上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

EFFICIENT HEAT PUMPS AND TERMINALS FOR DIFFERENT CLIMATE ZONES

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Outline

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1. Introduction
2. The definition of climate zone in China
3. Hot-summer and cold-winter zone
4. Cold region
5. Severe cold region
6. Conclusions and perspectives

Introduction

Since the establishment of PR. China, the space heating technologies in China has been developed rapidly.

The 1950s

Learned from USSR

In 1975

The first draft of heating and ventilation design specification

The 1980s

Rapid development period of district heating

21st century

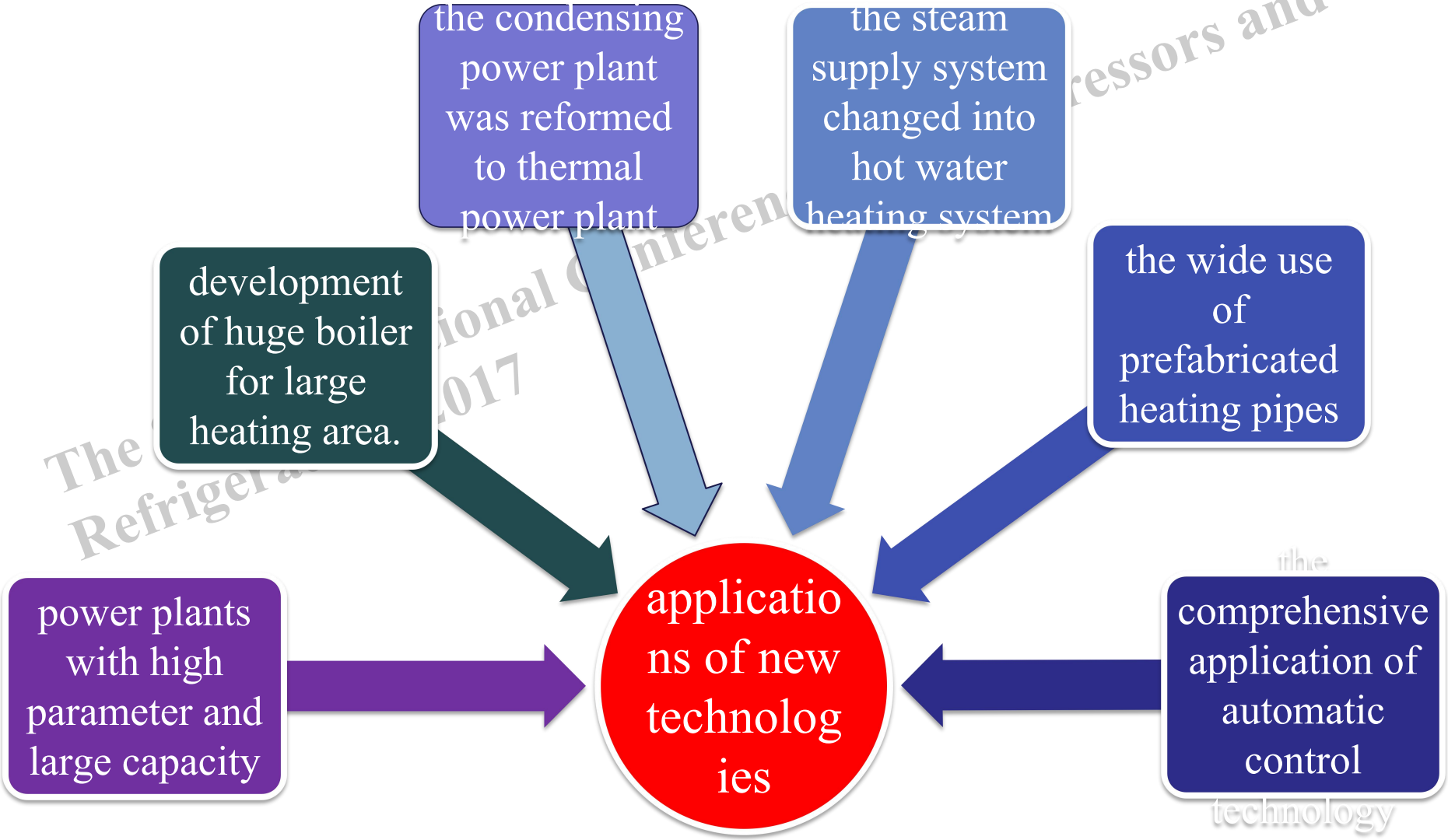
A lot of new technologies and new products

(GBJ50019-2003)

The first draft

There are more than 300 cities in China with district heating facilities, and more than 500 large and medium-sized thermal energy companies.

Introduction



Introduction

- The latest version of "Code for design of heating, ventilation and air conditioning for civil buildings (GB50736-2012)" was released in 2012.
- The new technologies includes heat and power cogeneration, household boiler, distributed heating, solar heating, **heat pump technology**.
- Space heating mainly depended on heat and power cogeneration, supplemented by centralized boiler, gradually replaced by other advanced and efficient heating methods.
- The central and local levels of government have made great efforts to adjust the energy structure, promote diversified heating methods and realize sustainable development.

Introduction： development stages

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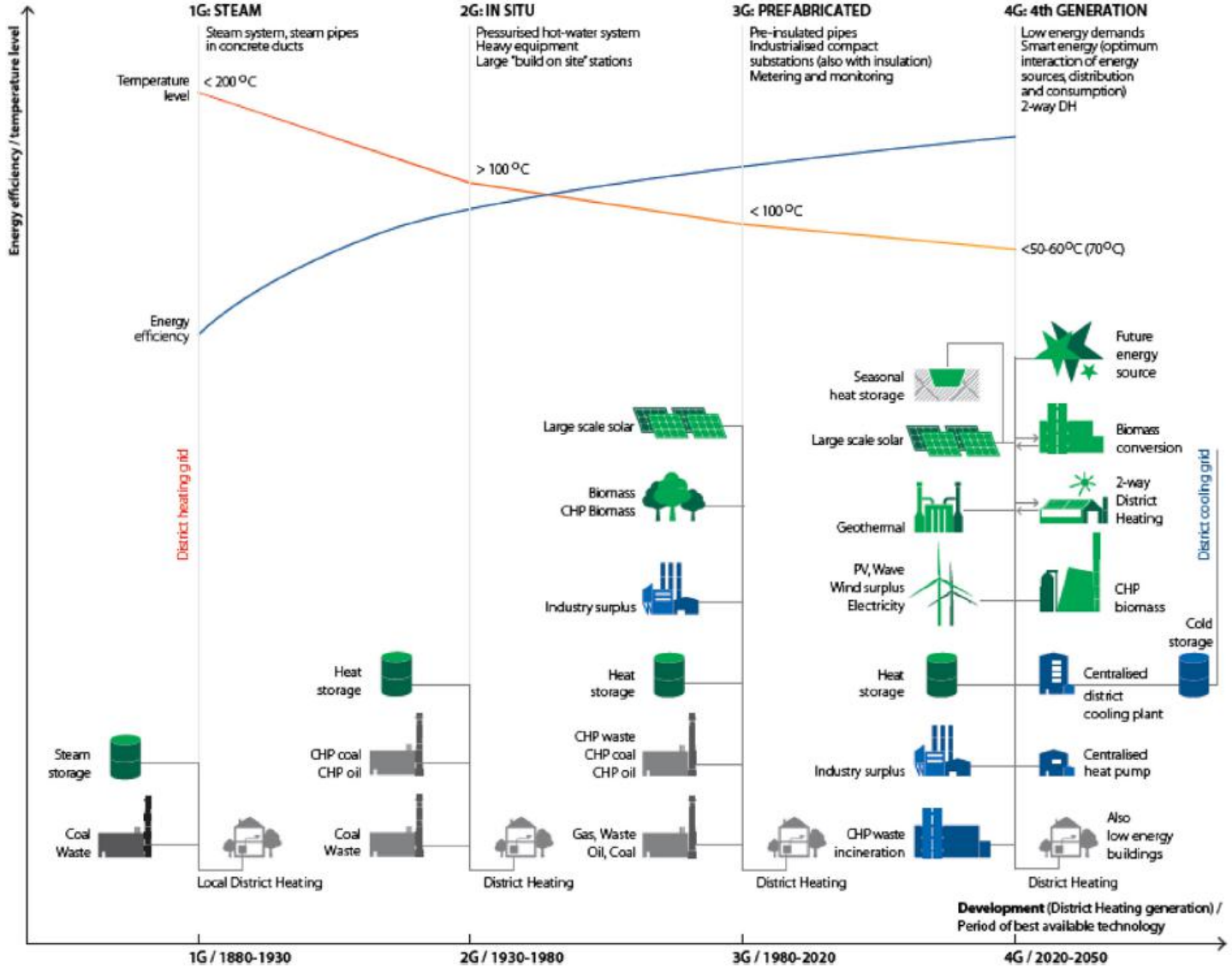
1
- the heat carrier is steam; concrete ducts, steam traps, and compensators; replace individual boilers to reduce the risk of boiler explosions

2
- supply water temperature is over 100°C; large tube-and-shell heat exchangers and heavy valves; achieve fuel savings and better comfort by utilizing CHP

3
- hot water temperatures is below 100°C; prefabricated components, pre-insulated pipes; replacing oil with various cheaper fuels: coal, biomass and waste

4
- lower distribution temperature; thermal grids with smart control; higher energy efficiency; assembly-oriented components; various renewable energy

Introduction



Lund H, Werner S, Wiltshire R, et al. 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems [J]. Energy, 2014, 68(4):1-11.

In China: Clean heating from coal to electric

- Fog Haze …… 。 “煤改电”政策
- ASHP for heating, a new market was born!

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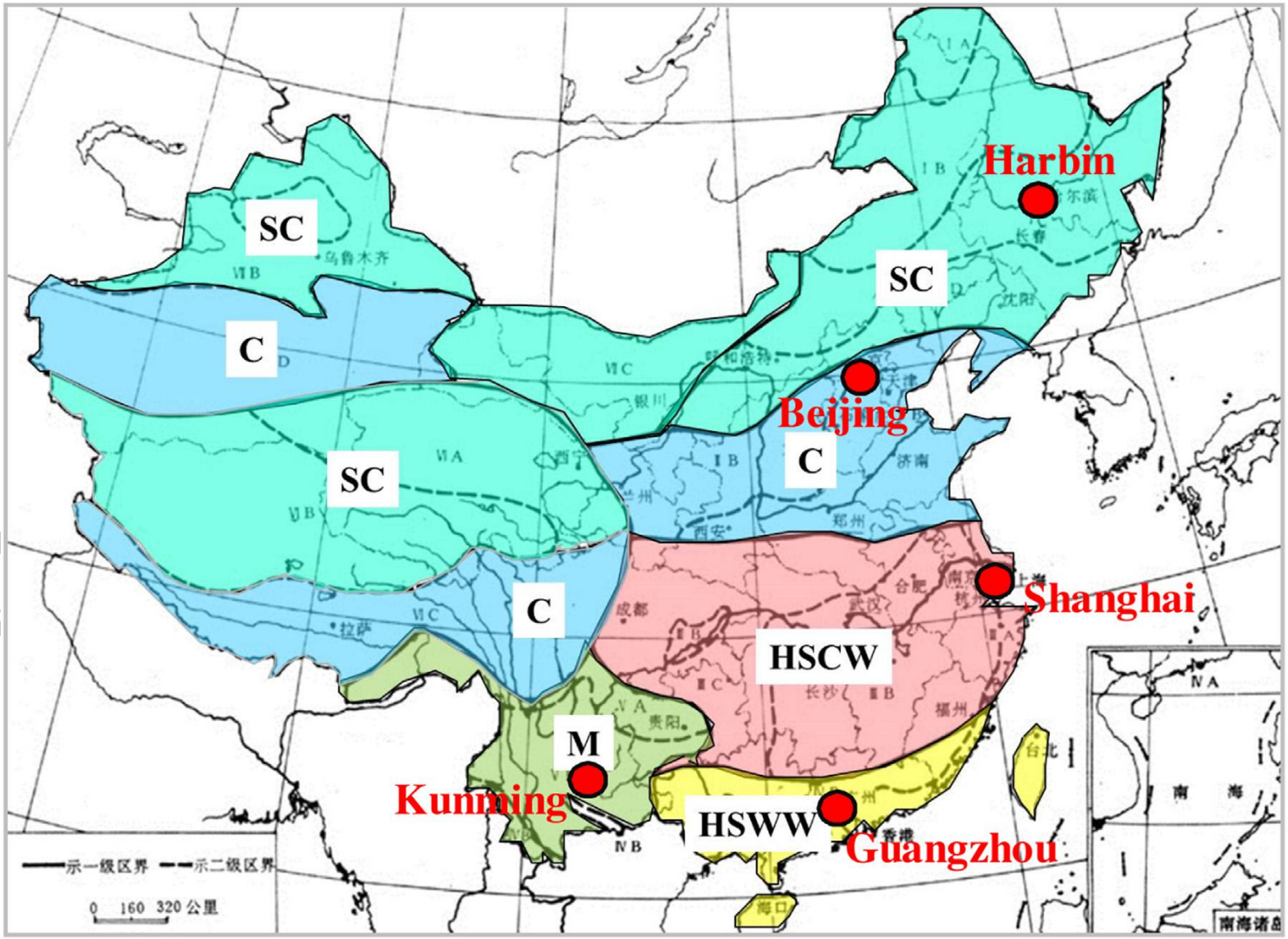
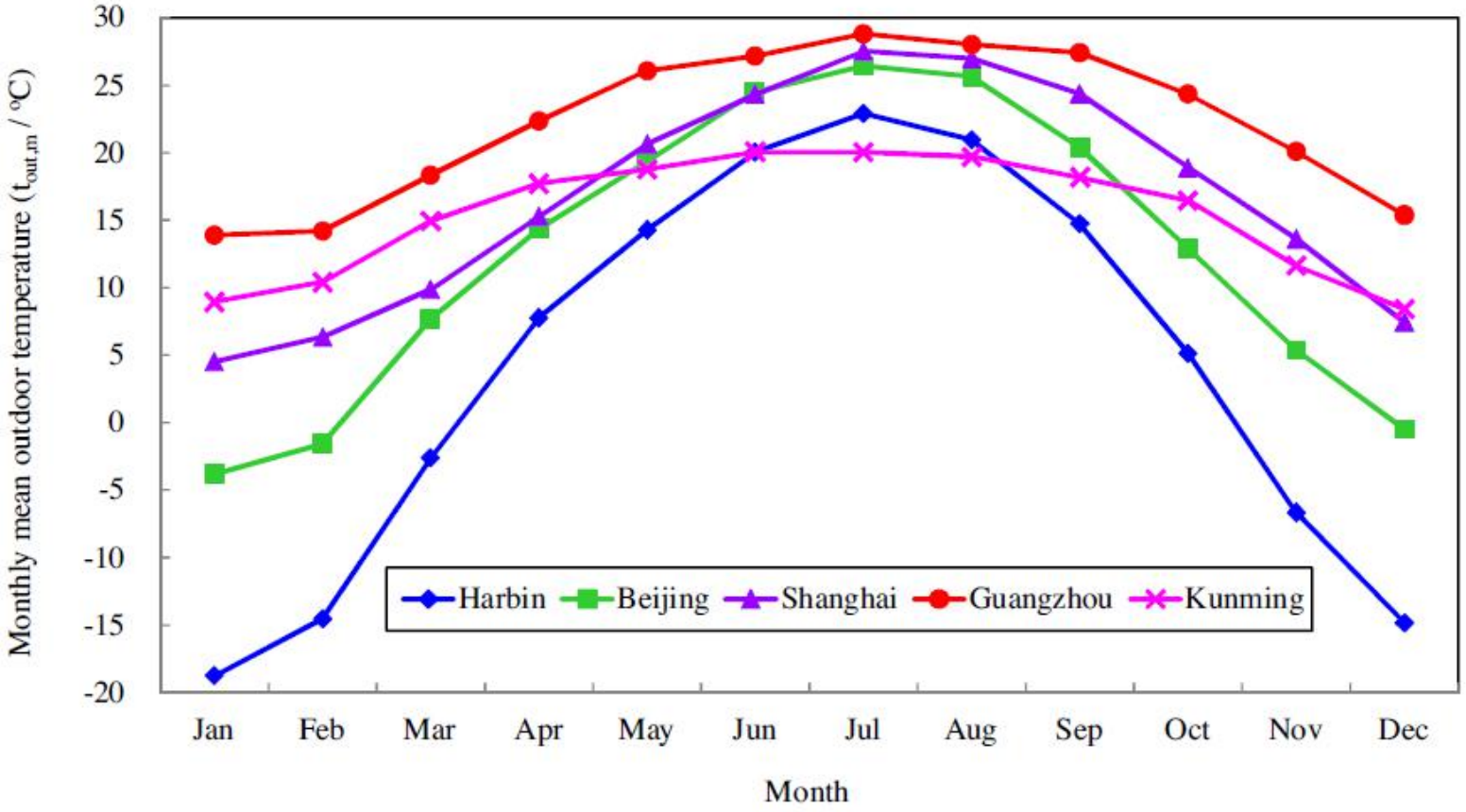
The climate zone in China



