SORPTION FRIENDS III

Experimental studies of silica-gel adsorption systems for data center cooling and cold storage applications

Shuai DU (Dr.)

Institute of Refrigeration and Cryogenics

Shanghai Jiao Tong University

Shanghai, China

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Overview

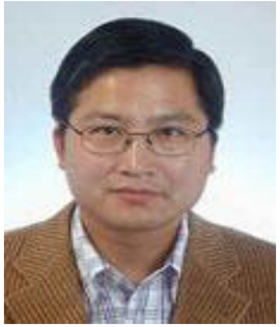
- **1896**, **Nanyang Mission College (the predecessor of Jiao Tong University) was established**
- **1956**, **Jiao Tong University firstly established the major of refrigeration and cryogenic engineering in China**
- **1981**, **authorized to confer master's degree**
- **1986**, **authorized to confer doctoral degrees**
- **2002**, **rated as a national key discipline for doctoral programs**
- **2010**, **Second prize of National technological invention**
- **2014**, **Second prize of National Natural Science**
- **2015**, **Innovation Group of NSFC**
- **2023**, **Major project of NSFC**

In refrigeration and cryogenics, Shanghai Jiao Tong University ranks top in the Chinese universities.

Teachers

30 faculties: 12 professors, 3 research professors, 8 associate professors, 2 assistant professors, 2 research assistant professors, 3 lab technicians

Ruzhu Wang



Jiangping Chen

Guoliang Ding

Yanjun Dai

Tianshu Ge

Tingxian Li

Liwei Wang

Xiaoqiang Zhai

Peng Zhang

Jingyi Wu

Yonglin Ju

Xinqiao Jin

Research fields

- Mainly 4 directions on basic research and applied research
- **Energy utilization of R & AC systems:** sorption refrigeration and heat pump systems, dehumidification, water harvesting from air, high temperature heat pump, CCHP, green buildings, solar systems, thermal and cold storage
- **Simulation and design of R & AC systems:** Dynamic simulation, Automobile air conditioning system design and thermal management, refrigeration equipment and heat exchanger design
- **Cryogenic systems and cryogenic heat transfer:** Heat and mass transfer of cryogenic fluids, Cryogenic techniques related to superconductivity, Liquefied natural gas technology, cryogenic refrigerator
- **Air conditioning system energy saving and thermal comfort:** Design and optimization of HVAC system，Indoor air quality control

Funding

1993, research funding 0.6 million RMB, 2 SCI papers

2006, research funding 15 million RMB, 60 SCI papers

2015, research funding 44.7 million RMB, 90 SCI papers

2021, research funding about 80 million RMB, >100 SCI papers

National support:

National Key Research and Development Program

Major project of NSFC

Key project of NSFC

Innovation Group Project of NSFC

Other projects from NSFC and SCST

Enterprise support:

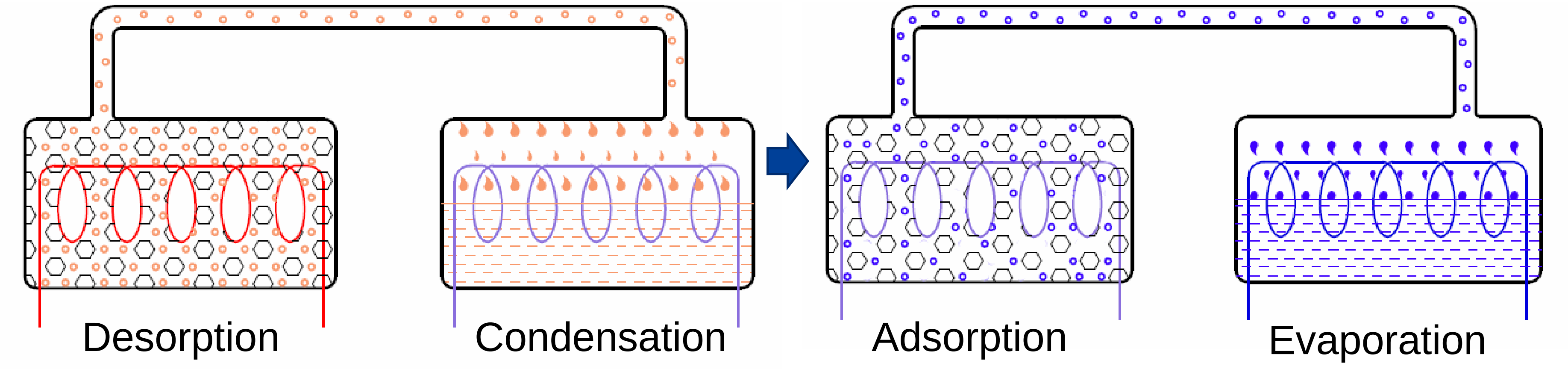
Media, Gree, Dakin, Linuo-paradigm, Hanbell, and so on

Lab conditions

1. A great many facilities for testing, Analysis and Test Centre
2. Sufficient space for experiment, 2000m^2 main building lab, 1000m^2 Sino-Italian green energy lab
3. Highly trained laboratory staff
4. Convenient manufacturing

Contents

1. Introduction



Advantage of no moving parts

Various working pairs

Most commonly used adsorbents: **activated carbon, zeolite and silica gel.**

Most commonly used refrigerants: **NH_3, methanol and H_2O**

1. Introduction

Adsorbent	Refrigerant	Adsorption heat (kJ/kg)	Remarks
Activated alumina	H_2O	3000	Vacuum;
Zeolite	H_2O	3300–4200	Vacuum;
	NH_3	4000–6000	Positive pressure; toxic;
	CH_3OH	2300–2600	Vacuum; flammable
Silica gel	CH_3OH	1000–1500	Vacuum; flammable
Silica gel	H_2O	2800	Vacuum;
Calcium chloride	CH_3OH	1800–2000	Vacuum; flammable; corrosive
Metal hydrides	Hydrogen	2300–2600	flammable
Complex compounds	NH_3 or H_2O	2000–2700	corrosive

MOFs, COFs: DUT-67 – water, COP 1.43

SFO aluminium phosphate: Te: 5 °C, Th: 65 °C, COP 0.85

Expensive

For current practical use, **Silica gel-water** is the preferable working pair in terms of **non-toxic, non-flammable and low cost.** Moreover, they are suitable for low temperature heat reuse.

1. Introduction

Sorbent and system properties and performance.

