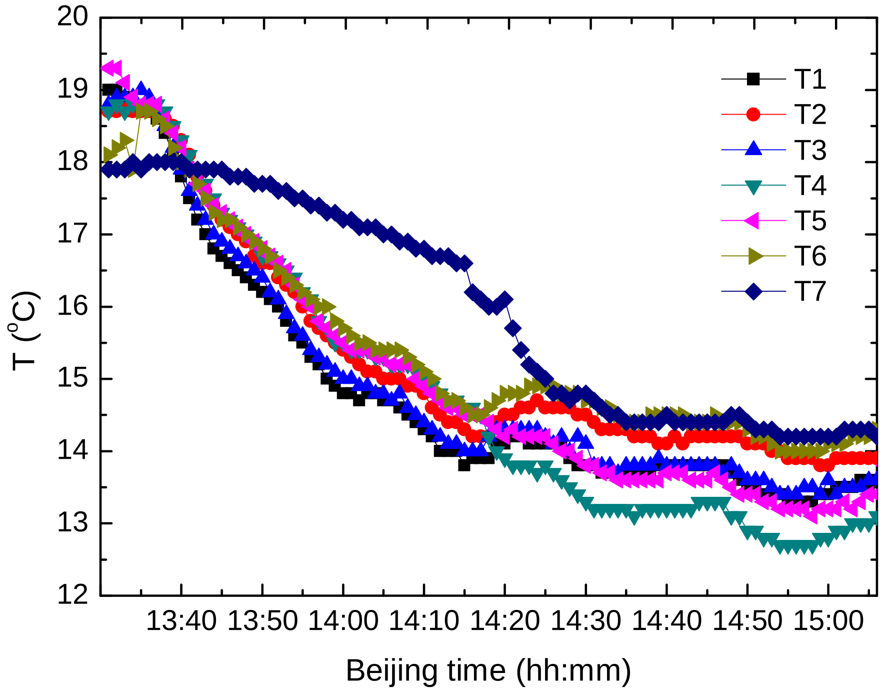
Indoor temperature



COP and cooling capacity



Inlet and outlet temperatures of generator, evaporator and condenser



Temperature variation of refrigeration terminal (a meeting room)

T1–T7 are temperatures of different positions in the room, meeting room volume：$279m^3$ （testing time：2014-03-02）

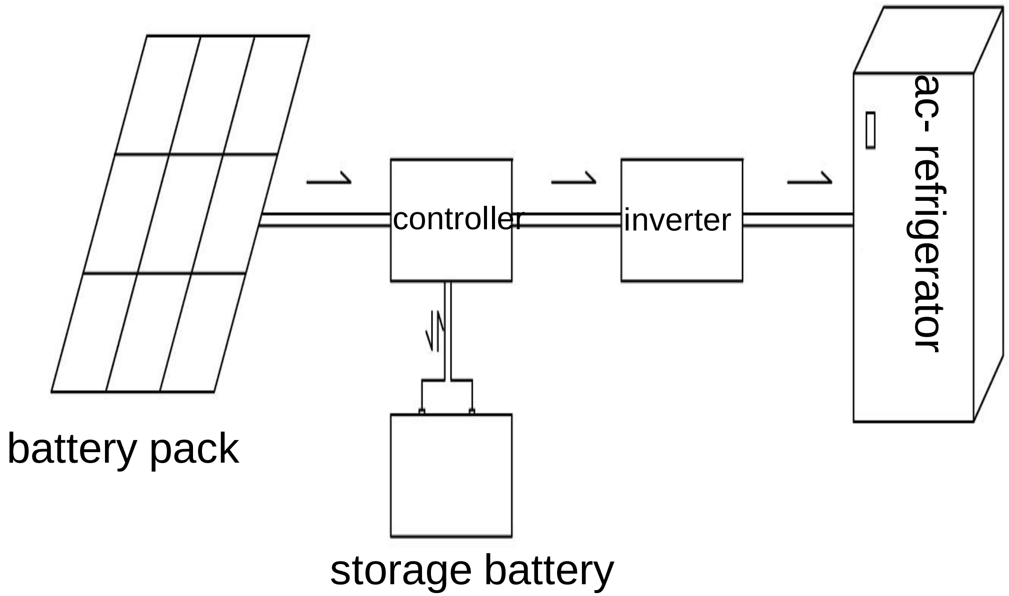
Room temperature dropped from 19℃ to 13℃, COP was 0.35-0.71

3 Solar energy photovoltaic refrigeration

3.1 The working principle

- Working principle ：

Through the panel light into electricity, and then through the controller, inverter, battery driven refrigerators work, etc.