Cao B, Luo M, Li M, et al. Too cold or too warm? A winter thermal comfort study in different climate zones in China[J]. Energy & Buildings, 2016, 133:469-477.

The climate zone in China

1) Harbin for SC, Beijing for C, Shanghai for HSCW, Guangzhou for HSWW and Kunming for M.
2) In January, outdoor temperature in Harbin is 35°C lower than that in Guangzhou.
3) In July, Guangzhou is no more than 10°C warmer than Harbin.



China Meteorological Administration, Tsinghua University, Meteorological Data for Built Thermal Environment Analysis in China, China Architecture &Building Press, Beijing, China, 2005 (in Chinese).

The climate zone in China

- A big challenge to develop the space heating systems for different climate zones
  - district heating
  - household base heating
  - individual heating
- How do the local people select the most efficient heat pump and terminals
  - single stage compression
  - vapor injection
  - multi-stage, cascade heat pump
  - transcritical CO_2 system
- Seldom studies focusing on the comparison between climatic zones (especially for winter condition) conducted in China

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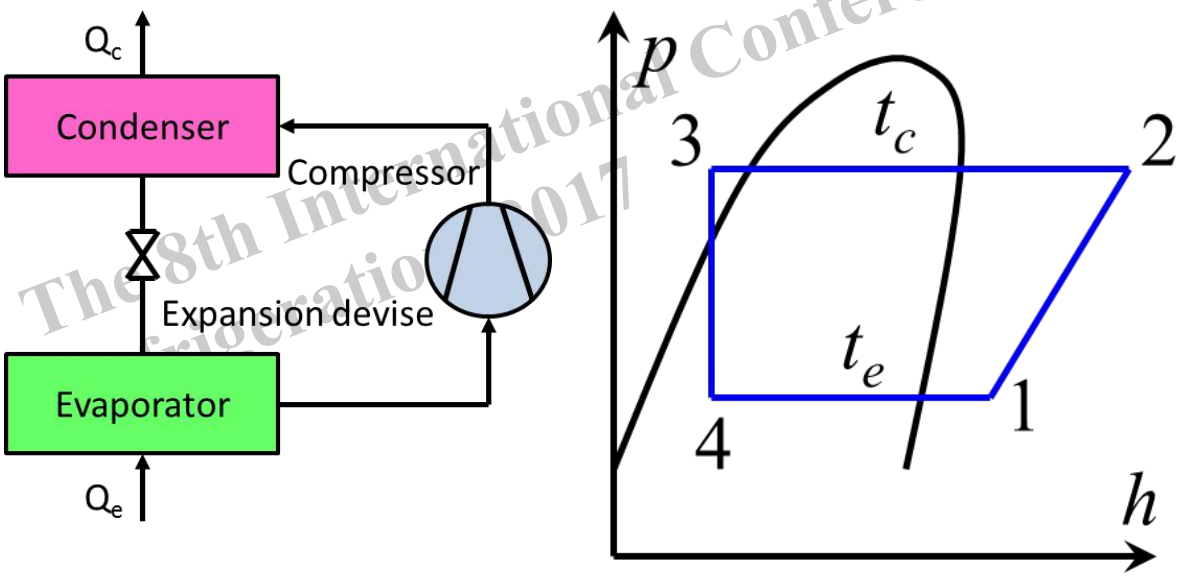
Hot-summer and cold-winter zone

Single-stage vapor compression cycle consists of a compressor, an expansion valve and two heat exchangers served as evaporator and condenser, respectively.



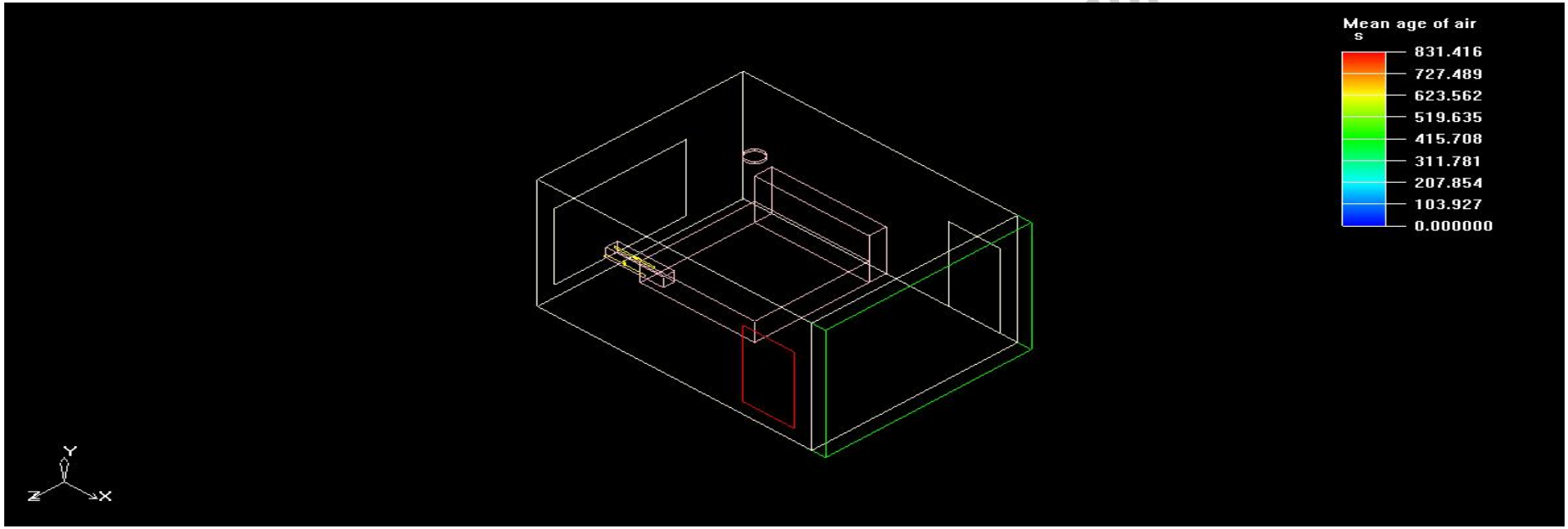
(a) (b)

Single stage compression HP (a) Schematic diagram; (b) *p-h* diagram

Hot-summer and cold-winter zone

Problems caused by air conditioner heating

1. The poor temperature distribution in heating room



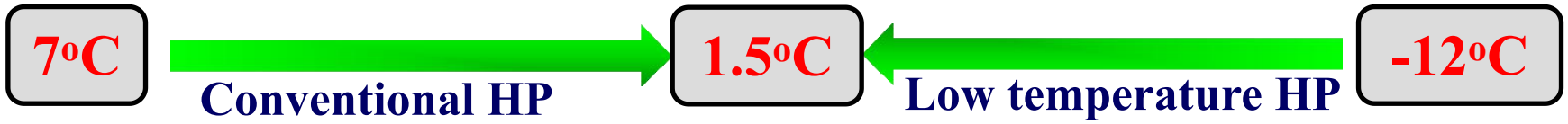
2. Repeated defrosting makes COP lower, room uncomfortable

3. Low COP for heating： high pressure ratio in winter

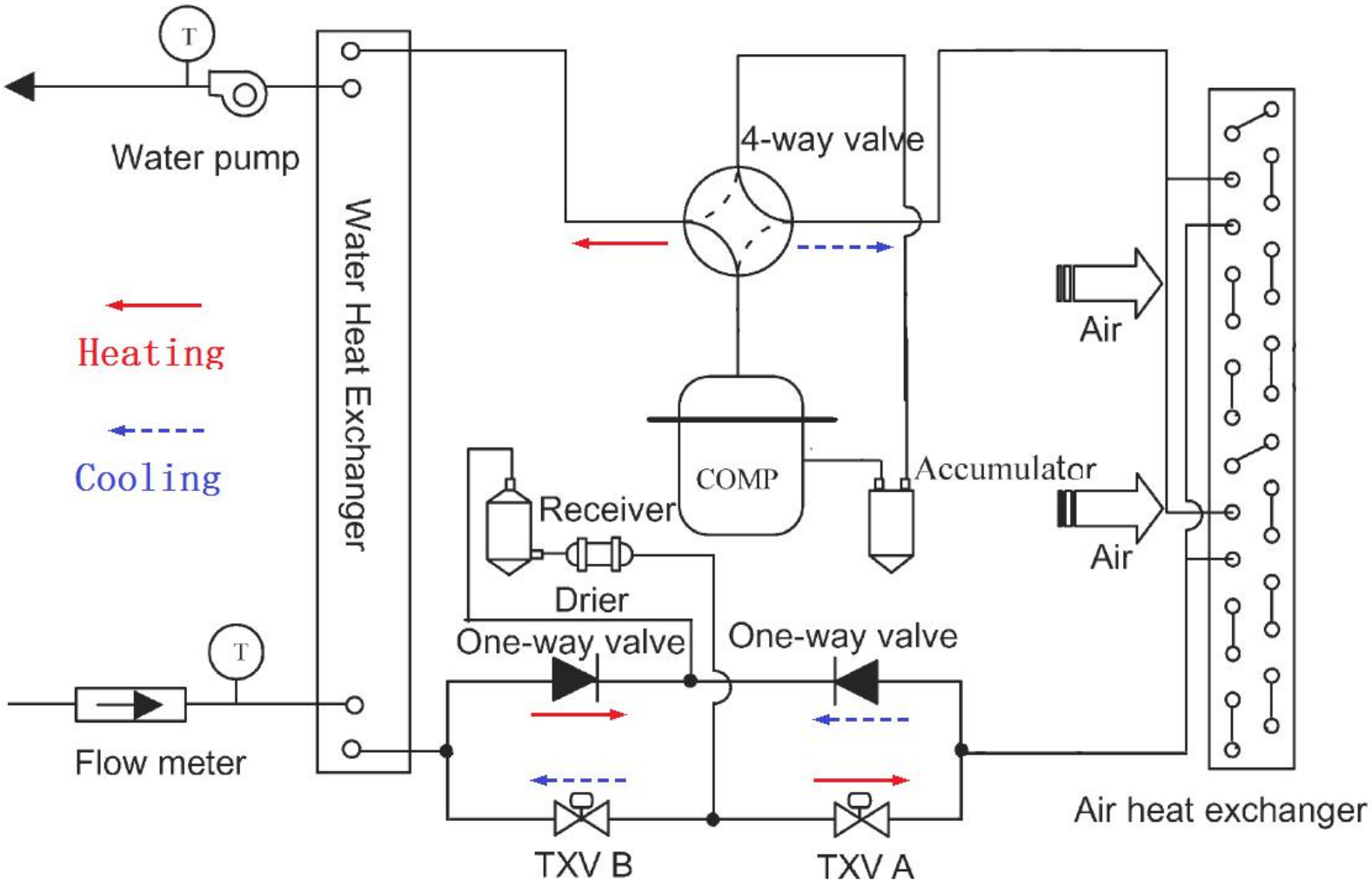
	Shanghai		Nanjing		Wuhan	
	Summer	Winter	Summer	Winter	Summer	Winter
最热（冷）月 Outdoor aver temp /℃	30	1.5	28.1	-0.1	28.9	0.7
Room temp/℃	25	20	25	20	25	20
Evap temp/℃	5	-8.5	5	-10.1	5	-9.3
Cond temp/℃	40	50	38.1	50	38.9	50
R22 P ratio	3.19	5.21	3.06	5.66	3.1	5.5
R410a P ratio	2.59	5.08	2.47	5.33	2.52	5.15