Sorption pair/ system	COP	SCP (W/ kg)	Te (°C)	Td (°C)	Thermal conductivity (W/m·kg)	Bulk density (kg/m^3)	Characteristics	Comments	Reference
Silica gel/water	0.61	208	12	82	–	–	–	–	[22,23,133–137]
	0.4	85	10	–	–	–	Split heat pipe type evaporator	Data obtained experimentally	[22,109,138]
	0.36	–	10	55	–	–	–	–	[26,139]
	0.5	–	15	85	–	–	–	–	[26,140]
	0.50	–	10	84	–	–	–	–	[26,141]
	0.41	–	2	80	–	–	x_{weak} = 0.03 kg/kg; x_{strong} = 0.125 kg/kg	Data calculated	[26]
	0.31	–	2	95	–	–	x_{weak} = 0.03 kg/kg; x_{strong} = 0.0.80 kg/kg	Data calculated	[26]
	0.26	–	2	110	–	-	x_{weak} = 0.03 kg/kg; x_{strong} = 0.040 kg/kg	Data calculated	[26]
	–	2800 kJ/ kg	–	–	–	1000	Used mostly for descent cooling	–	[5]
	0.20–0.30	–	–	–	–	–	Solar adsorption with 170 m^2 of vacuum tube collector	–	[5,142]
	0.10–0.13	–	–	–	–	–	–	–	[5,143]
	0.25	–	14	55	–	–	Amount of adsorbent is allocated to adsorbent beds and effect of mass ration is investigated	–	[21,144]
	0.3–0.65	–	14	60	–	–	Effect of silica gel mass on COP is investigated	–	[21,145]
	–	–	5	100	–	–	Solar energy driven adsorption heat pumps are studied	–	[21,146]
	0.6	–	–	–	–	–	AHP system is applied on air-conditioning of buildings	–	[21,147]
	0.5	–	–10	100	–	–	Lab scale AHP system is constructed	–	[21,148]
	0.6	–	10	80	–	–	AHP system is applied on air-conditioning of buildings	–	[21,149]
	0.5	–	10 to 20	80–95	–	–	Small capacity AHP is constructed and tested for heating and cooling applications	–	[21,150]
	–	–	15 to 20	95	–	–	Compact solid sorption heat pump is developed and tested	–	[21,151]
	0.117–0.143	–	14	55–65	–	–	Development of hybrid desiccant cooling system combined with two stage adsorption chiller	–	[21,152]
	0.32–0.4	–	15.1	55–67	–	–	Novel adsorption chiller is developed and tested	–	[21,153]
	0.4	–	15	60–92	–	–	Micro adsorption chiller is applied on natural gas and LPG power cogeneration system	–	[21,154]
	0.427–0.434	–	–	–	–	–	Effects of variation of heat source on COP of AHP are investigated	–	[21,155]

L.F. Cabeza, A. Sole, C. Barreneche. Review on sorption materials and technologies for heat pumps and thermal energy storage. Renewable energy 2017

1. Introduction

Sorbent and system properties and performance.

Sorption pair/ system	COP	SCP (W/kg)	Te (◦C)	Td (◦C)	Thermal conductivity (W/m·kg)	Bulk density (kg/m³)	Characteristics	Comments	Reference
	–	–	25	100	–	–	Development of micro-refrigeration system	–	[21,156]
	0.16	–	–	–	–	–	2.05 MJ/day/m2 solar ice making	–	[20,157]
	0.36	–	–	–	–	–	3.2 kW/unit solar chilled water	–	[20,139]
	0.28	–	–	–	–	–	12.0 kW/unit solar chilled water	–	[20,158]
	0.35−0.60	–	–	–	–	–	15 kW m^3 solar chilled water	–	[20,140]
	0.3–0.6	–	–	–	–	–	20 W/kg solar chilled water	–	[20,159]
	0.33–0.5	–	–	–	–	–	91.7–171.8 W/kg solar chilled water	–	[20,160]
	–	1000	30	150	–	–	–	–	[25,139]
	–	600	20	130	–	–	–	–	[161,162]
	0.49	84	80	14	–	–	–	–	[163]
	0.37	14	85	12.2	–	–			[164]
	0.42	270	10	80	14	14	–	–	[164]
	0.32	144	30	85	–	–	–	–	[164]
	0.36−0.66	132–164	3	200	–	–	–	–	[137]
	0.37−0.45	–	12.2	85	–	–	–	–	[165]
	0.42	270	10	80	–	–	–	–	[160]
	0.32	144	30	85	–	–	–	–	[164]
	0.36	241	14	50–70	–	–	–	–	[139]
	0.27	138	14	55	–	–	–	–	[166]
	0.24	168	14	55	–	–	–	–	[144]
	0.27	86	14	70	–	–	–	–	[144]
	0.27	71	14	80	–	–	–	–	[167]
	0.14	–	12	40	–	–	–	–	[168]
	0.19	28	12	50	–	–	–	–	[169]
	0.13	–	14	50	–	–	–	–	[170]
	0.14−0.23	84–190	14	50–60	–	–	–	–	[171]

L.F. Cabeza, A. Sole, C. Barreneche. Review on sorption materials and technologies for heat pumps and thermal energy storage. Renewable energy 2017

1. Introduction

(a) 5kW

(b) 10kW

(c) 15kW

(d) 50kW

Silica gel-water adsorption chiller developed by Shanghai Jiao Tong University

1. Introduction

Applications：

- Library of Himin Solar
- Power Grid Exhibition Hall Expo 2010 in Shanghai，China
- Green building in Beijing Olympic Forest Park
- Green building in Shanghai Academy of Construction Science
- Sino-Italian green energy lab in Shanghai Jiao Tong University
- Baosteel waste heat recovery project

Contents

2. Data center cooling

It is estimated that data centers will account for 4.5% of energy consumption by 2025 and 13% by 2030.

Power consumption: IT: 52%, Cooling: 38%, Lighting, etc.:10%

Decreasing PUE is important

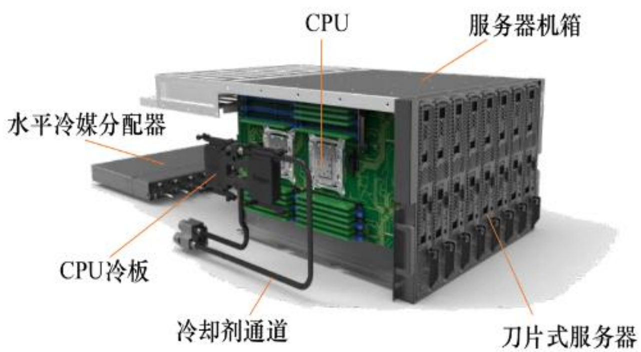
$$PUE = \frac{P_{\mathrm{DC}}}{P_{\mathrm{IT}}} = \frac{P_{\mathrm{cooling}} + P_{\mathrm{IT}} + P_{\mathrm{lighting}}}{P_{\mathrm{IT}}}$$