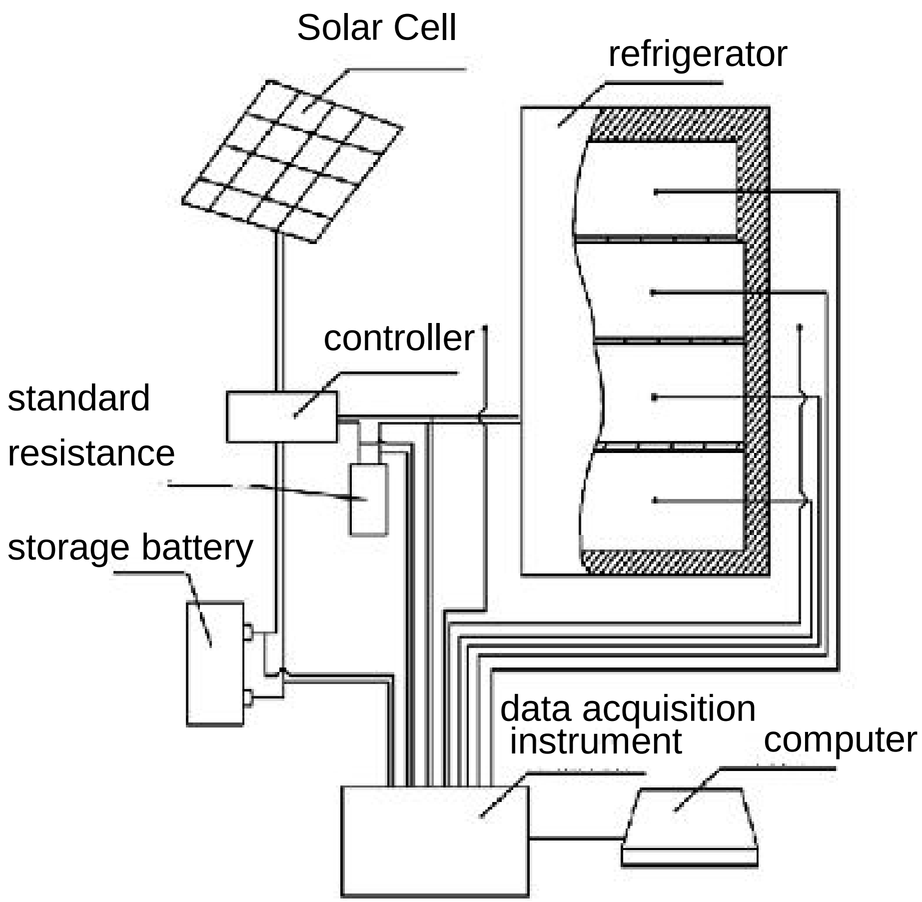
PV refrigeration

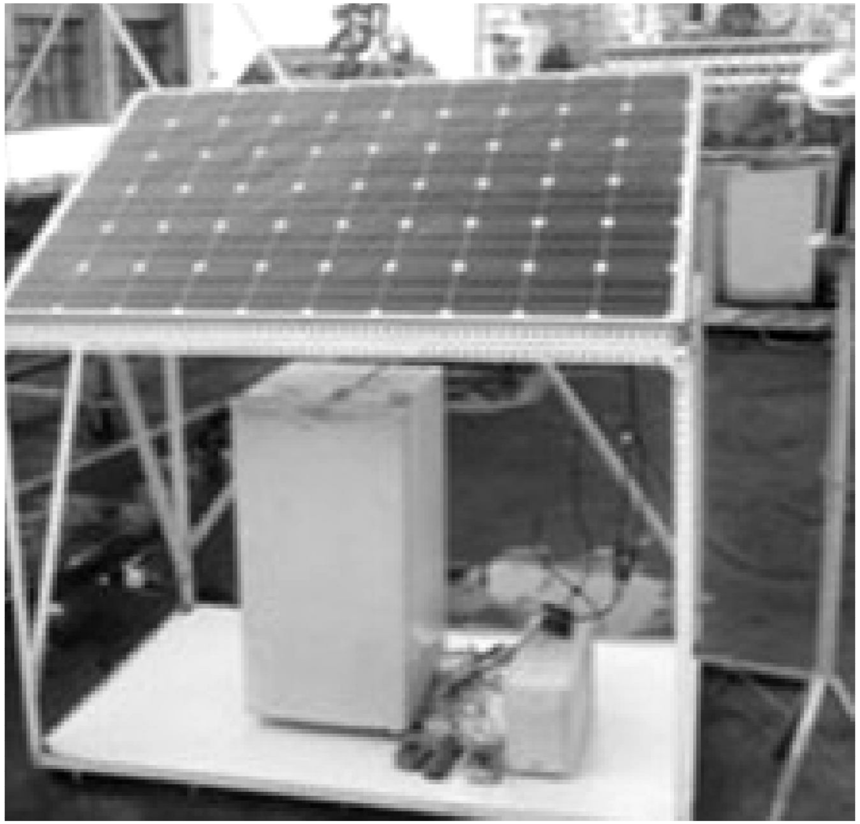
- **main device**

solar cell panel ， inverter ， transformer ， storage battery ， ac- refrigerator and so on 。

3.2 Solar energy photovoltaic fridge

3.2.1 Photovoltaic fridge working principle and experiment platform





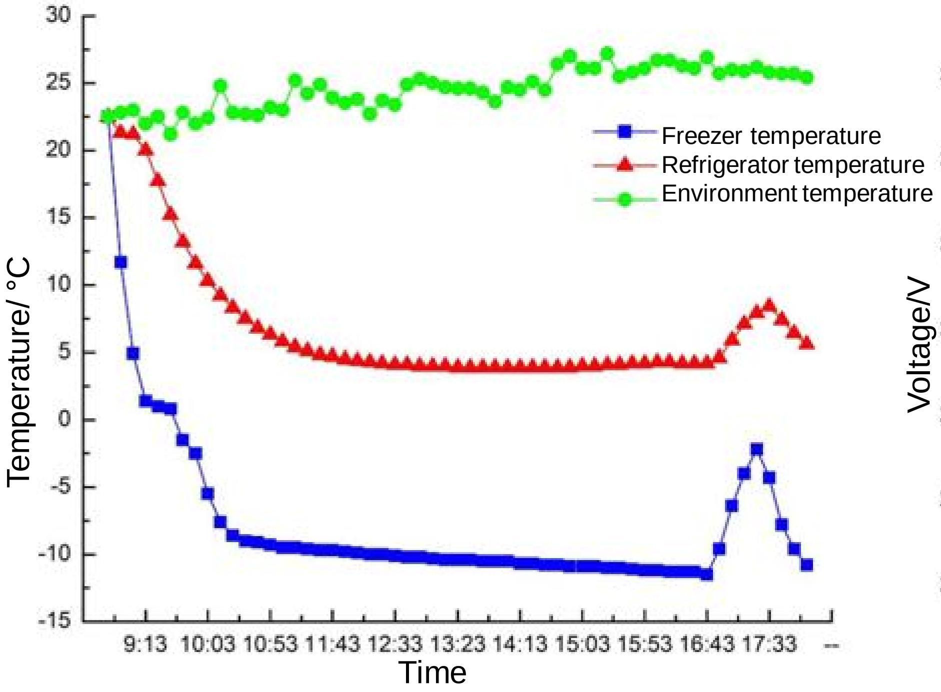
3.2 Solar energy photovoltaic fridge

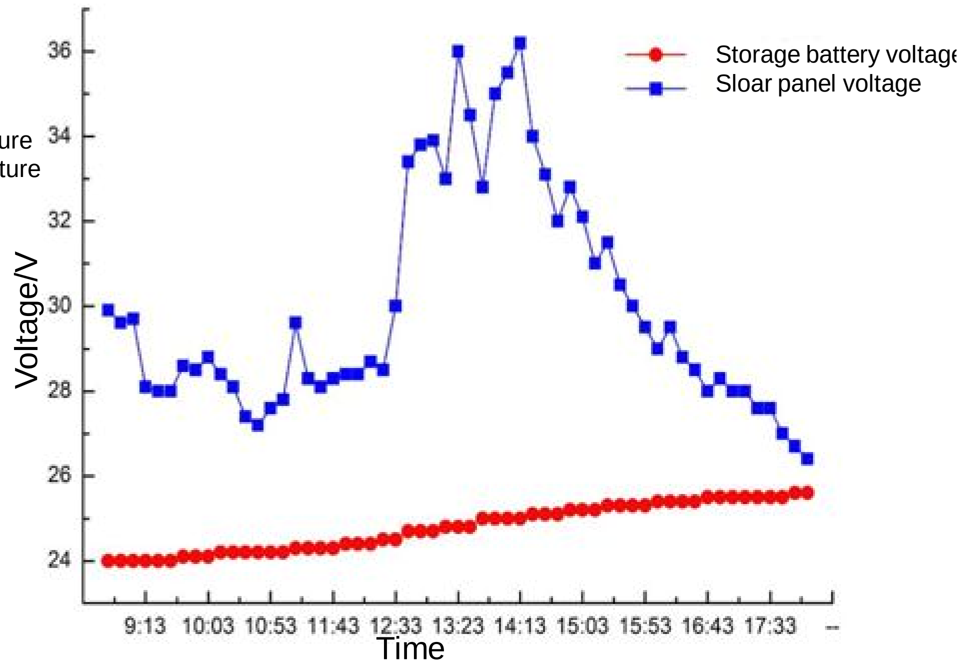
3.2.2 Photovoltaic fridge experimental results