Deviation of design condition and operating conditions

(GB 18430) “力不从心” (Statistics) “大材小用” (GB 18430)



Hot-summer and cold-winter zone



Schematic diagram of the single-stage compression heat pump [13]

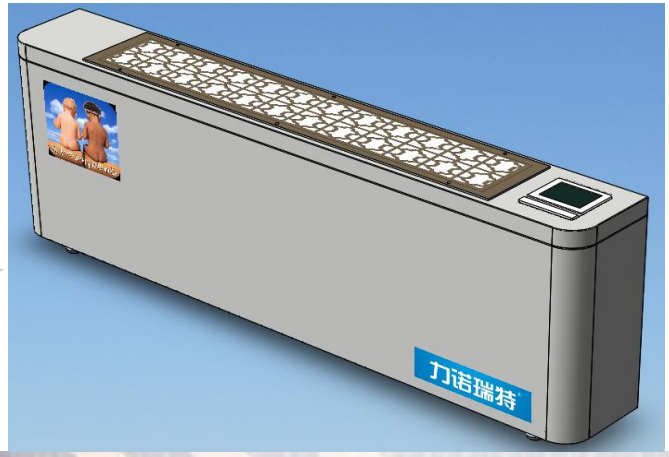
Hot-summer and cold-winter zone

- Compared with the conventional air conditioner, the heat pump system is equipped with a 4-way valve which can switch the flow direction in the system to operate in heating mode or cooling mode.
- There are also two expansion valves and one-way valves for heating or cooling, respectively.
- There is a receiver in the system to balance the difference of the refrigerant.
- A suction line accumulator is added to prevent the compressor from exposing to liquid drops.

Hot-summer and cold-winter zone

Typical applications of heat pump for hot water, heating and cooling

Hot-summer and cold-winter zone



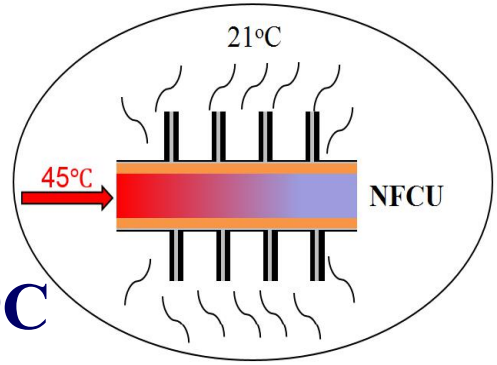
New products based on comfort and high efficient heating

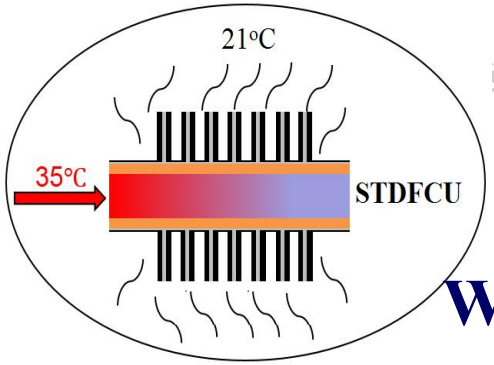
Hot-summer and cold-winter zone

Small temperature difference fan-coil unit

NFCU

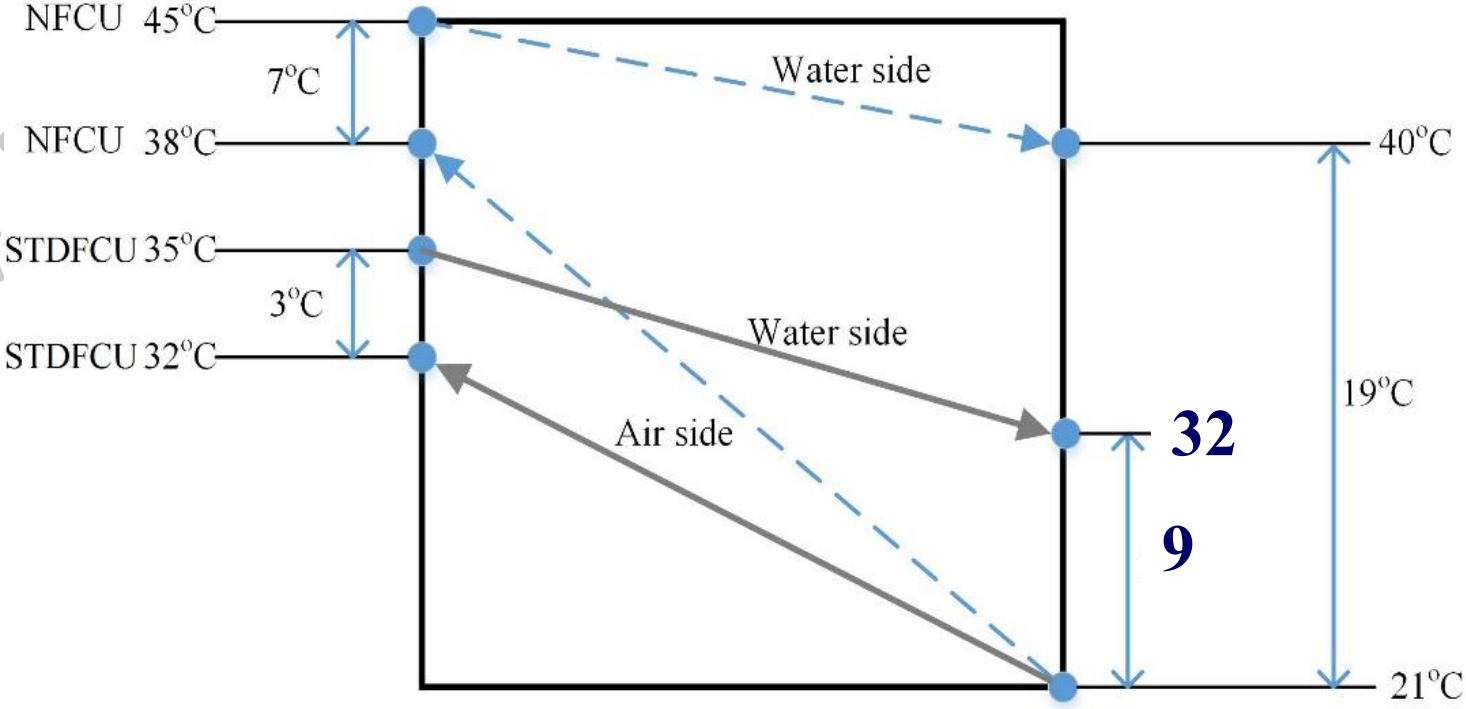
Air: 38-21°C
Water: 45-40°C





STDFCU

Air: 32-21°C
Water: 35-32°C



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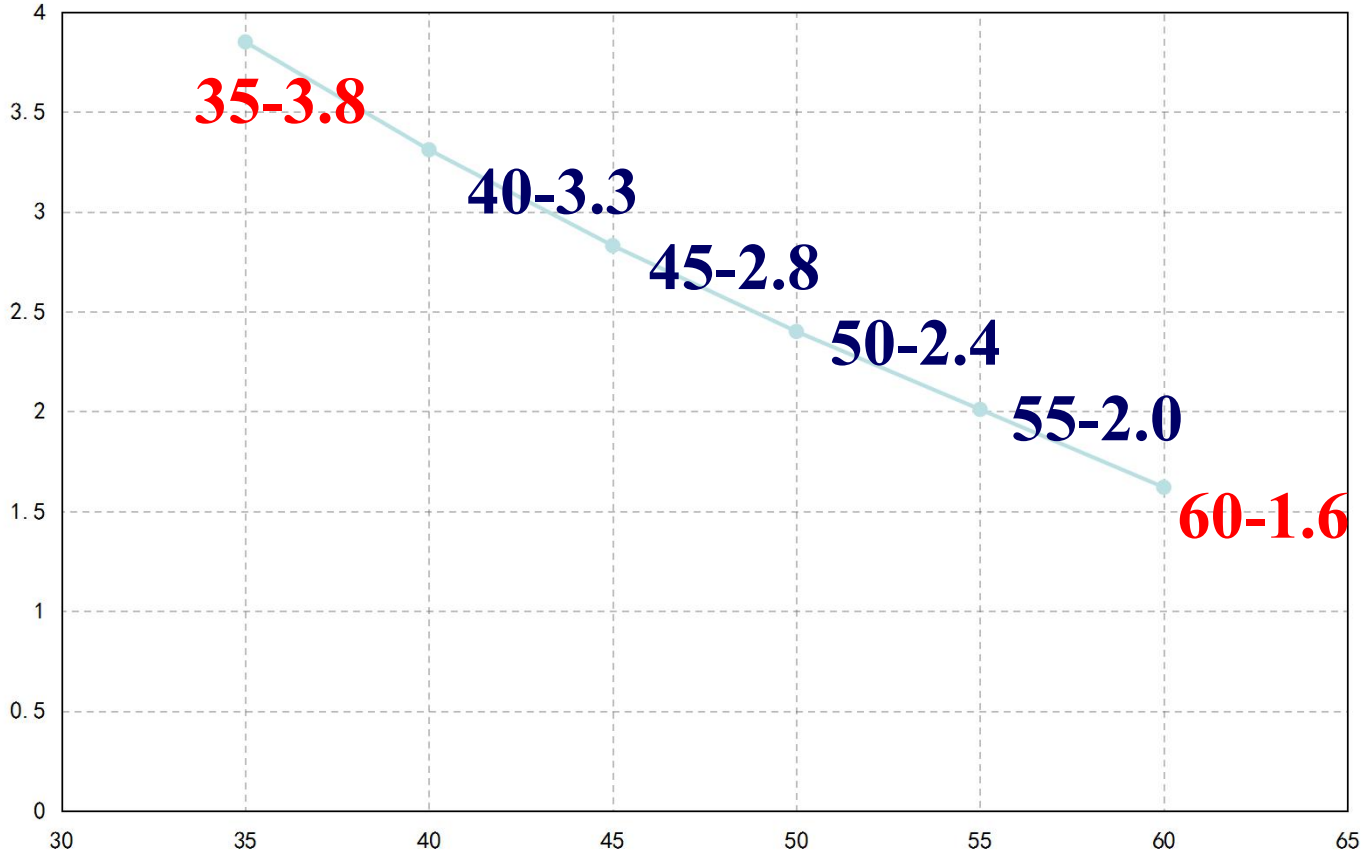
7°C ambient



The supplied hot water temp from the ASHP

Hot-summer and cold-winter zone

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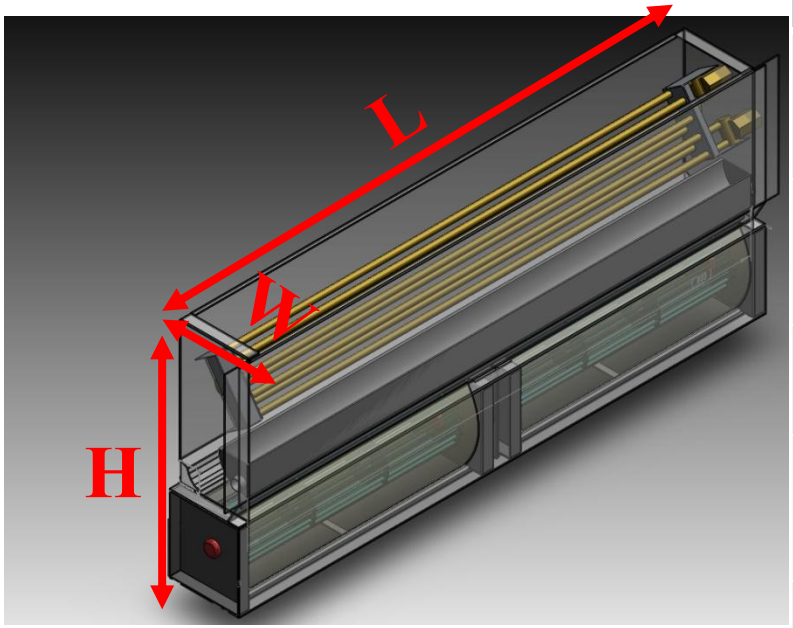
Development of small temperature difference fan-coil unit