PUE: <**1.4**, 1.3、1.2、1.1

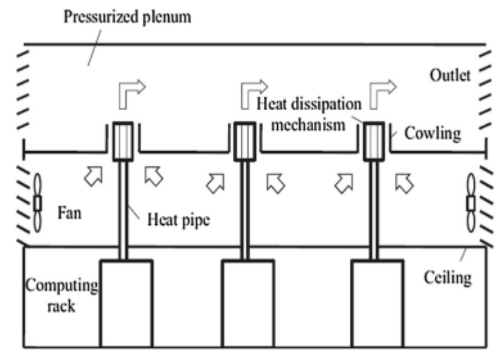
2. Data center cooling

Heat rejection： increasing the temperature of heat source – **liquid cooling**
Cooling： decreasing the temperature of heat sink

Indirect

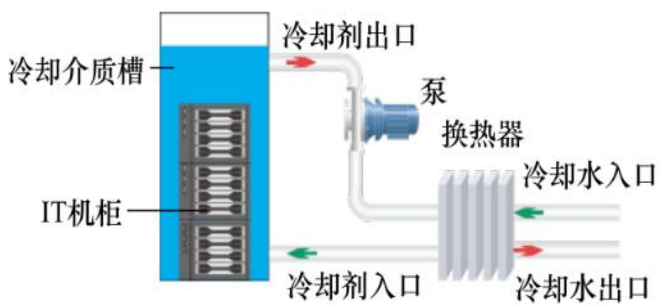


Water-cooled plate-type

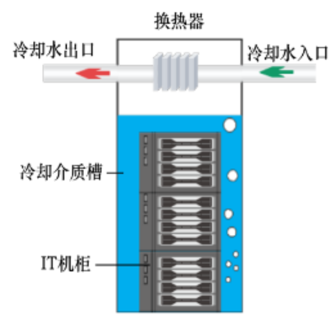


Heat Pipes

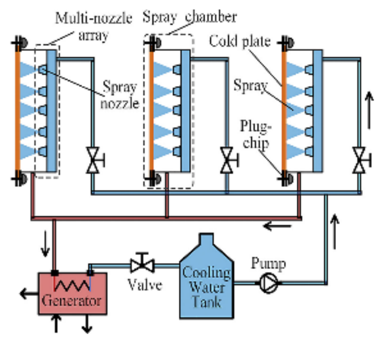
Direct



Single-phase immersion

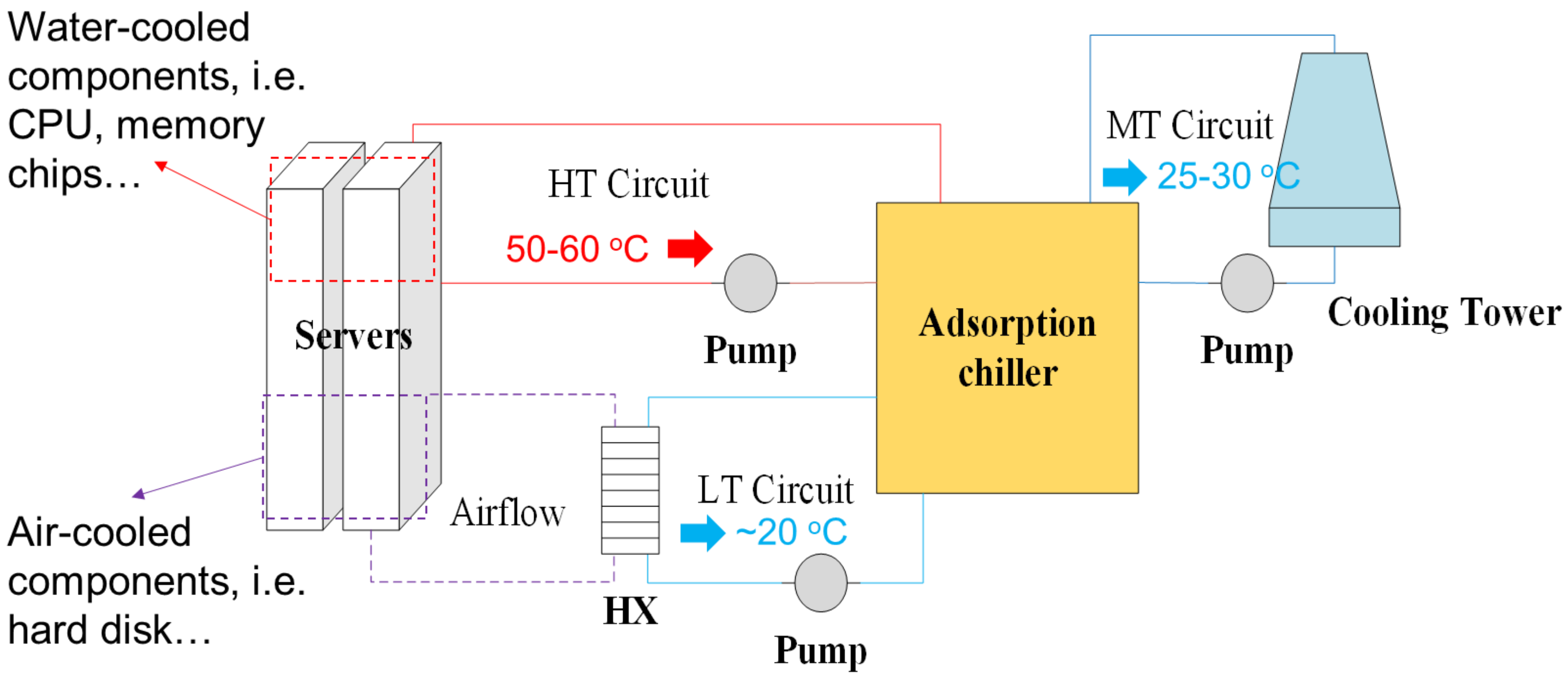


Two-phase immersion

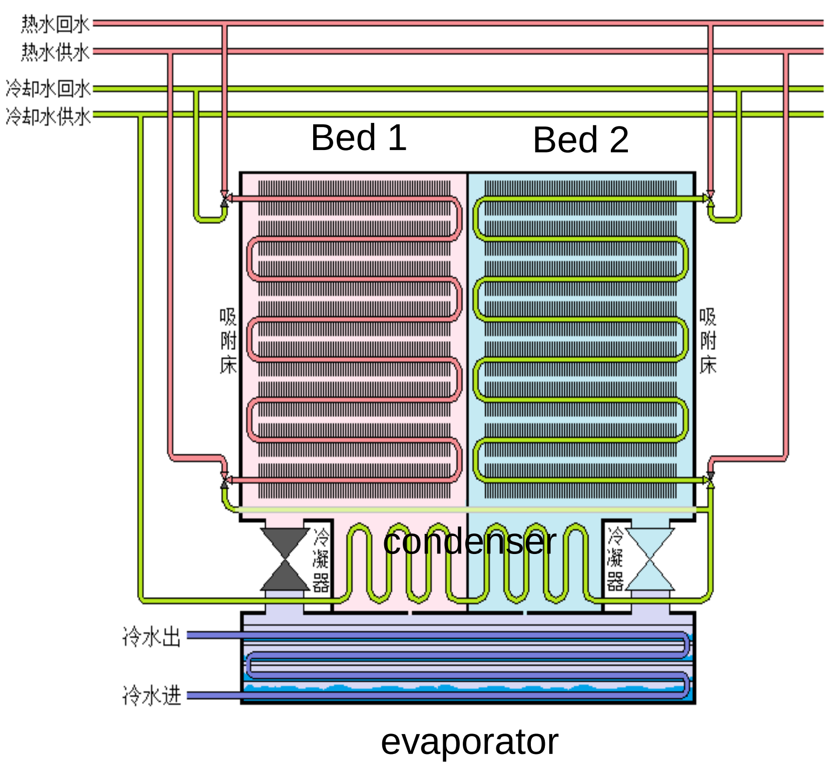