Date	2013.08.30	2013.09.15	2014.05.28	2014.05.30
Receive the total radiation (MJ)	5.37	12.19	11.3	13.79
The fridge minimum temperature (℃)	-9.7	-15.5	-16.0	-17.7
Ice-making capacity (kg)	1.58	3	6	7
COP	0.15	0.12	0.25	0.24

3.2 Solar energy photovoltaic fridge

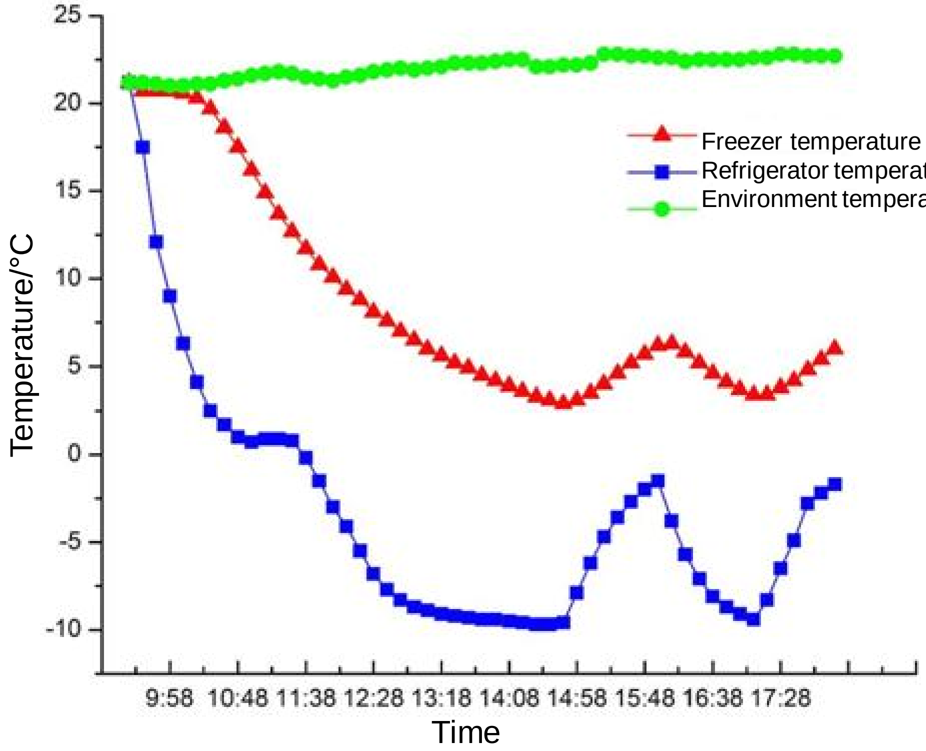
3.2.3 Photovoltaic fridge performance analysis