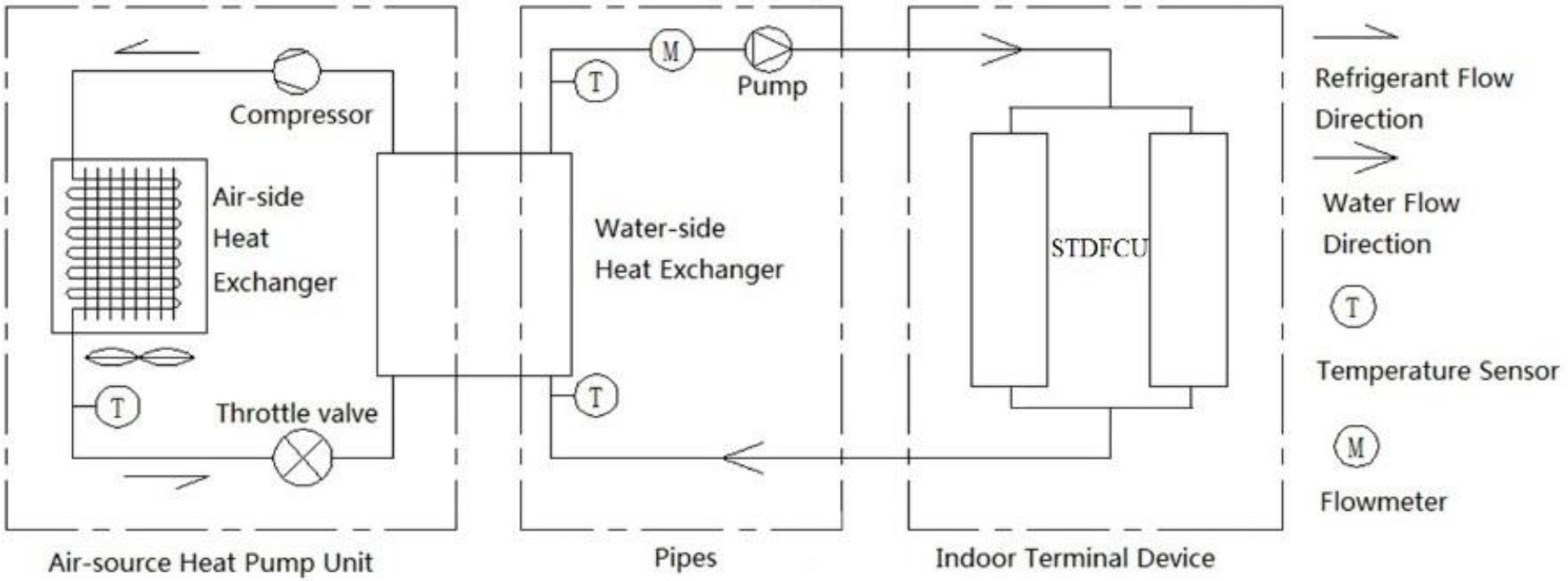
Typical heating conditioning			
Heat trans Area m2	4.2	Delta T ℃	7.8
Air flow rate m3/h	450	Water flow rate L/s	0.11
Air inlet T℃	21	Air outlet T℃	36
Water inlet T ℃	40	Water outlet T ℃	35.2
Heating power W	2190		

Structure parameters

L: 1.24m **W: 0.13m** **H: 0.41m**

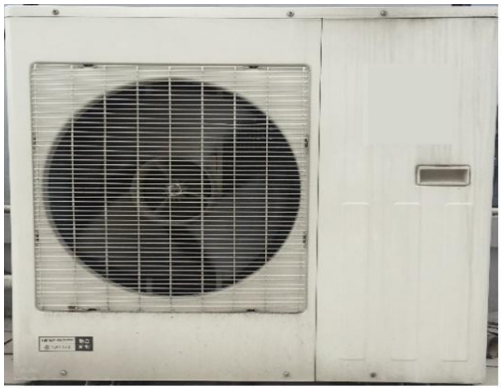
Hot-summer and cold-winter zone

Schematic of ASHP system in SJTU



- The system includes: an ASHP unit with rated heating capacity of 9.5 kW, a 150 L water tank and small temperature difference fan-coil units.

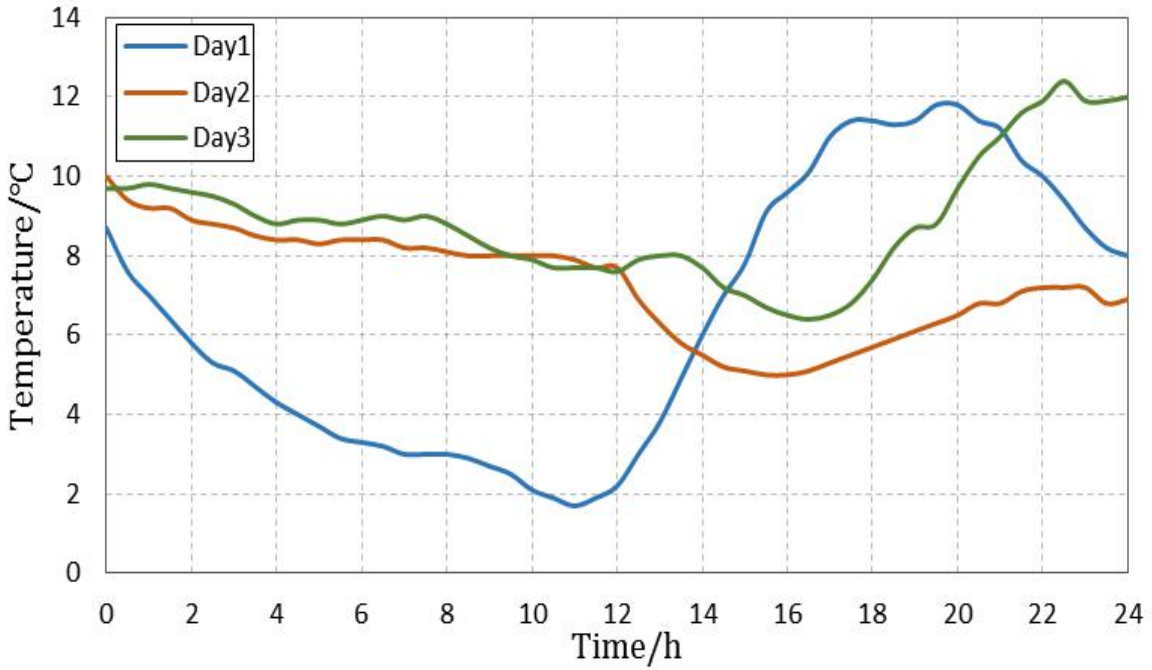
Hot-summer and cold-winter zone



- ✓ An ASHP is installed in a 92m^2 apartment in SJTU.
- ✓ The ASHP unit's heating capacity in this experiment is 9500W and power is 2370W.

Hot-summer and cold-winter zone

Outdoor air temperature



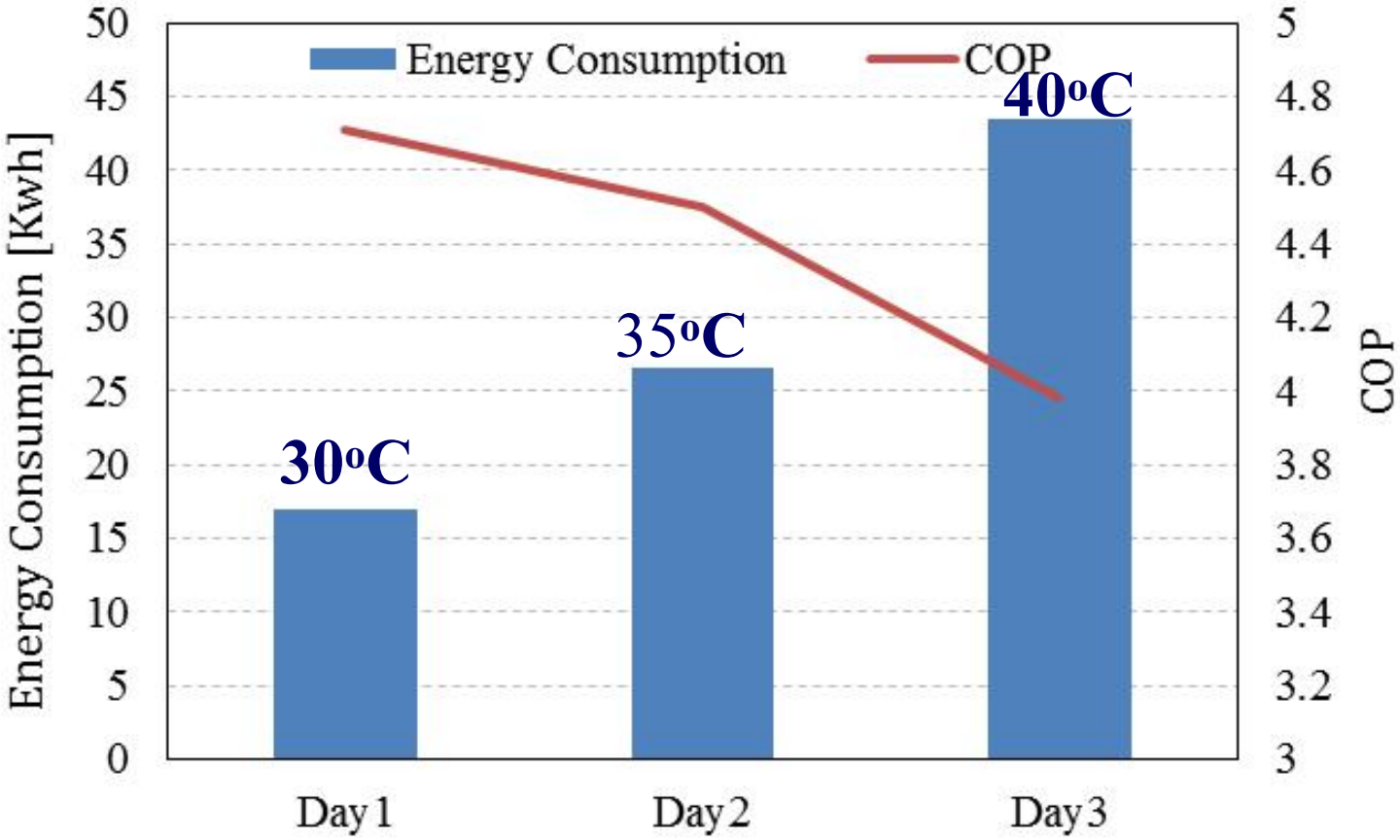
The average outdoor temperatures are 8.8°C, 7.3°C, 6.4°C, respectively.

The return water temperatures are set to 30°C, 35°C, 40°C, respectively.

Average air temperature in different rooms during the test/ °C

	Living	Dining	Kitchen	North Bed	South Bed
Day1	19.5	19.2	18.5	20.1	21.8
Day2	19.9	20.0	19.2	21.3	23.3
Day3	19.8	20.2	19.5	21.5	23.6

Hot-summer and cold-winter zone



Energy consumption and COP of ASHP with STDFCU at different supplying hot water temp for heating

ASHP heating at the extremely cold conditions in Shanghai in Jan.2016

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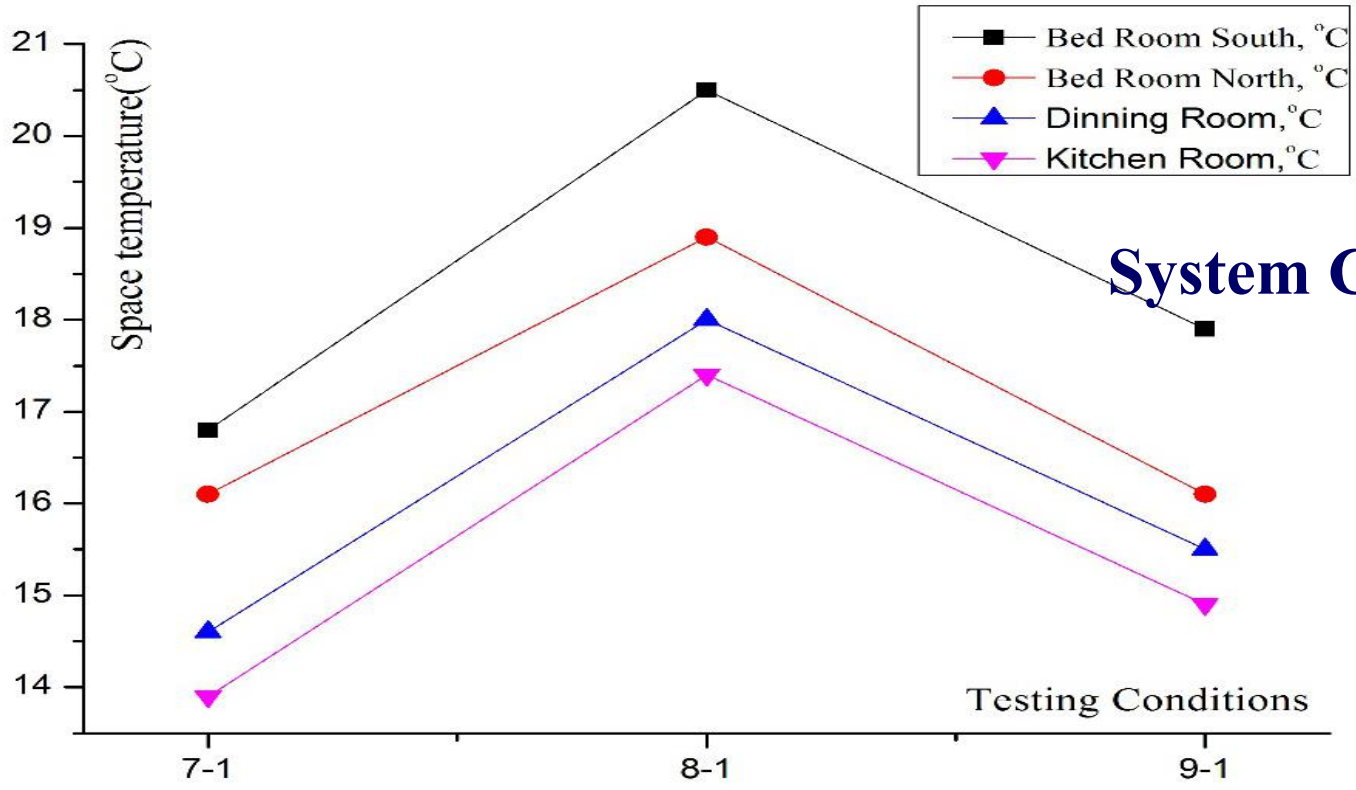
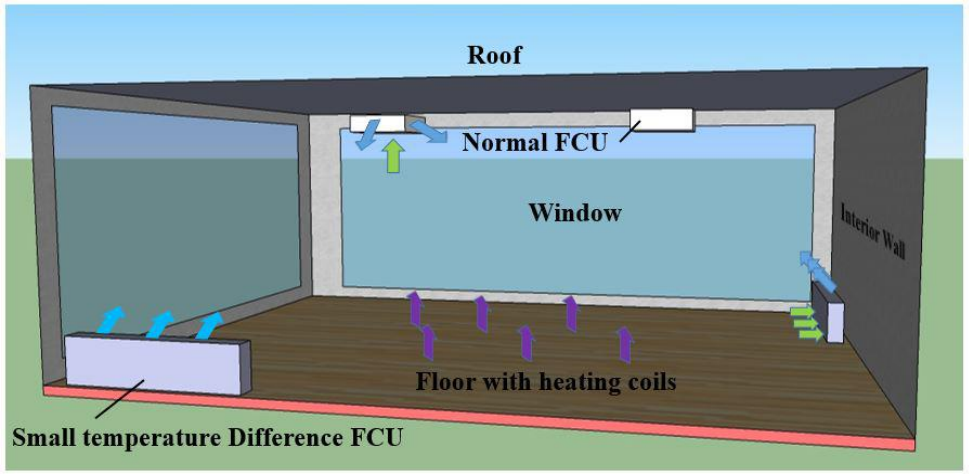
Exp. On 3 days	Return hot water T, °C	FCU set room air, °C	Out door air Average T, °C	Fan Coil Control
7-1	40	22	-4.8	Automatic gear
8-1	35	22	2.5	Automatic gear
9-1	30	22	-4	Automatic gear