Spray-type

2. Data center cooling

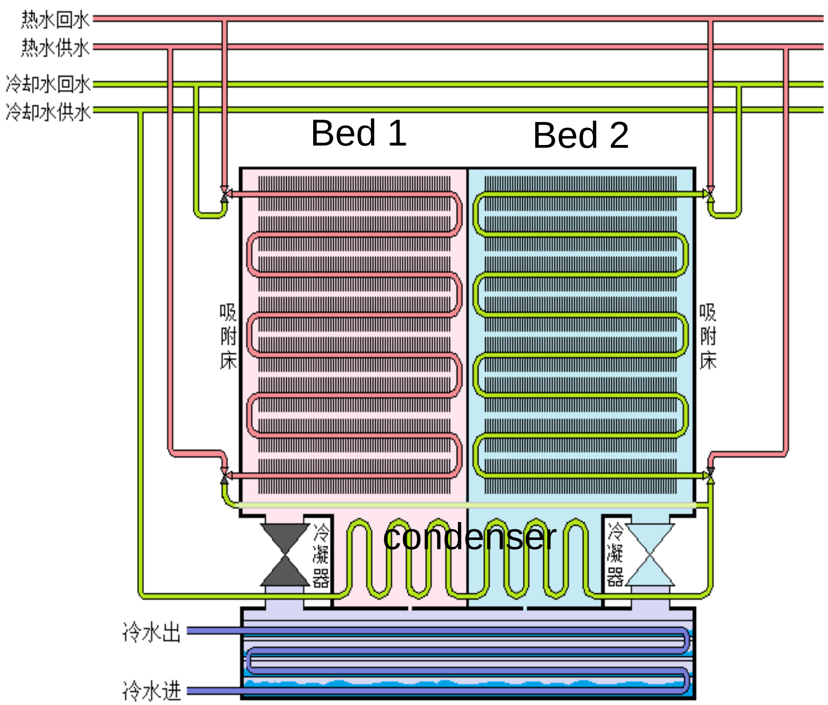


1. Heat of the hot water is still released, but its grade is made efficient use
2. The produced chilled water may cool the air-cooled component.
3. Compression refrigeration system can be standby.

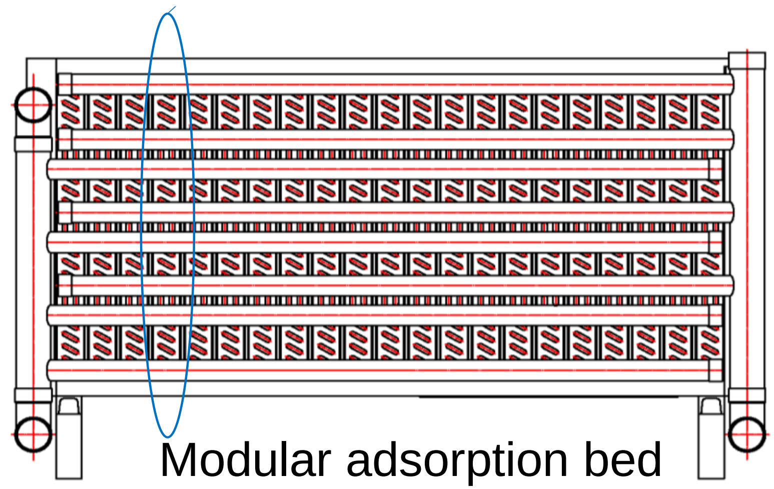


Schematic and photos of the developed silica gel-water adsorption chiller for modular data centers. The designed cooing power is between 5-10 kW. The size is limited in 2.2 m×1.5 m×0.6 m.