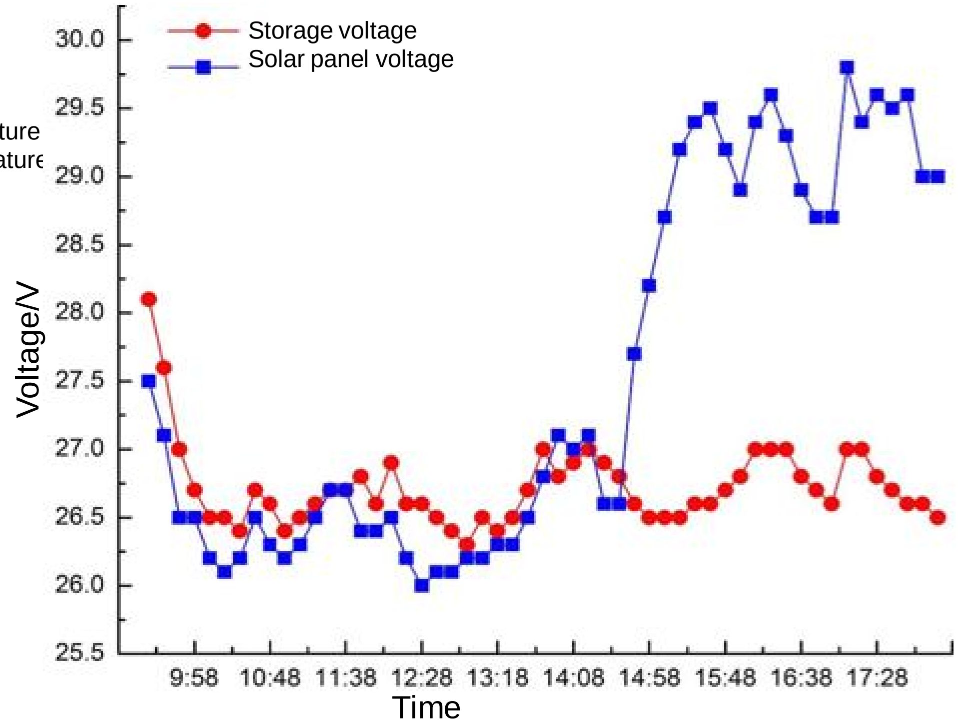




Solar energy fridge system performance test under the condition of suny day

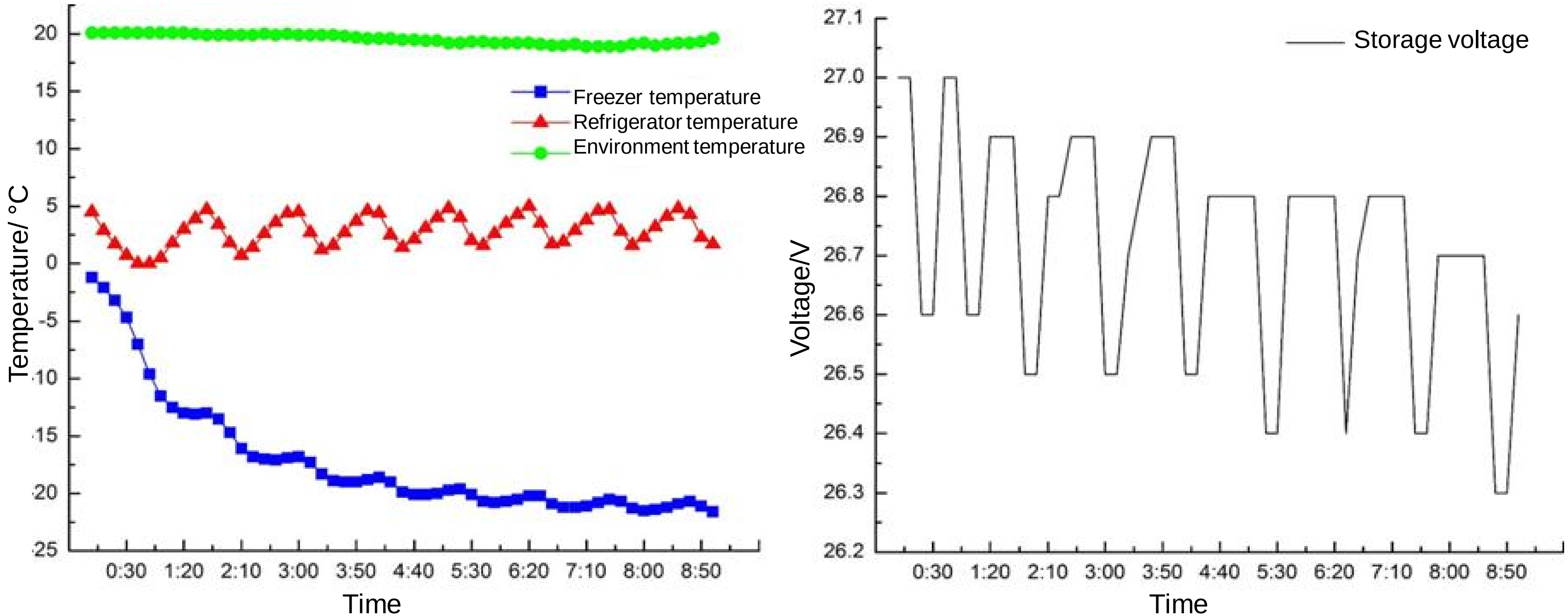
The freezer and fridge temperature dropped to 0 ℃, 5 ℃， respectively whithin 60 min, 18 min, provided power by standing alone solar panels, battery voltage added 1.6 V in the process of experiment





Solar energy fridge system performance test under the condition of cloudy day

The freezer and fridge temperature dropped to 0 and 5 ℃， respectively whithin 50 min, 130 min, the storage battery and solar panels alternating provide power to the system in the experiments, battery voltage droped 1.6 V in the process of experiment



Solar energy fridge system performance test under the condition of overcast day

The fridge is provided power by the storage battery ,the minimum temperature of the freezer was - 22 ℃, freezer temperature was cyclical changed within 0 to 6 ℃, storage battery voltage drop 1.9 V, the fridge operation rate was 32%

3.3 Solar energy photovoltaic air-condition

3.3.1 Photovoltaic air-condition system main components

Photovoltaic generate electricity components

The control inverter

The storage battery

The air-condition

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.2 Parameters of photovoltaic air conditioning system

Office area	23.3m^2
Office volume	88.3m^3
Thermal load	1087.74w
Cooling load	971.397w

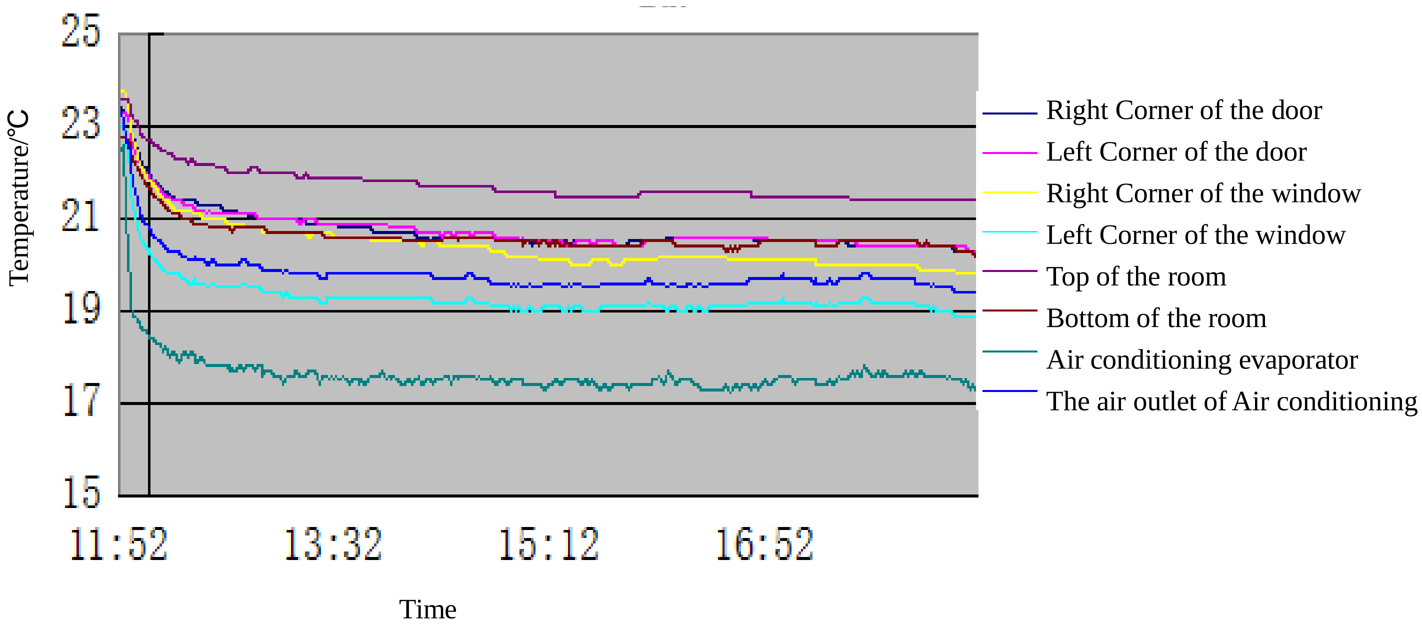
Solar energy photovoltaic air conditioning office

part	Parameter name	Value
Solar cell array	Rated power	2.65kw
Controller	Rated voltage	48V
	Maximum current	60A
Inverter	Rated voltage	48V
	Rated power	3kW
Battery	Rated voltage	48V
	Rated power	130Ah
Inverter Air Conditioner	Refrigeration input power	0.1—1.4kW
	Heating input power	0.19—1.57kW