System COP=3.0

Hot-summer and cold-winter zone

Further test in SJTU-GEL



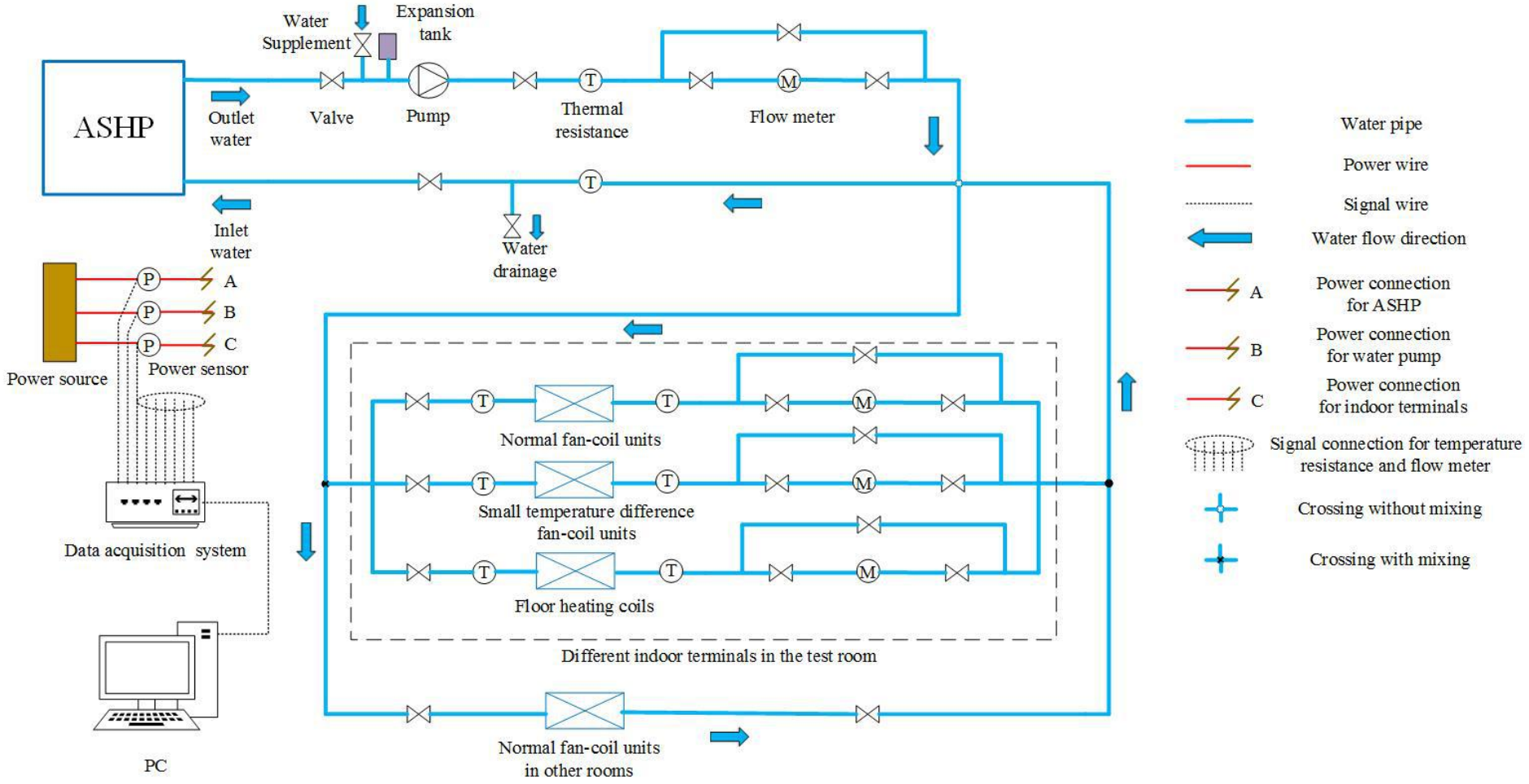
装有不同类型末端的实验室

1. Normal FCU
2. Small deltaT FCU
3. Floor heating

中意绿色能源楼

Sino-Italian GEL

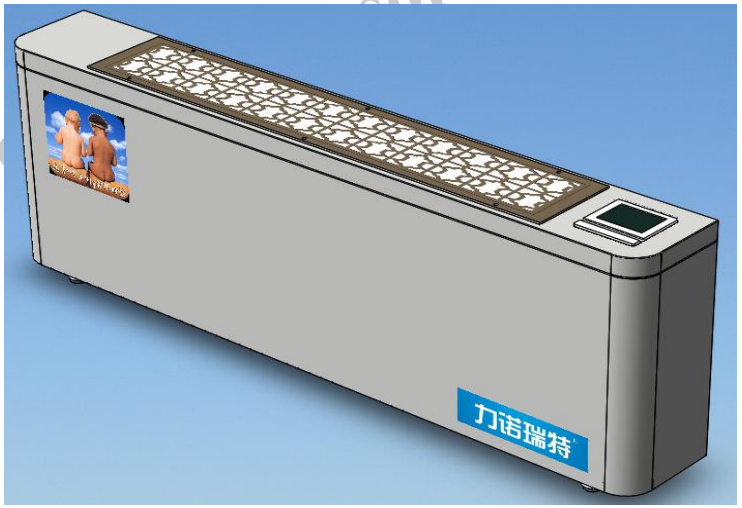
Hot-summer and cold-winter zone



Test System

Hot-summer and cold-winter zone

+



Research Results

- Comfortable
- High efficiency
- Economic
- Comfortable cooling option
- Low initial investment
- Option to make hot water

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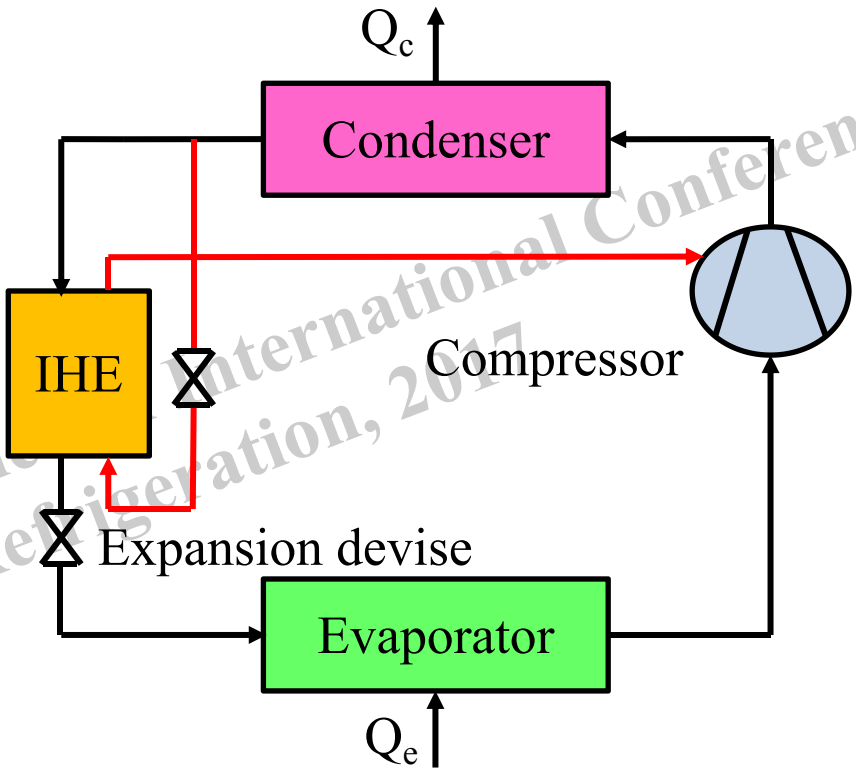
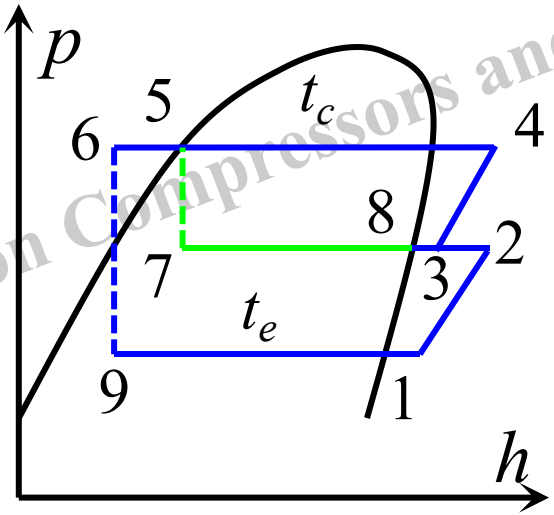
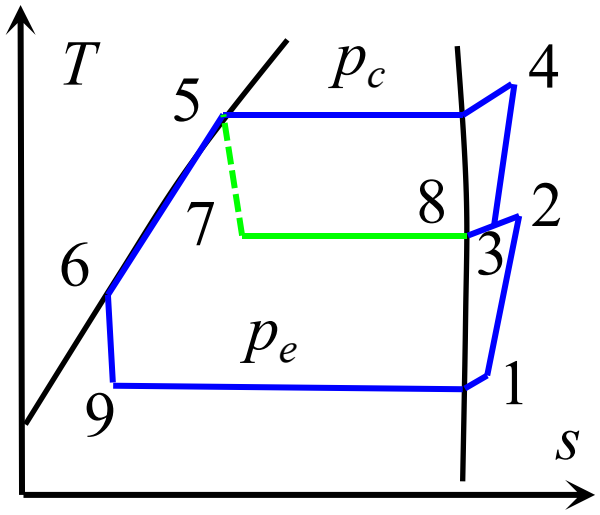
Cold region