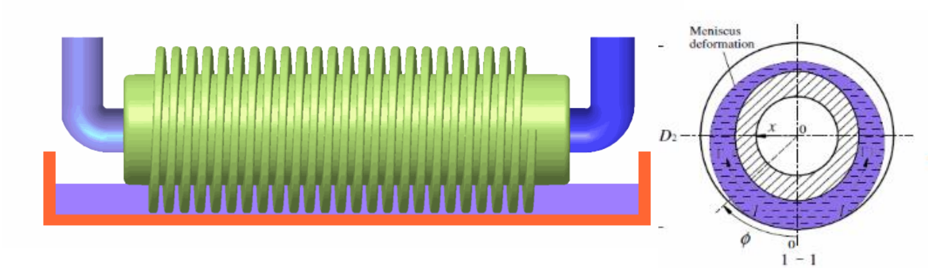
2. Data center cooling



evaporator



Modular adsorption bed

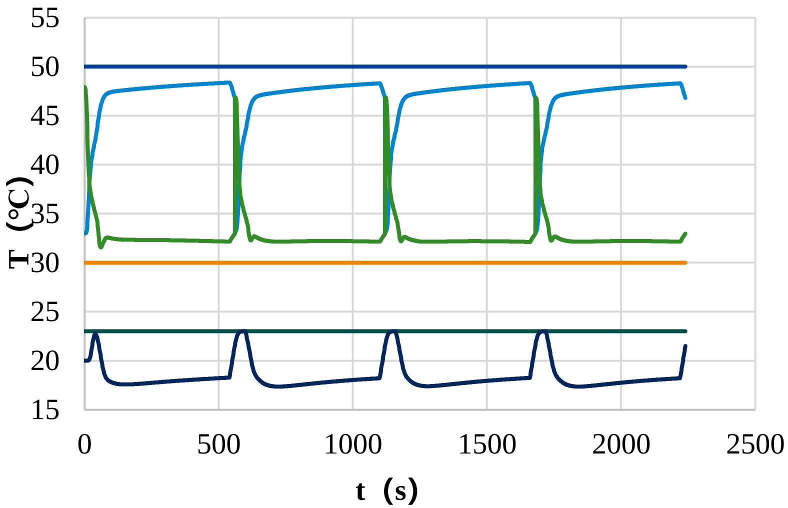


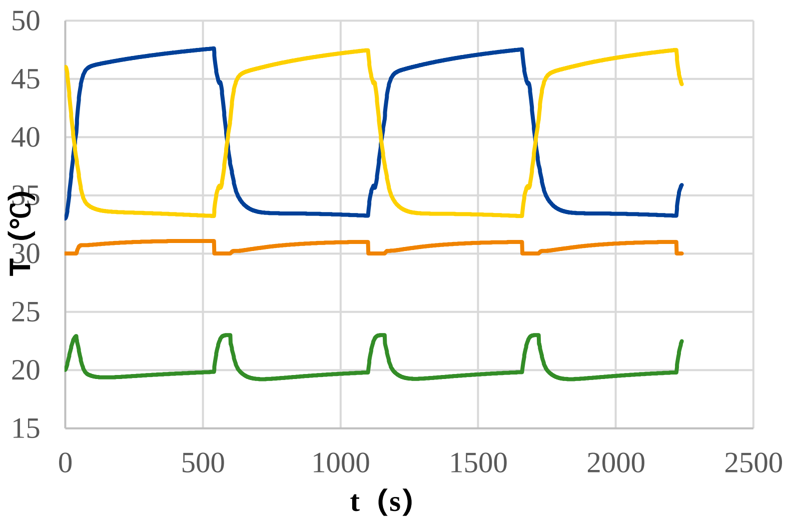
Rising film evaporation

Modular adsorption bed and rising film evaporation were applied.

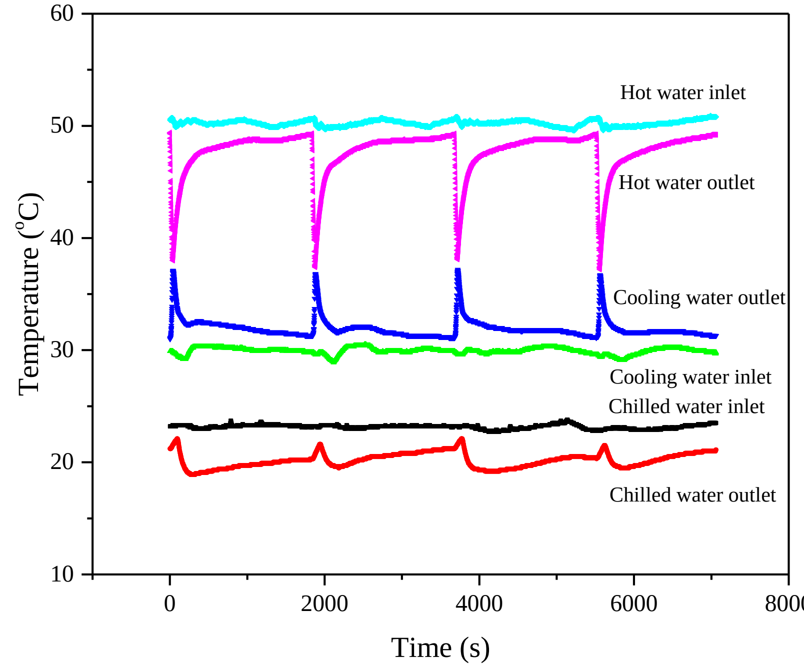
2. Data center cooling

Simulation results



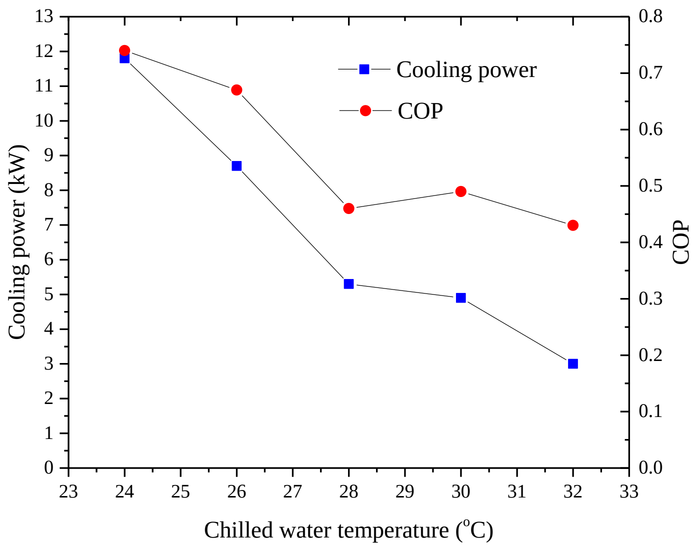


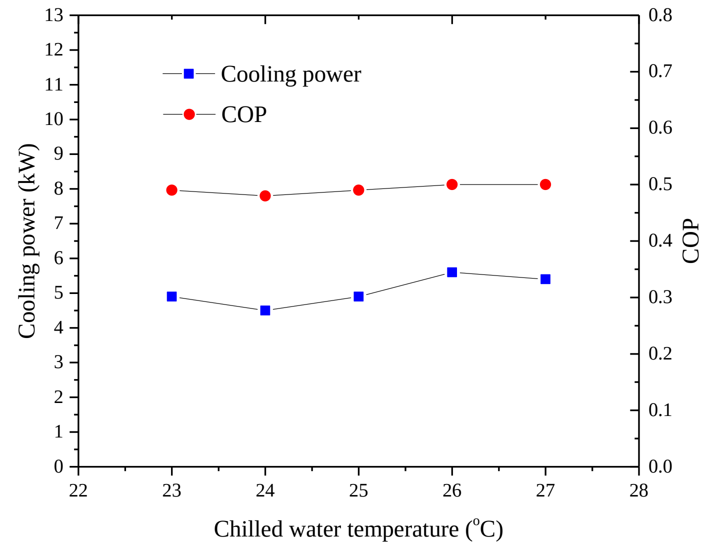
Experimental results

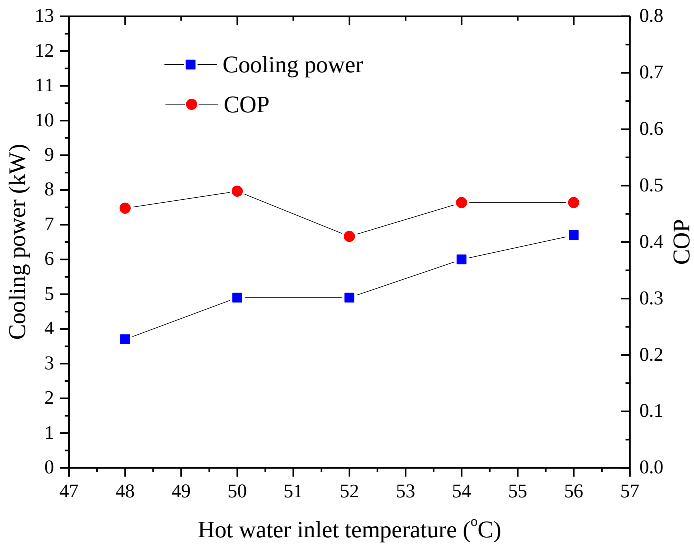


Cycling time:	**1800**	s
Average T_{hi}:	**50.2**	°C
Average T_{ci}:	**29.9**	°C
Average T_{chi}:	**23.1**	°C
Average Q_e:	**4.9**	kW
Average COP:	**0.49**	
Average SCP:	**41.2**	W/kg