Parameters of solar energy photovoltaic air conditioning system

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.2 Performance analysis of photovoltaic air conditioner for energy supply model

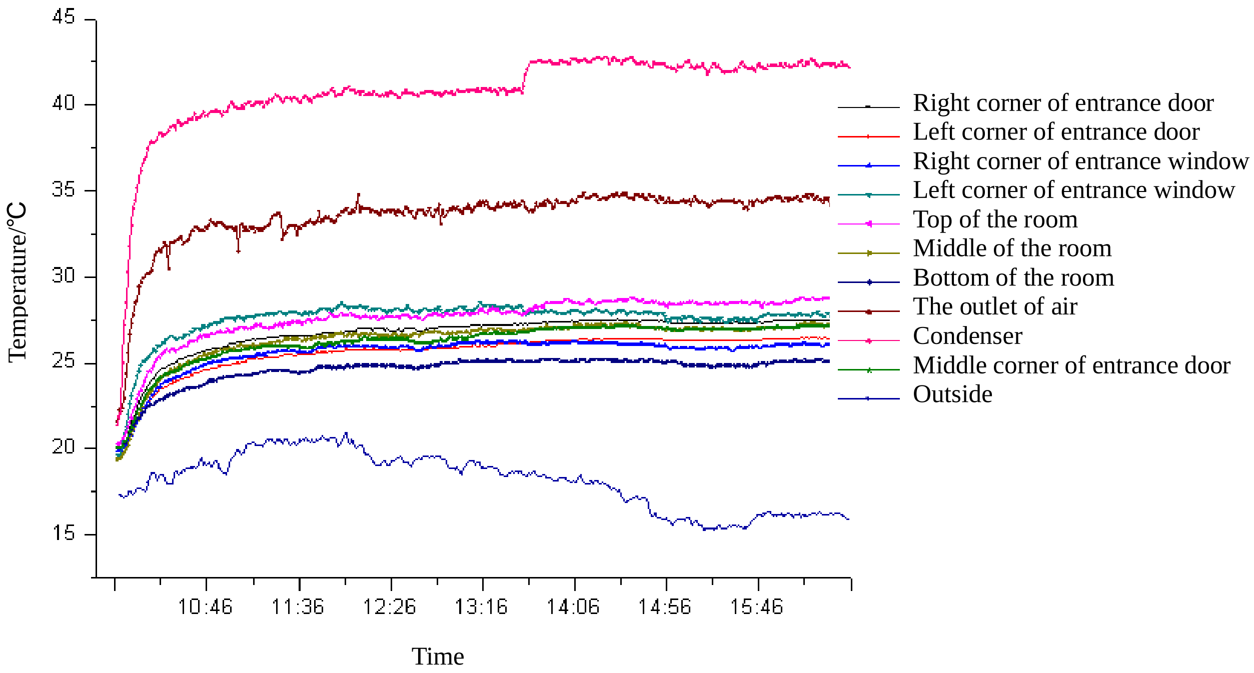


The drop graph of cooling Air temperature

It was observed that the room air temperature takes 40 minutes to decrease from 24℃ to 21℃ and it takes 2 hours to be stable at 19.3 ℃. The COP for the whole system ranged from 0.32 to 0.4

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.2 Performance analysis of photovoltaic air conditioner for energy supply model

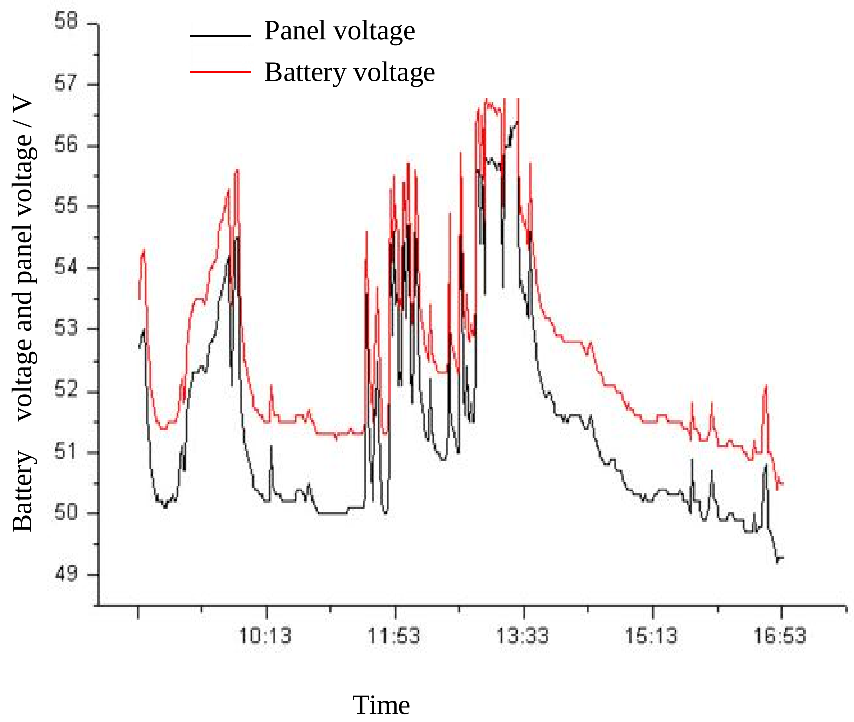


The rise graph of heating Air temperature

It was observed that the room air temperature takes 40minutes to increase from 19℃ to 26℃ and The COP for the whole system ranged from 0.3 to 0.38

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.3 Photovoltaic air conditioner Operation Conditions



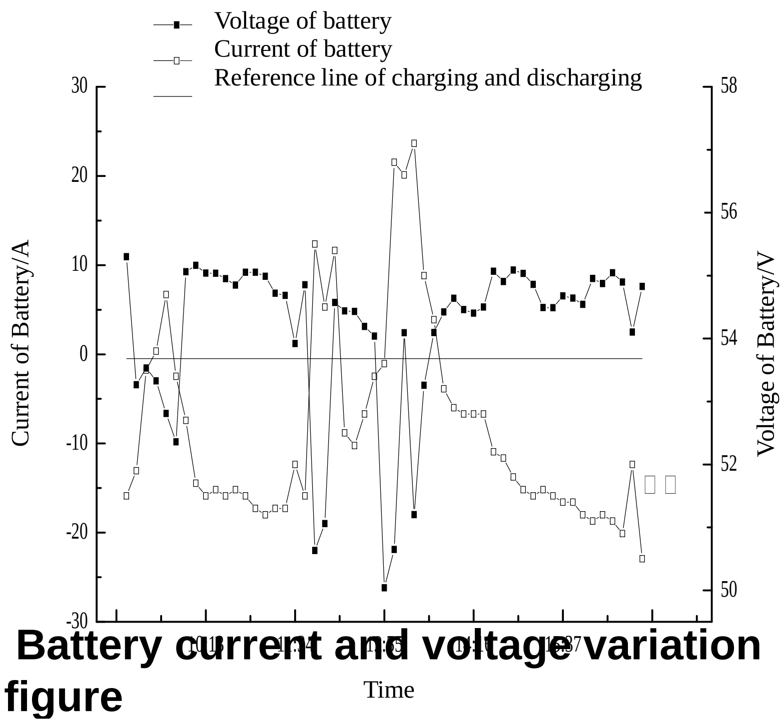
System voltage parameter change

Time of only batteries supply energy	
Maximum power at the thermal mode	7 hours
Maximum power at the refrigeration mode	9 hours
Automatic Mode	13 hours