- **Vapor injection cycle**



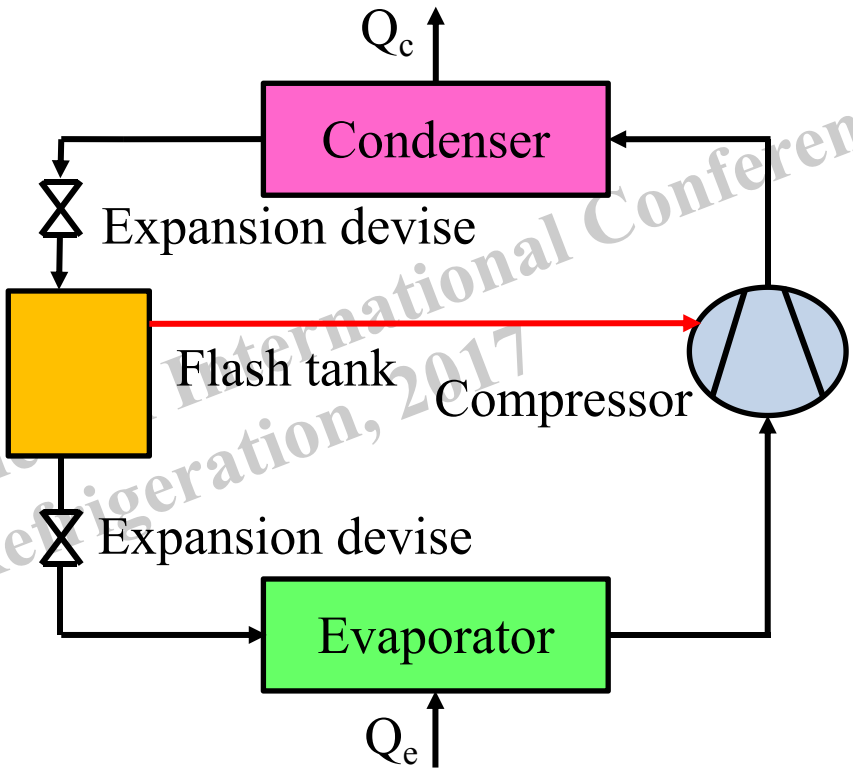
(a) internal heat exchanger



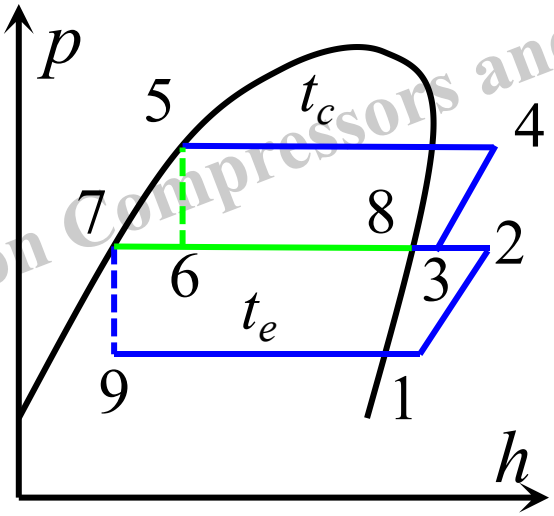


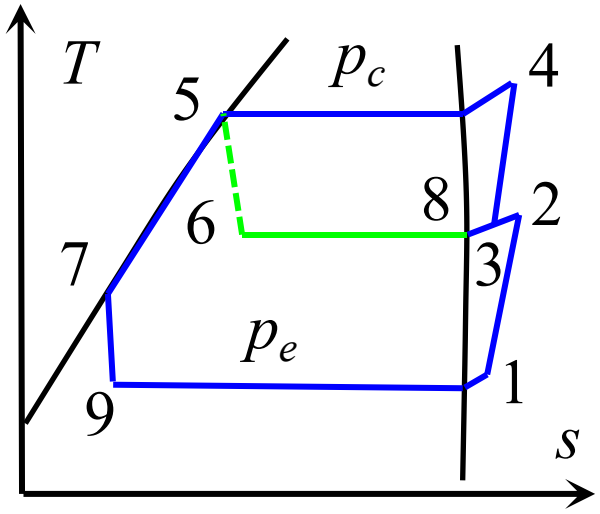
Cold region

- **Vapor injection cycle**



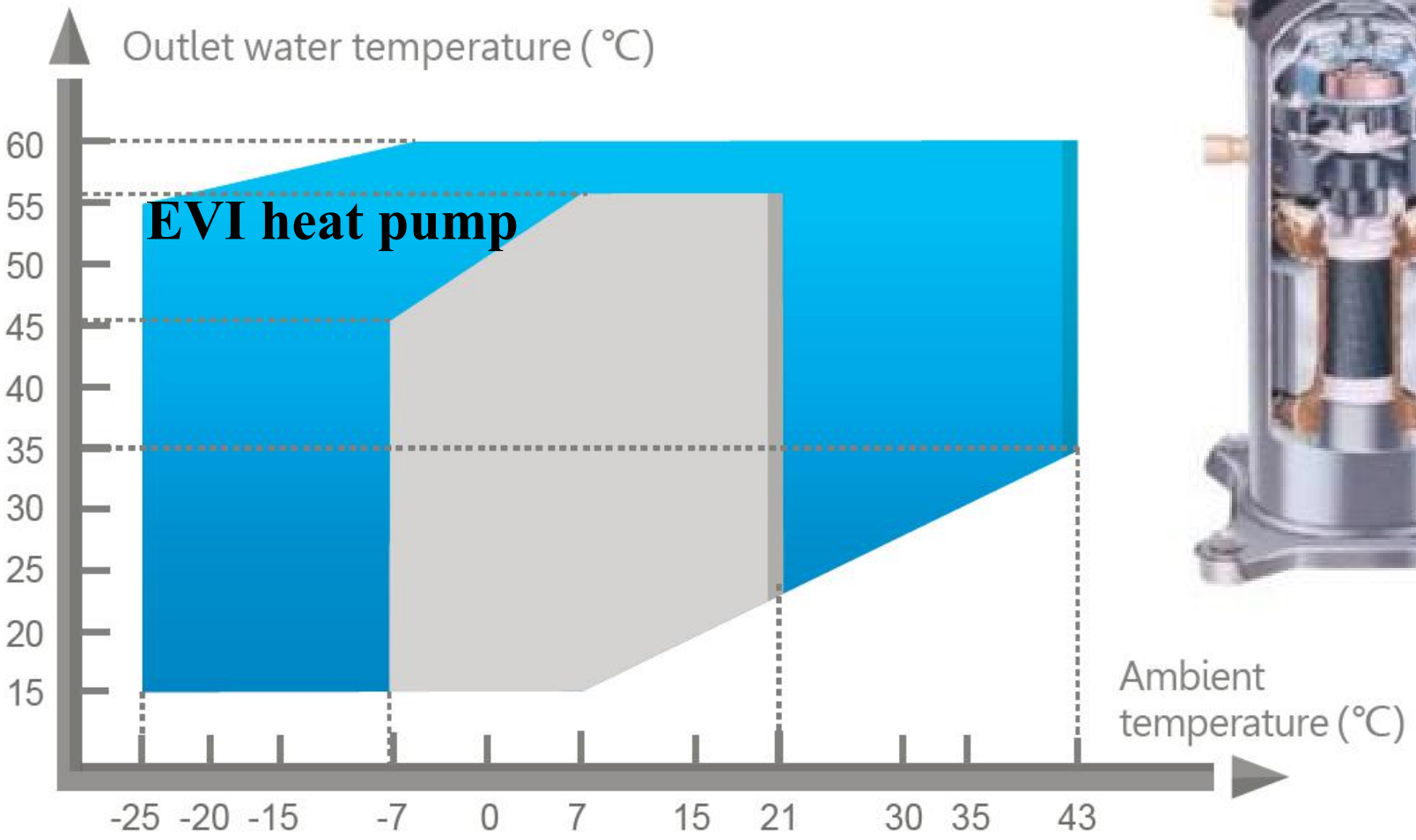
(b) flash tank



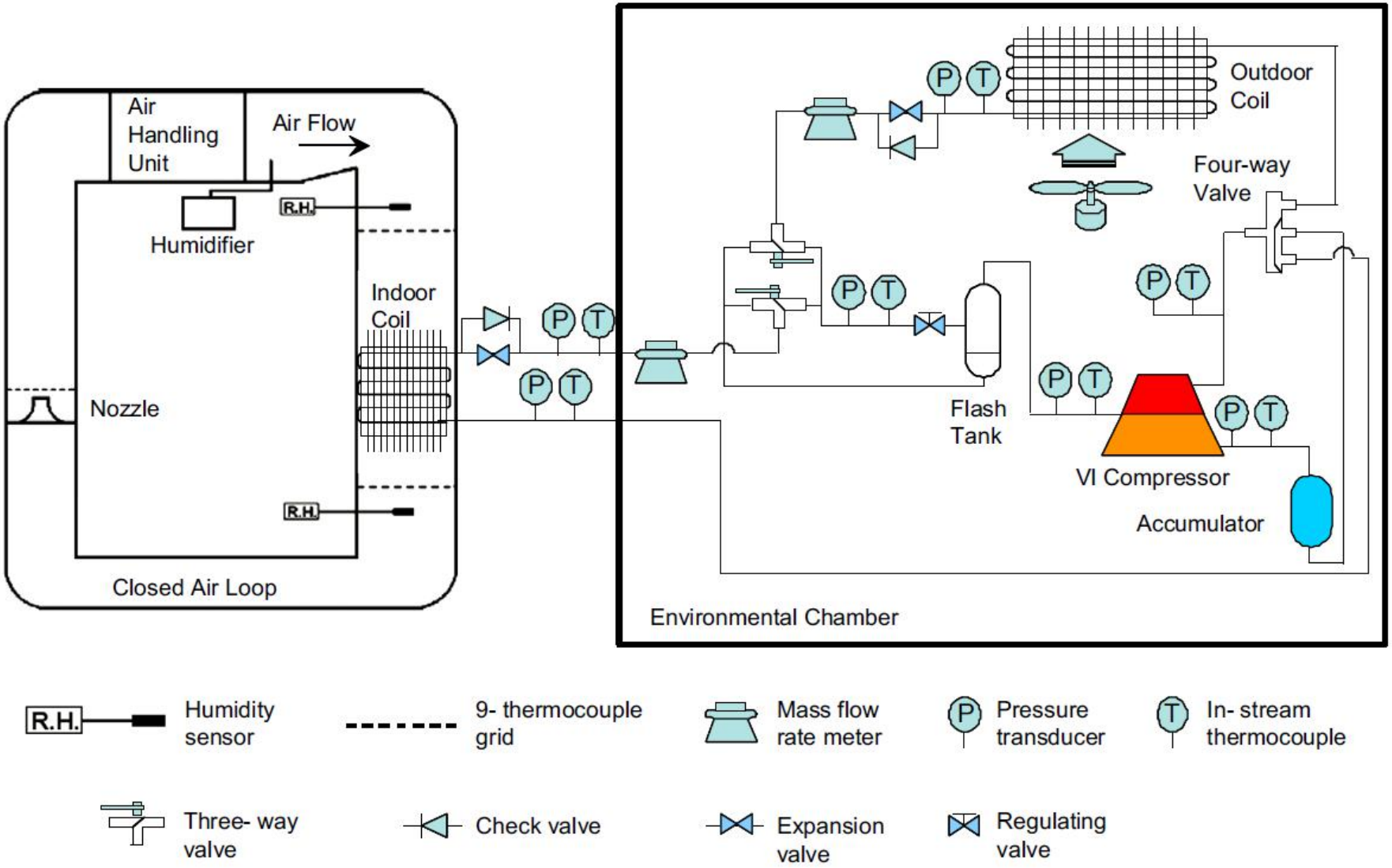


Cold region

EVI compressor: low temperature application



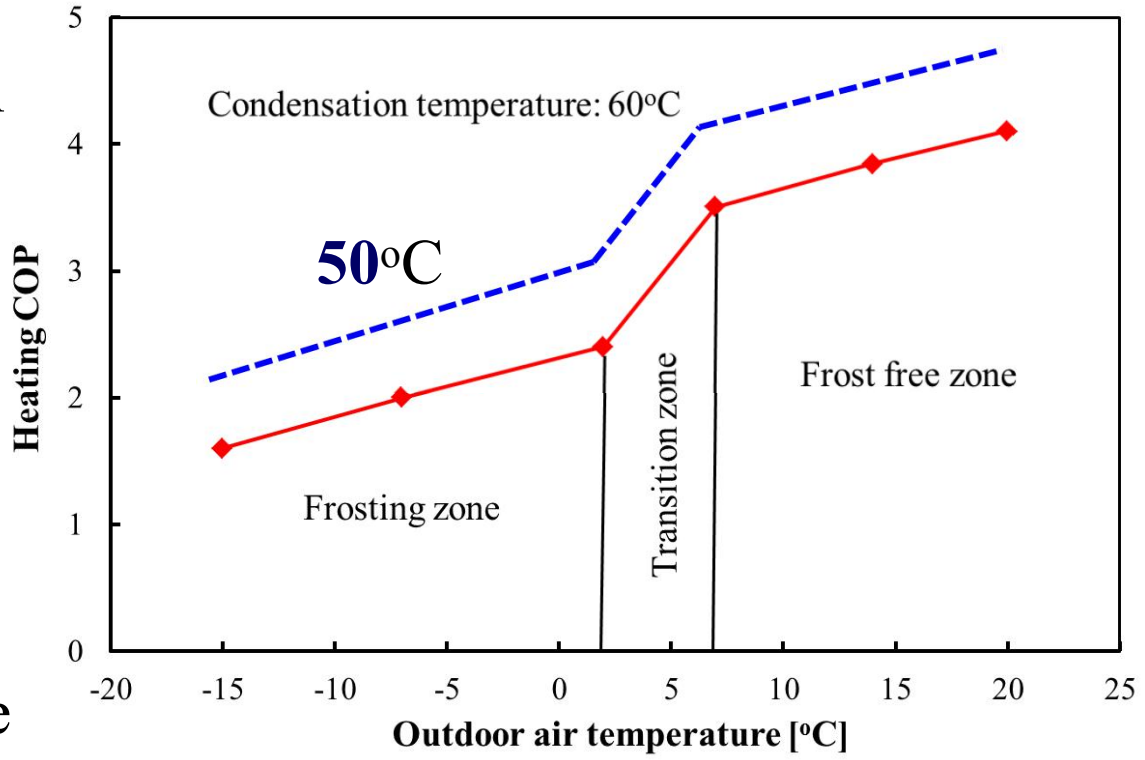
Cold region



Wang X, Hwang Y, Radermacher R. Two-stage heat pump system with vapor-injected scroll compressor using R410A as a refrigerant[J]. International Journal of Refrigeration, 2009, 32(6):1442-1451.

Cold region

- COP increases a lot with outdoor air temperature increasing
- Defrost energy consume is also considered in the frosting zone.
- Lower the condensation temperature can improve the COP greatly.