2. Data center cooling







1. The silica gel-water can be operated **under low heat source temperature** such as 50°C for data center cooling applications.
2. The performance is more **sensitive to cooling water temperature**
3. Peak cooling effect is low and the cycling period is long.
4. **Alternative adsorbent** should be developed to improve Δx and the heat & mass transfer performance

Contents

3. Cold storage

- Scenario: off-grid cooling


- Demand: long term cold storage (more than 12 hours)

- A set of typical conditions:

Cooling: 22~27℃; Ambient: 30~35℃;

Cooling power: 100W; Cold storage capacity: 500Wh

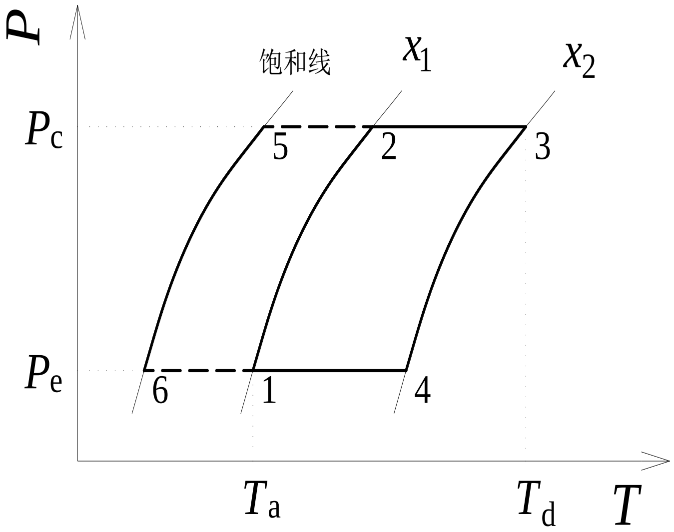
3. Cold storage

	Silica gel (Type A)	Zeolite (5A、13X)	Zeolite-like (FAM-Z02)	MOF (MIL-101(Cr))
Bulk density, kg/m^3	800	800	800	600
Cp, kJ/(kg•K)	0.92	0.8	0.8	—
Tup,limit ℃	400	600	600	—
Tdesorb℃	<80	100~200	<80	<80
Adsorption isotherm	Type Ⅰ	Type Ⅰ	Type Ⅱ	Type Ⅱ
Price	Cheap	Cheap	Expensive	Very expensive

	Silica gel	Zeolite（5A)	Zeolite（13X)
Tdes℃	120	120	120
Tcon℃	35	35	35
Tads℃	45	45	45
Teva℃	15	15	15
Δx g/g	0.128	0.049	0.057
SCE J/g	315	112	140

Silica gel-water is preferred to develop the cold storage prototype

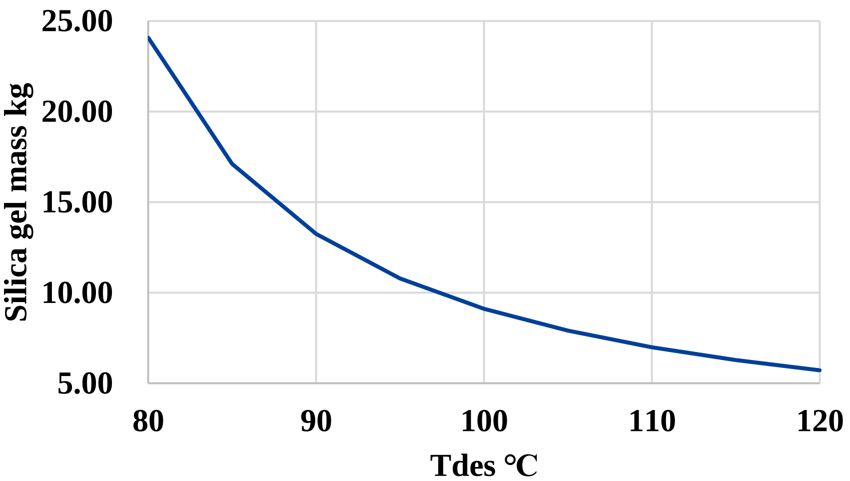
3. Cold storage



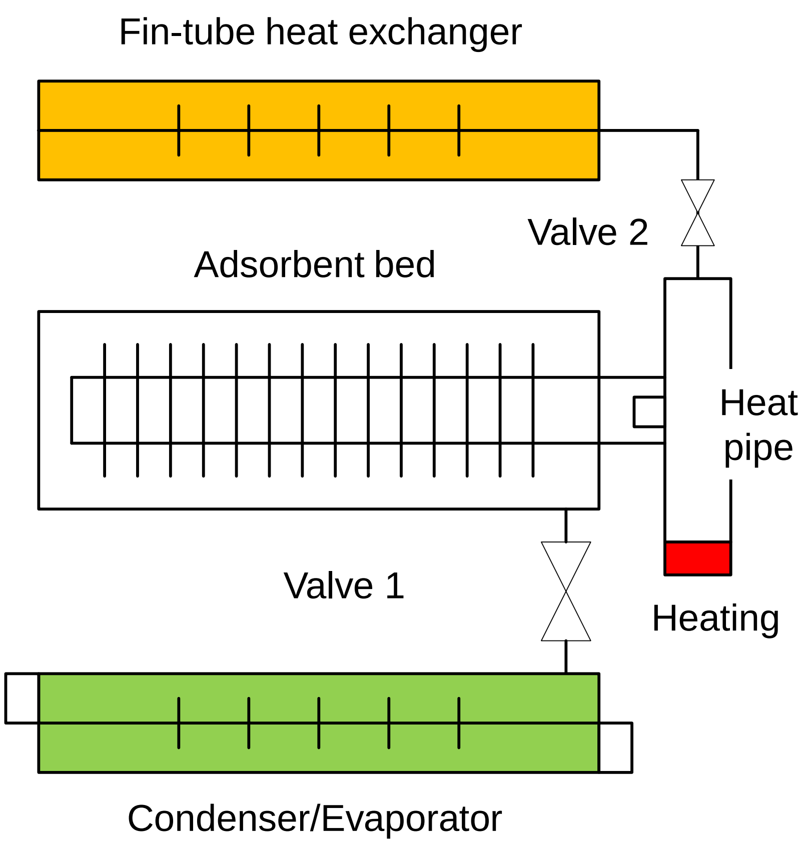
Desorption: 1-2-3 (heating)
2-3-5 (condensation)
3-4 (cooling)