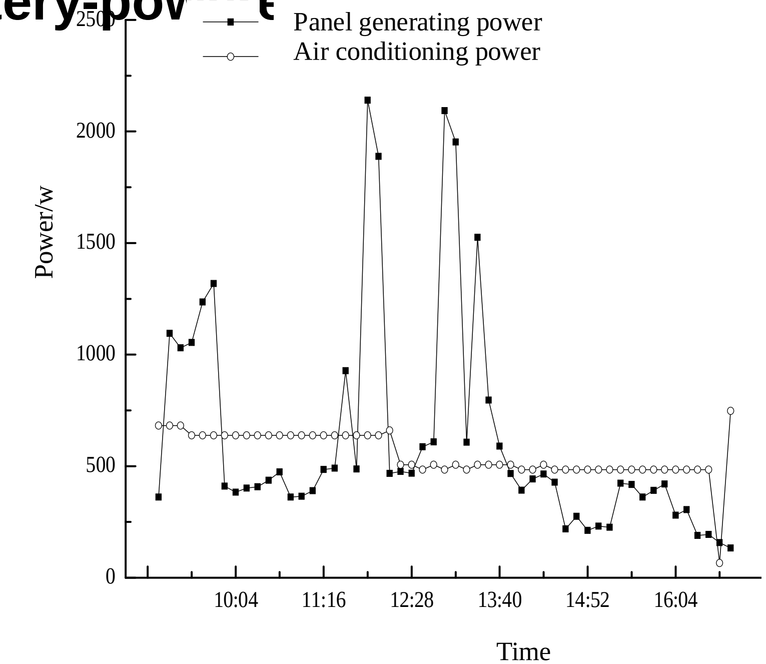
System operation time

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.4 The result analysis of combined power supply at the mode of PV modules and battery-powered



Battery current and voltage variation figure



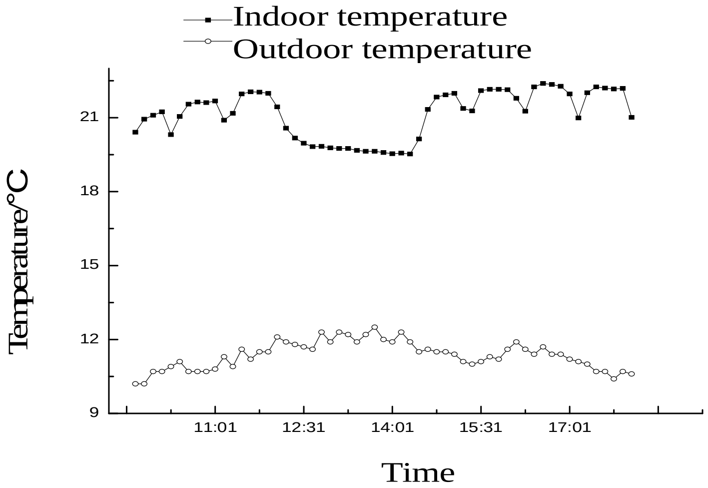
PV power and air conditioning power

The maximum charging current of the battery was 26.5A ,
Total charging of battery during the operation was 58Ah

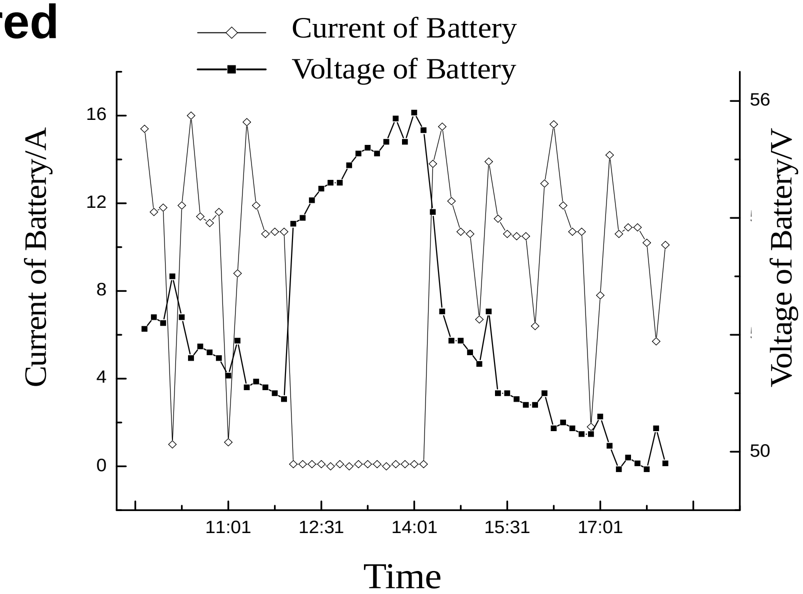
The total output of electrical energy was bigger than the air conditioning total electricity consumption on day time , highest generated output 2.2kW,and the ai conditioning maximum power was 0.8kW