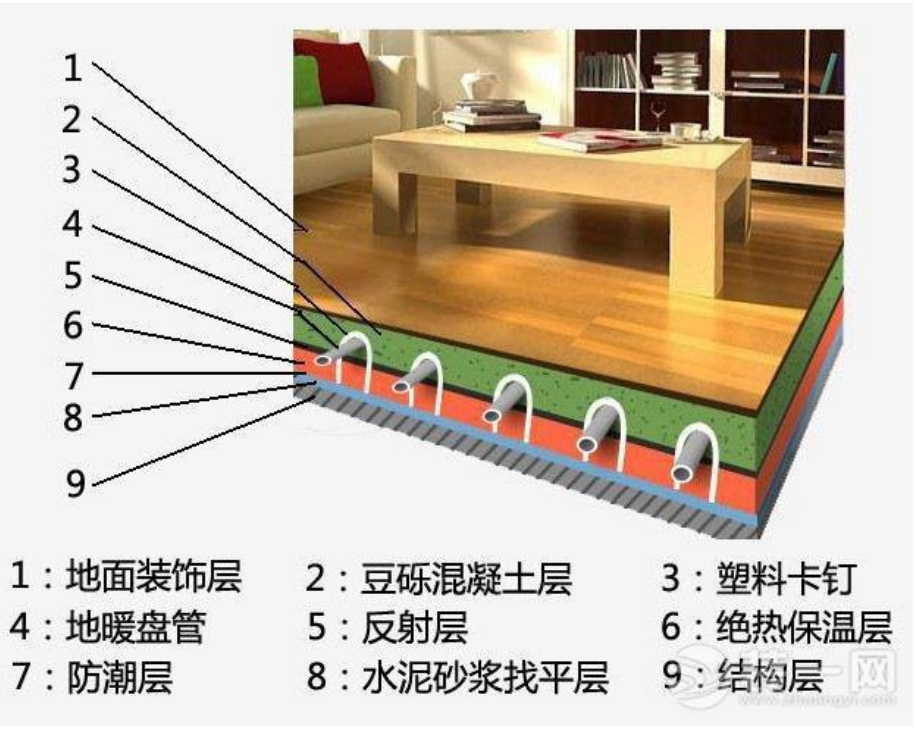


Heating COP under different outdoor air temperature

To make the water supply temperature as low as possible, the more suitable terminals in cold region of China are radiant floor heating or STDFCU.

Cold region

Radiant floor heating (Underfloor heating) is a form of central or distributed heating terminal which achieves indoor climate control for thermal comfort using heat conduction, radiation and convection.

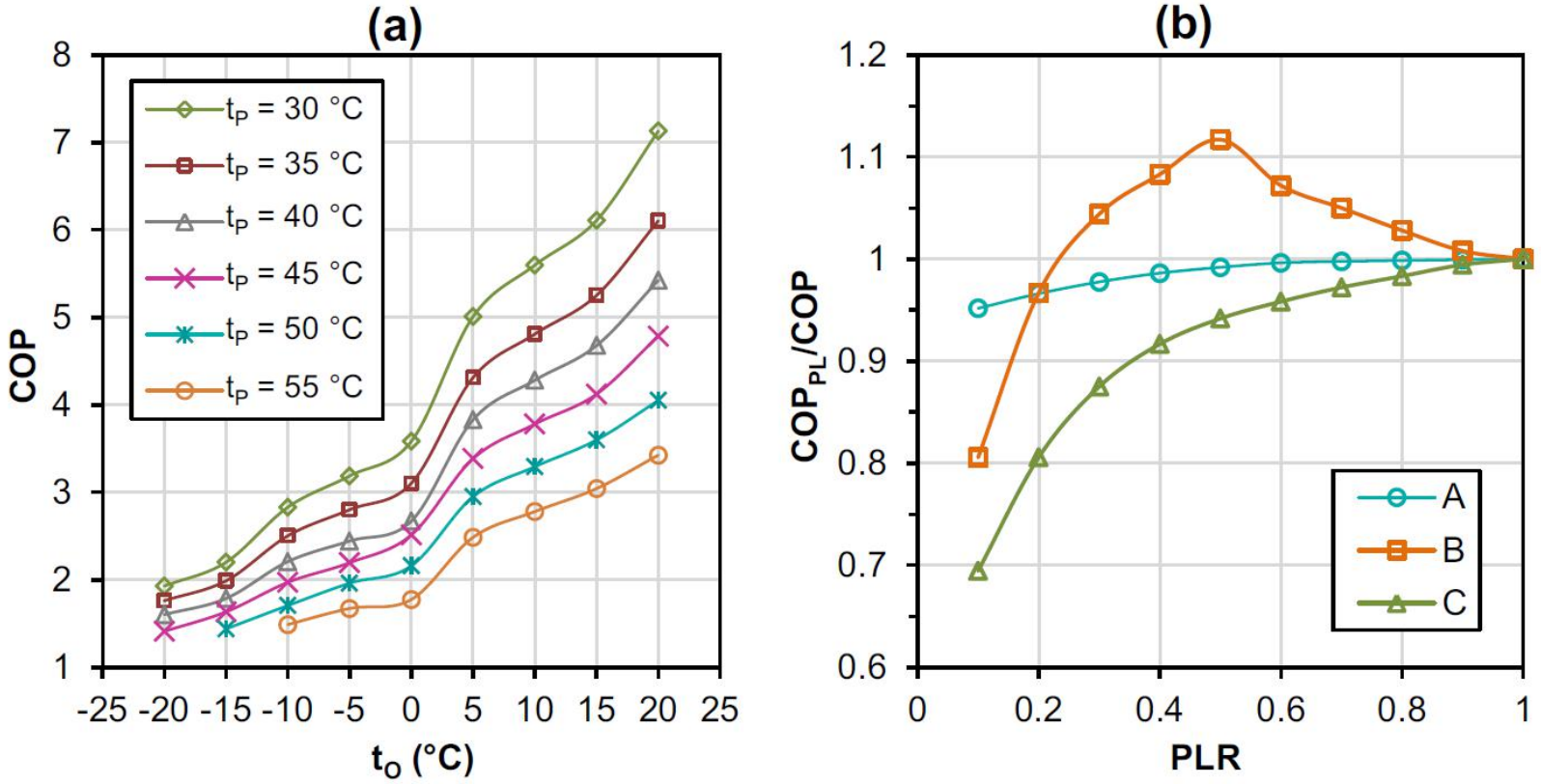


Cold region

Advantages of radiant floor heating :

- The temperature distribution from floor to ceiling is uniform, which could provide an acceptable thermal environment.
- It is more efficient than baseboard heating and usually more efficient than forced-air heating because it eliminates duct losses.
- The supply hot water and return water temperature for underfloor radiator is 45°C and 35°C, or even lower.

Cold region



(a) COP as a function of outdoor temperature (t_o) and water production temperature (t_p); (b) Part load operation (Edwards and Finn).

Márquez A A, López J M C, Hernández F F, et al. A comparison of heating terminal units: fan-coil versus radiant floor, and the combination of both[J]. Energy & Buildings, 2017, 138: 621-629.

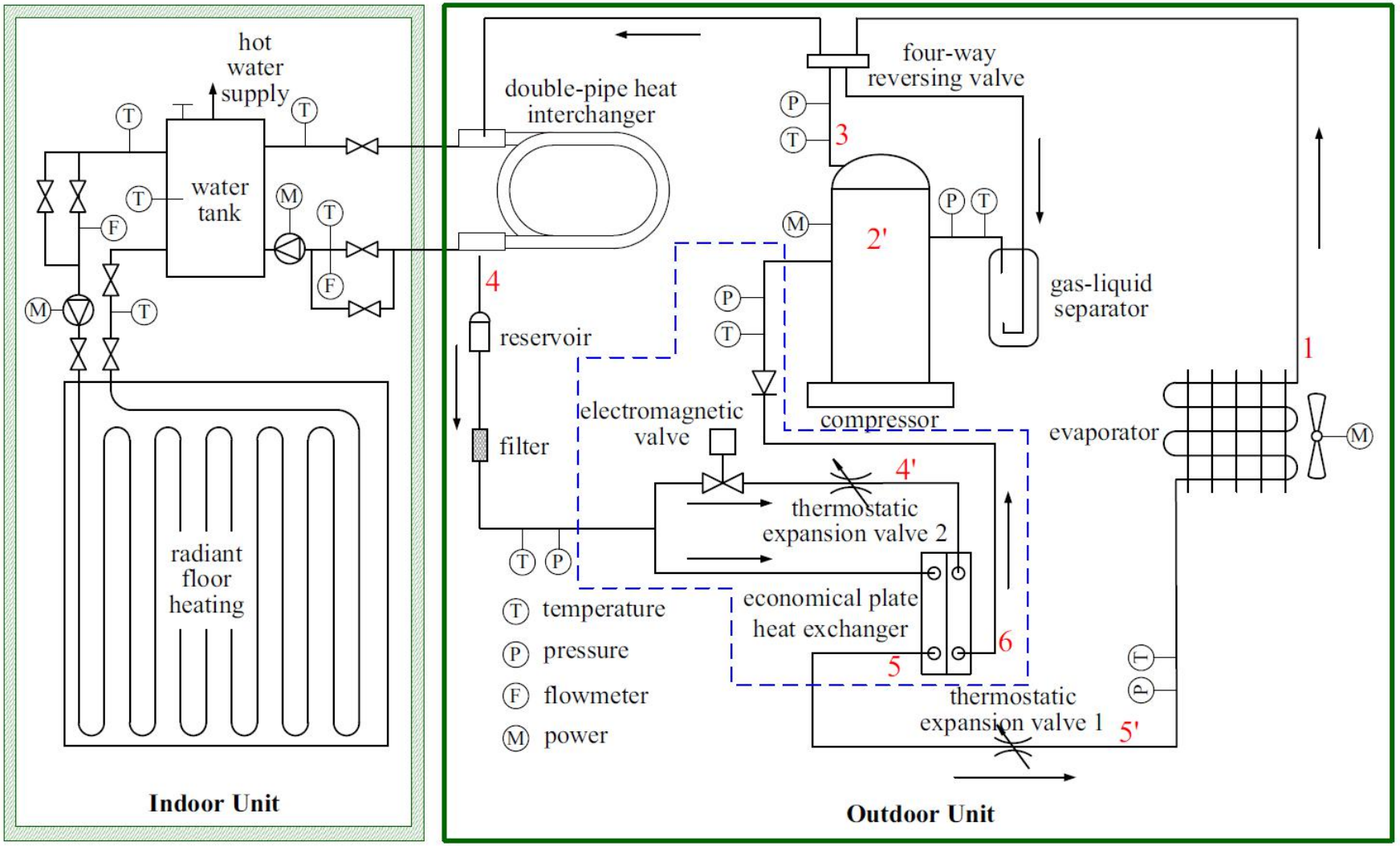
Edwards K C, Finn D P. Generalised water flow rate control strategy for optimal part load operation of ground source heat pump systems[J]. Applied Energy, 2015, 150:50-60.

Cold region

- the unit COP can be greatly improved with water production temperature decreasing for the same outdoor air temperature.
- when the outdoor air temperature is -15°C, the unit COP is about 1.6 with the 50°C hot water produced. However, the unit COP can be increased to 2.1 with the 35°C hot water produced.
- the radiant floor heating with low temperature water supply can be adopted to satisfy the heating demand and keep the ASHP unit operating with high efficiency.

Márquez A A, López J M C, Hernández F F, et al. A comparison of heating terminal units: fan-coil versus radiant floor, and the combination of both[J]. Energy & Buildings, 2017, 138: 621-629.
Edwards K C, Finn D P. Generalised water flow rate control strategy for optimal part load operation of ground source heat pump systems[J]. Applied Energy, 2015, 150:50-60.

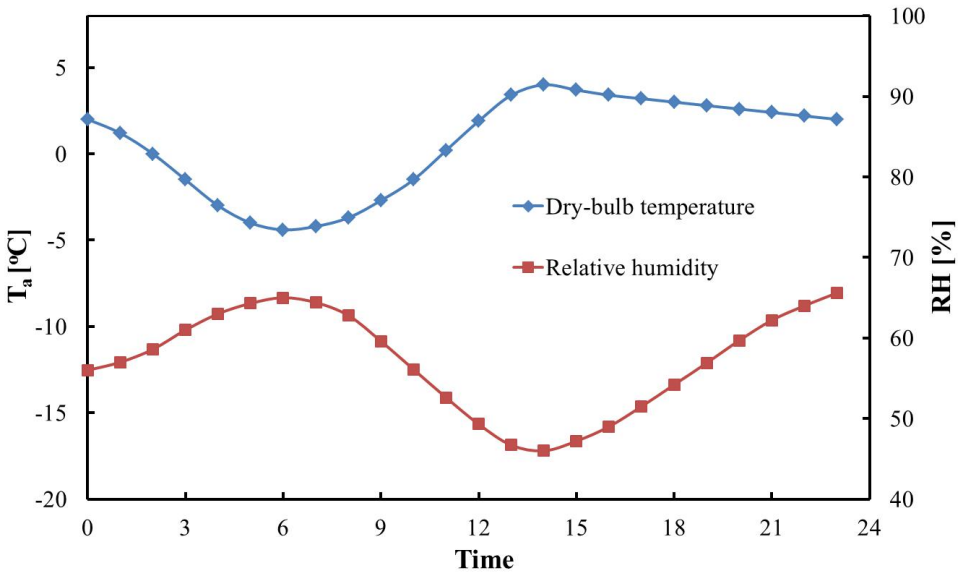
Cold region



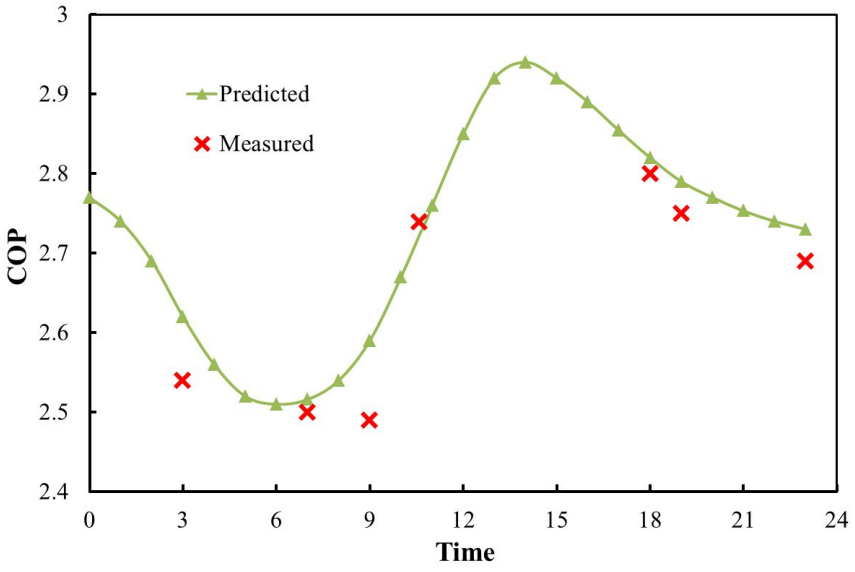
Schematic diagram of EVI-ASHP and radiant floor heating system

Zhang D, Li J, Nan J, et al. Thermal performance prediction and analysis on the economized vapor injection air-source heat pump in cold climate region of China[J]. Sustainable Energy Technologies & Assessments, 2016, 18:127-133.