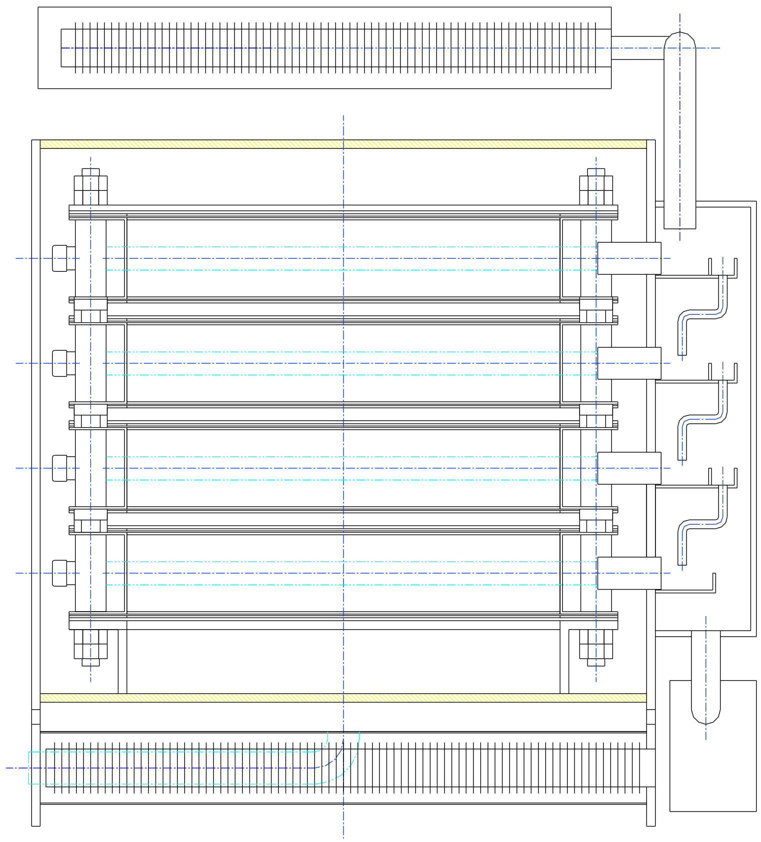
Adsorption: 6-4-1 (cooling)
5-6 (refrigeration)

Parameters	Value
Tdes ℃	80~120
Tcon ℃	35
Tads ℃	45
Teva ℃	15
Cold storage capacity Wh	500



3. Cold storage





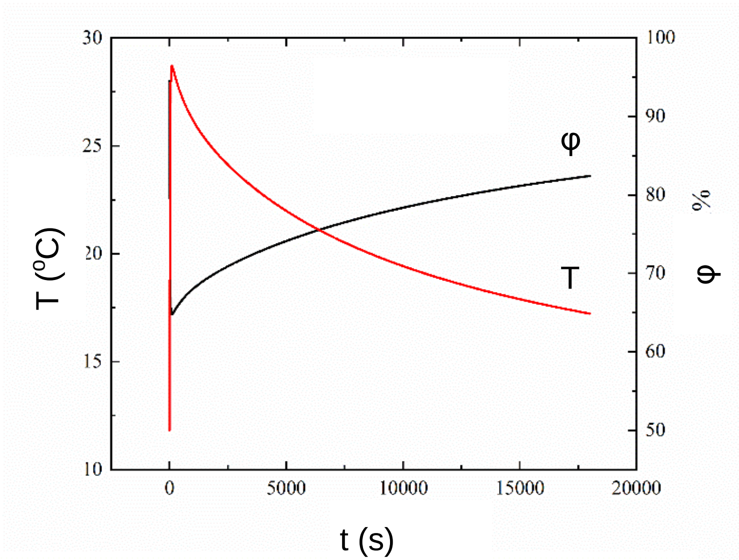
1. Desorption and condensation (valve 1 open, valve 2 closed)
2. Standby (valve 1 closed, valve 2 open)
3. Adsorption and evaporation (valve 1 open, valve 2 open)
4. Standby (valve 1 closed, valve 2 open)