3.3 Solar Energy Photovoltaic Air Conditioner

3.3.5 The result analysis of power supply at the mode of battery-powered



Indoor and outdoor environment temperature variation figure



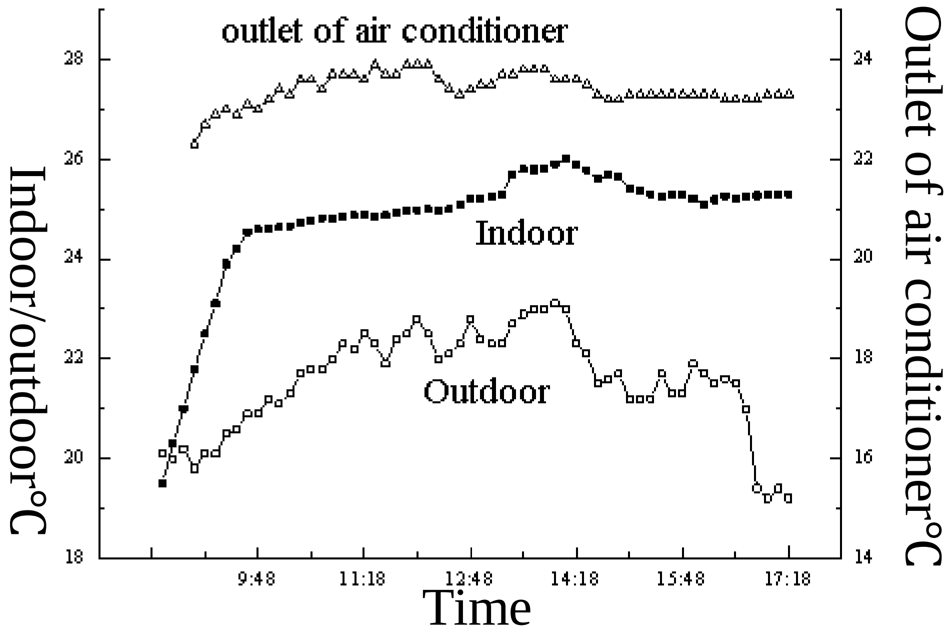
Battery current and voltage variation figure

The time operation for the Air conditioner was 8:30-12:00 and 14:00-18:00. it was found that the average air temperature differences between indoor and outdoor was 10.5℃ during the operation periods.

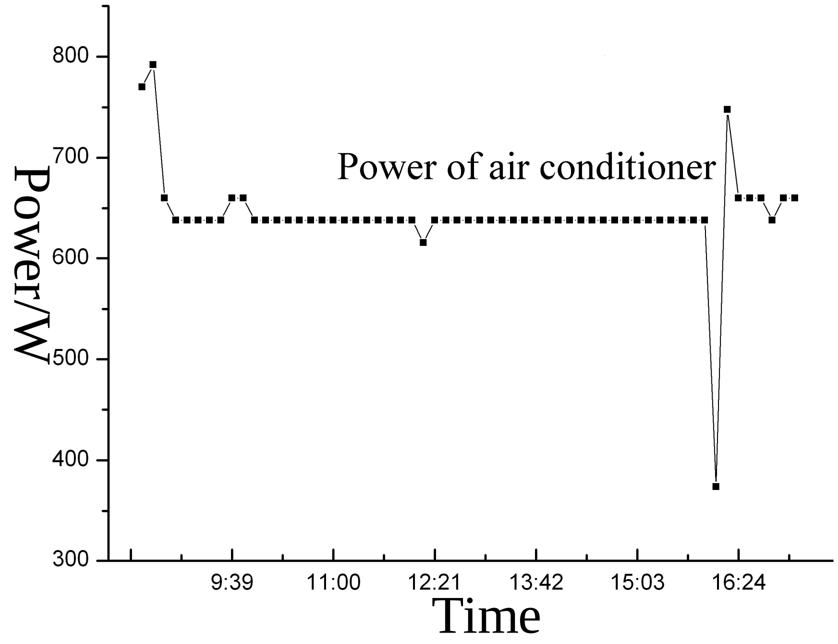
Battery Max discharging current was 16.3A ，battery minimum voltage was 49.8V

3.3 Solar Photovoltaic air conditioner

3.3.6 In the model of grid power providing independently



The changes of environment



The changes of air conditioner power

Open time 8:00-19:00，setted temperature: 25℃

Time consuming(19.4℃-24℃):50min

Maximum power: 0.8kW;

Average power: 0.65kW

3.4 solar photovoltaic ice making and ice storage air conditioning

Ice storage is widely used in central air conditioning system of large buildings for its low cost and mature technology because it can alleviate the pressure of electricity using peak and save electric charge

Set up a experimental platform

Photo of ice maker

Photos of ice storage air conditioning

3.4 solar photovoltaic ice making and ice storage air conditioning

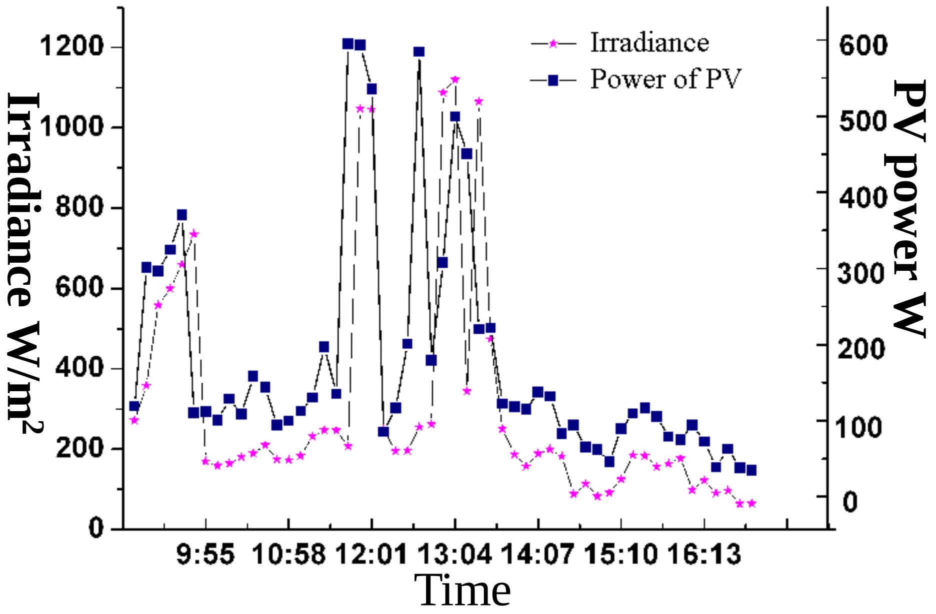
3.4.1 Experimental results

Ice （kg/d）	23.2
Power consumption（kW·h/d）	9.50
Ice making efficiency	0.40
Cold exchanger efficiency	0.70
Comprehensive efficiency	0.28
Ice temperature（℃）	-5
Ice storage tank temperature（℃）	-2
Refrigerant outlet temperature（℃）	2
Air conditioner outlet temperatre（℃）	15
Refrigerating capacity unit PV（W/m^2）	310

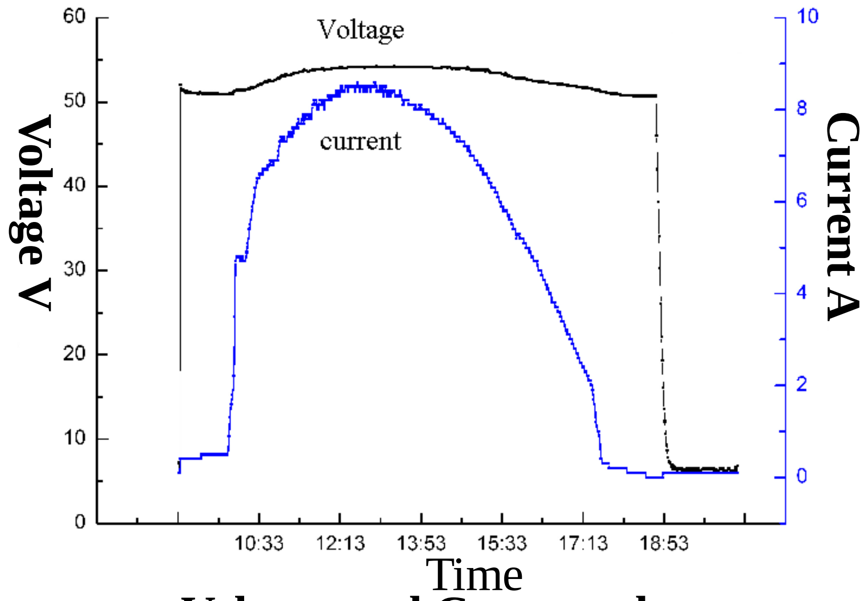
The air conditioning system efficiency was 0.28 which is close to the single effect LiBr/H_2O absorption system

3.4 solar photovoltaic ice making and ice storage air conditioning

3.4.2 Results analysis



PV power varies with solar irradiance

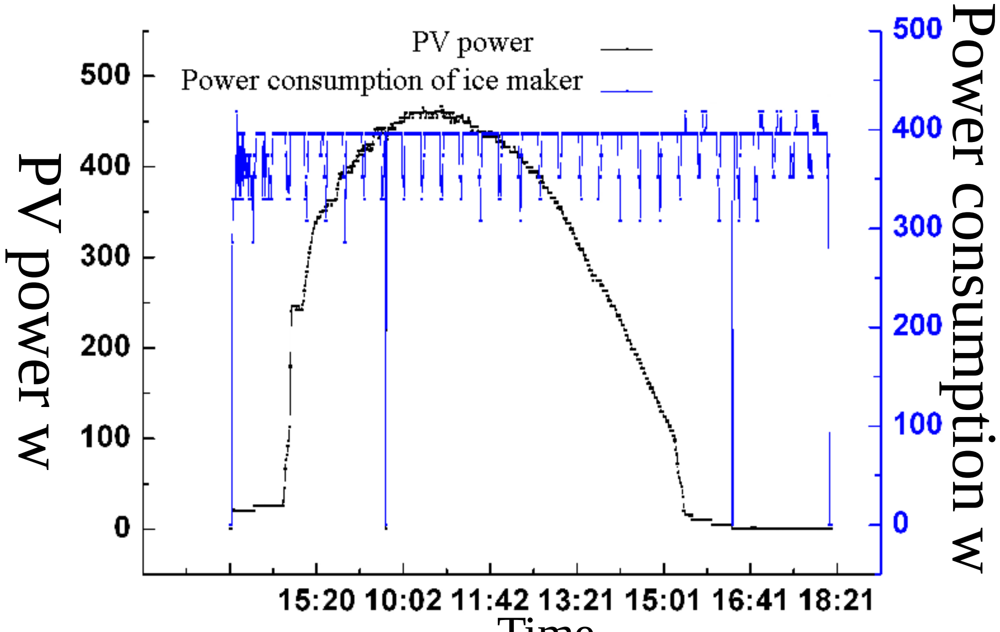


Voltage and Current change

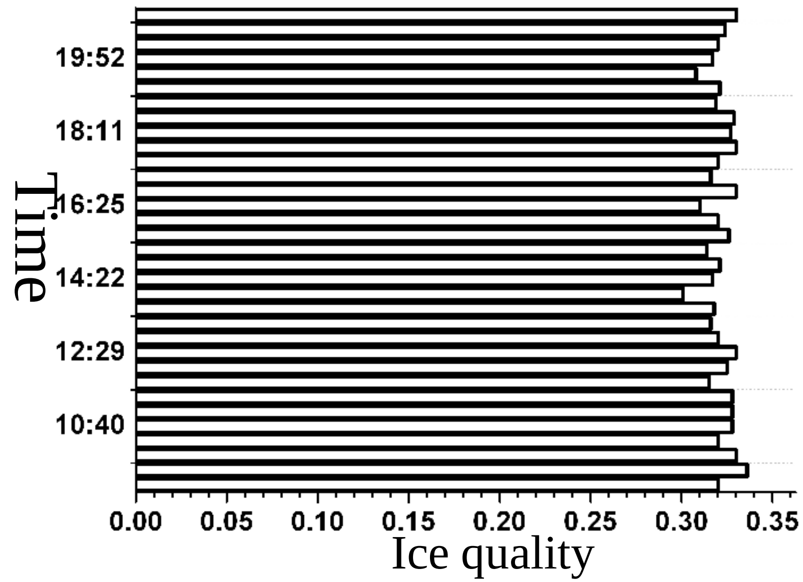
Output power changes with irradiance and its stability is very poor so the coupling performance between PV and energy using units will be given the priority of research work in future.

Current changing with irradiance is the main reason for the instability of output power

3.4 solar photovoltaic ice making and ice storage air conditioning



Changes of PV power and ice maker consumption power



Ice quality of maker driven by PV

The consumed Power was 380W by ice maker which is always stable in ice making process

Time consuming was 10min and ice quality was 0.32kg in every ice making process.

4 Summary

4.1 Solar heating adsorption refrigeration

a. The refrigeration efficiency can be improved by 50% with enhancing the mass transfer achieved by pipeline pump. At the same time, refrigerating cycle can be shortened.

b. Green refrigeration will come true when photovoltaic is used to drive pipeline pump to enhance refrigerant mass transfer.

4 Summary

4.2 Solar heating absorption refrigeration

a. Driven by trough concentration heating system, 23kW Double LiBr/H_2O absorption refrigeration coefficient can reach about 0.37 at a running stable system .

b. The temperature of 50m^2meeting room can drop from 19 degree down to 13 degree within 2 hours and remaining stable when it is cooled by 23kW Double LiBr/H_2O absorption refrigeration driven with trough concentration heating system.

4 Summary

4.3 Photovoltaic refrigeration

a. The development of PV refrigeration is depending on the cost and technology of energy storage, the main problem is the energy storage, therefore it should be changed to a PV refrigeration.

b. Ice storage technology has a huge advantages for replacement the batteries.

Thanks you for your Attention!