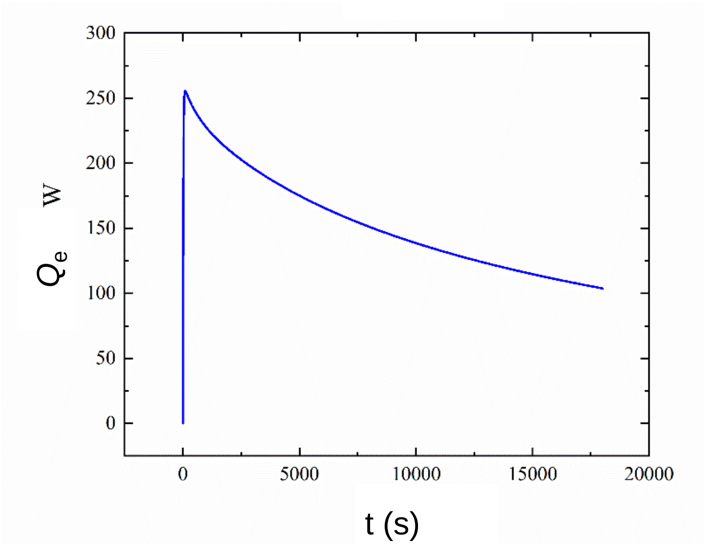
3. Cold storage

Pictures of the prototype

3. Cold storage

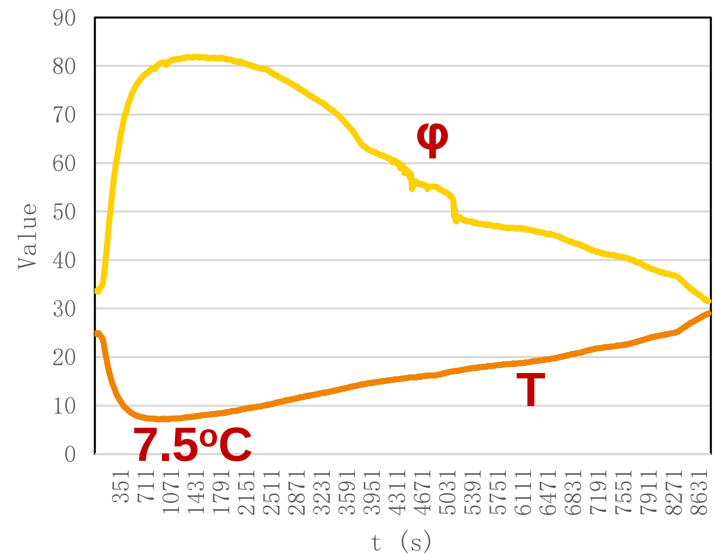
Simulation results





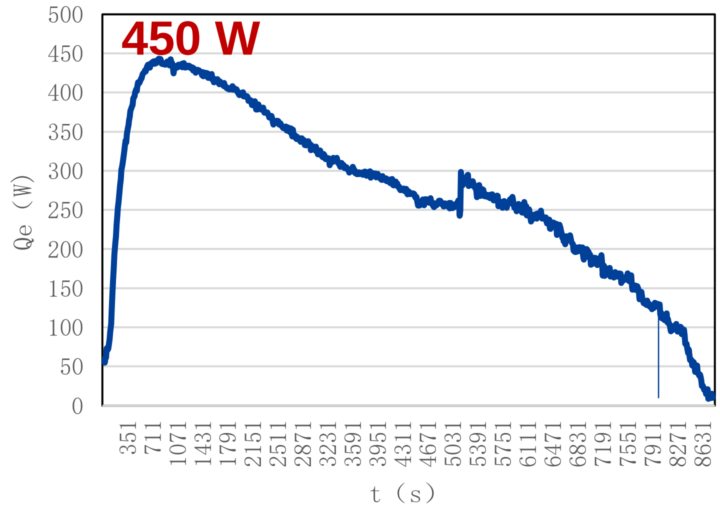
Experimental results

T_{am}=28°C



Sensible heat variation
15 mins

2.4 h

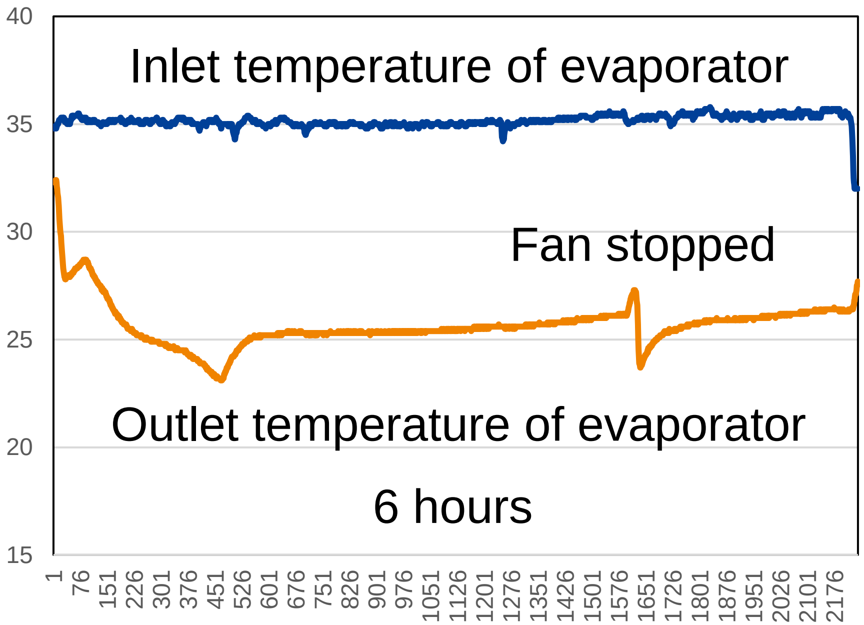


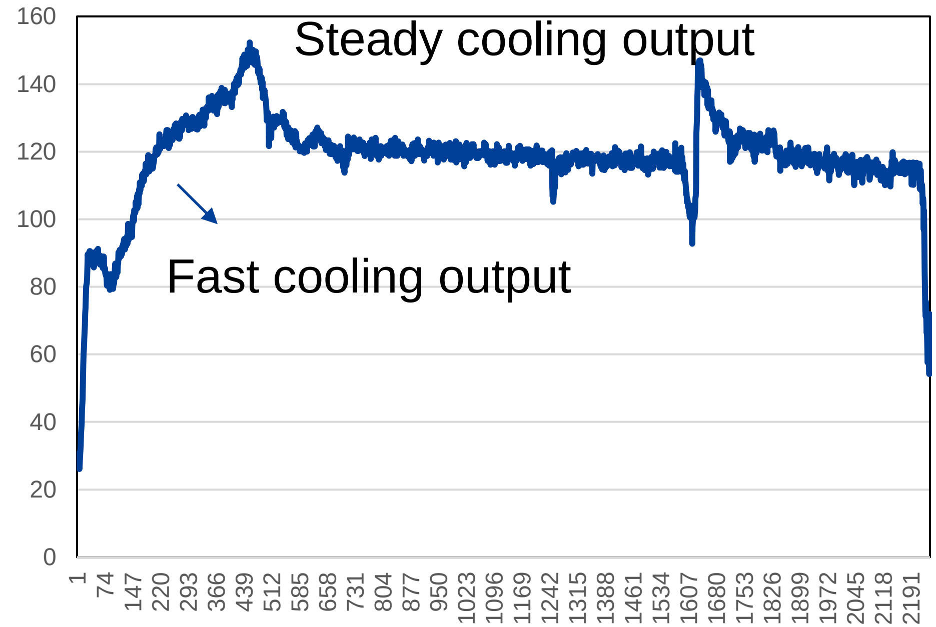
Cooling effect releasing fast

Peak value is high

3. Cold storage

T_{am}=35^{o}C





Cooling power was regulated by electrical valves based on feedback control

During the 6 hours of producing cooling effect, the average cooling power was

118W and the cooling storage capacity reached **735Wh**. SCE: 200 kJ/kg

Contents

4. Conclusions

1. **Silica gel-water adsorption chiller which can be driven by low temperature heat source, is applicable for data center cooling to reduce PUE.**
2. A silica gel-water adsorption chiller is developed, employing modular adsorbent bed and rising film evaporator. It shows an average cooling power of 4.9 kW and COP of 0.49 when the inlet temperatures of hot water, cooling water and chilled water are 50^{o}C, 30^{o}C and 23^{o}C, respectively.
3. **Silica gel-water adsorption chiller is also applicable for cold storage for air-conditioning in off-grid scenarios.**
4. A silica gel-water adsorption cold storage unit is developed, employing heat pipe heating technology, which decreases the adsorbent bed bulk. The SCE is more than 200 kJ/kg, when the desorption temperature, ambient temperature and evaporator outlet temperature are 85^{o}C, 35^{o}C and 26^{o}C, respectively.
5. The bulk is the main drawback of the silica gel-water adsorption system.