Cold region



Dry-bulb temperature and relative humidity

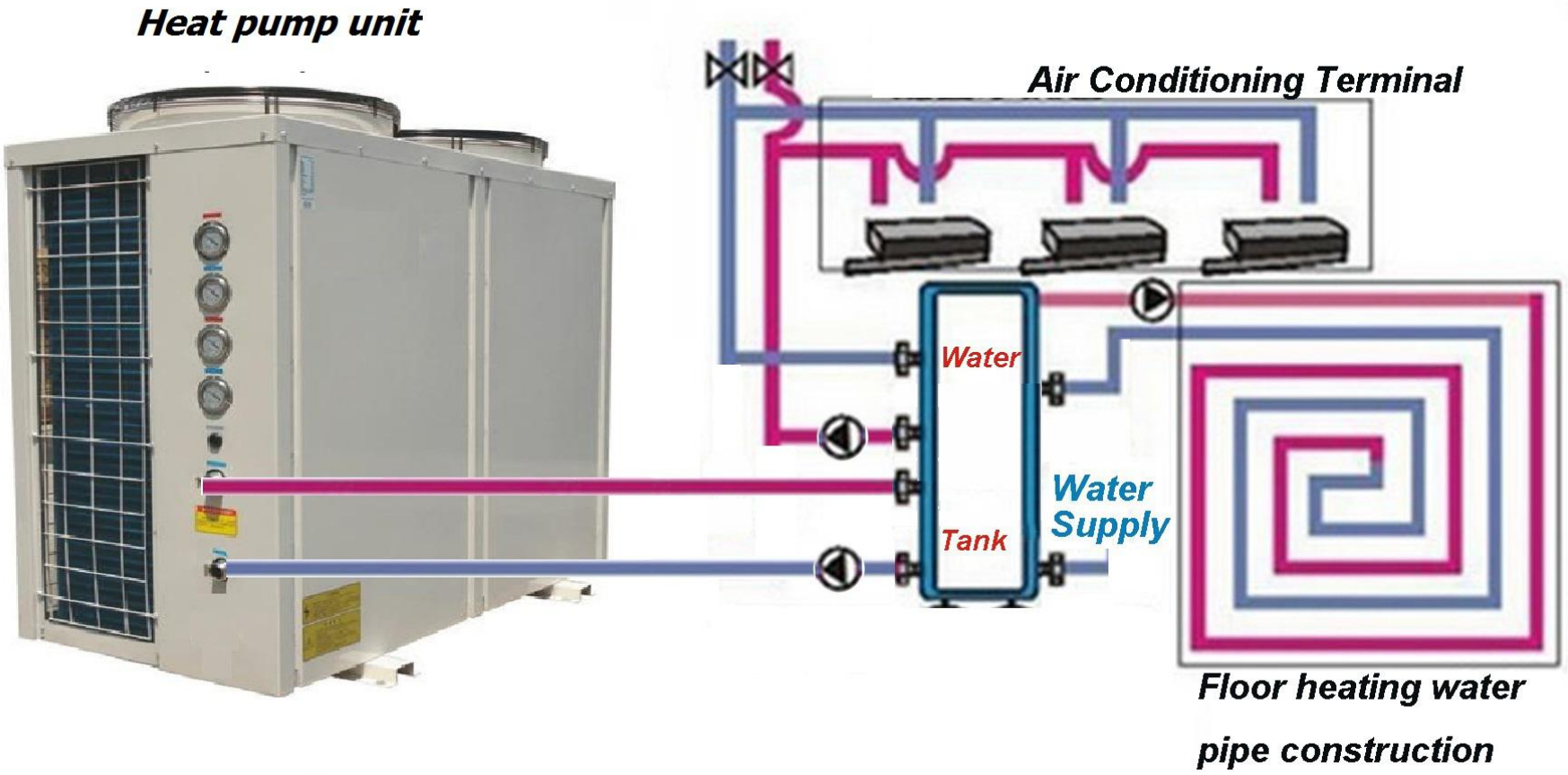


The predicted and measured COP

- The COP of heat pump in December 1st in Lanzhou is above 2.5.
- Water inlet temperature in double-pipe heat exchanger is 40ºC.
- The experimental COP is lower than predicted ones because of the lower environmental temperature.

Cold region

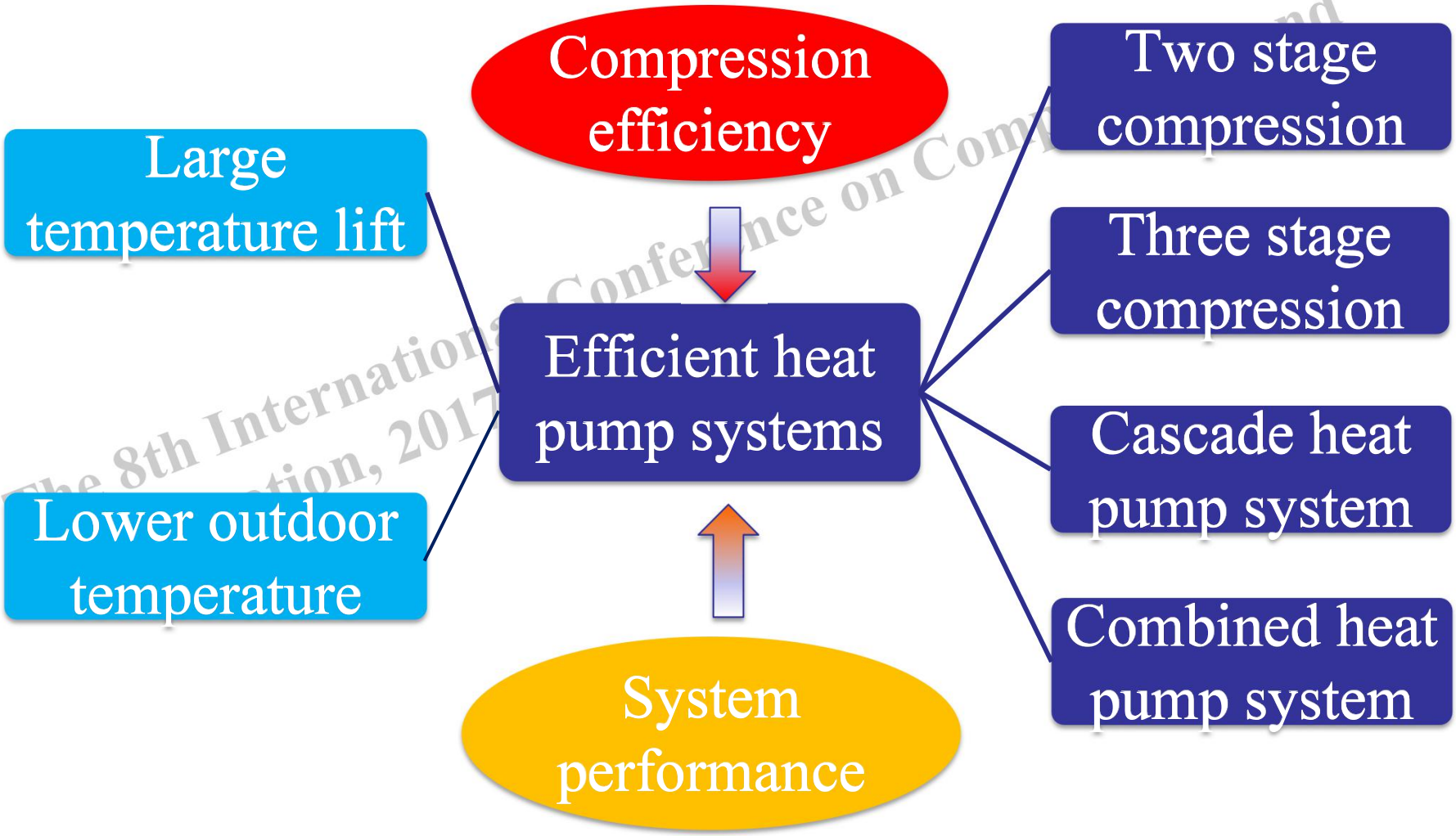
EVI-ASHP and floor heating system/STDFCU



Outline

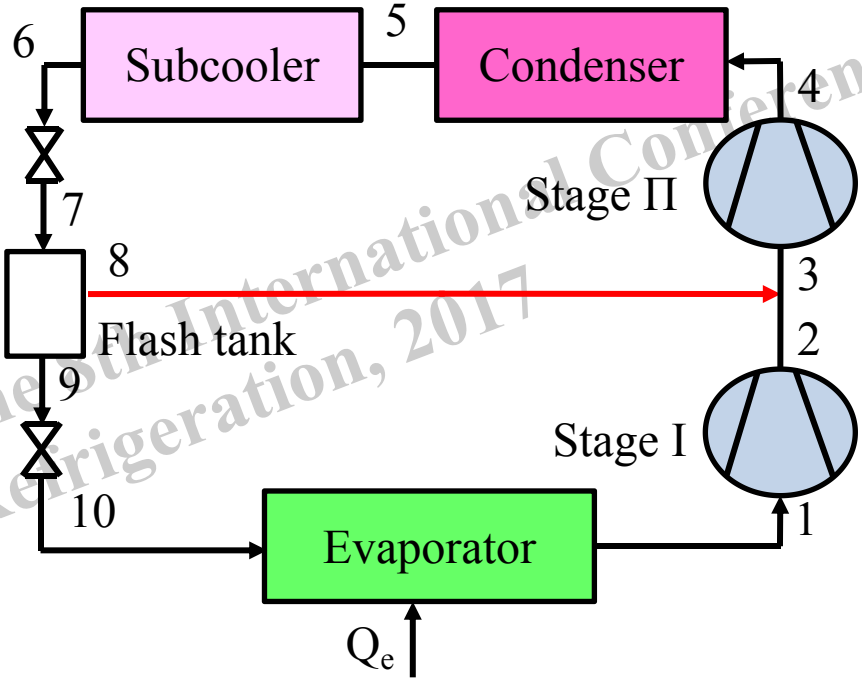
1. Introduction
2. The definition of climate zone in China
3. Hot-summer and cold-winter zone
4. Cold region
5. Severe cold region
6. Conclusions and perspectives

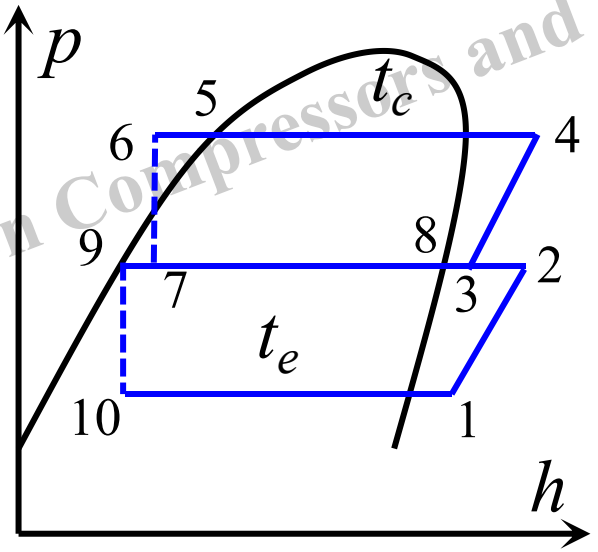
Severe cold region

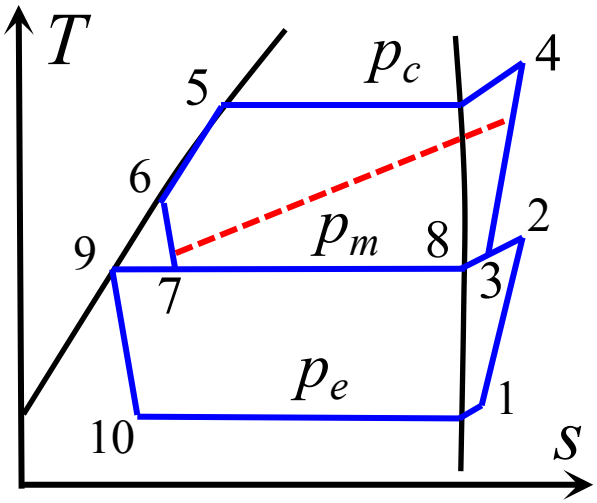


Severe cold region

- Two stage compression cycle

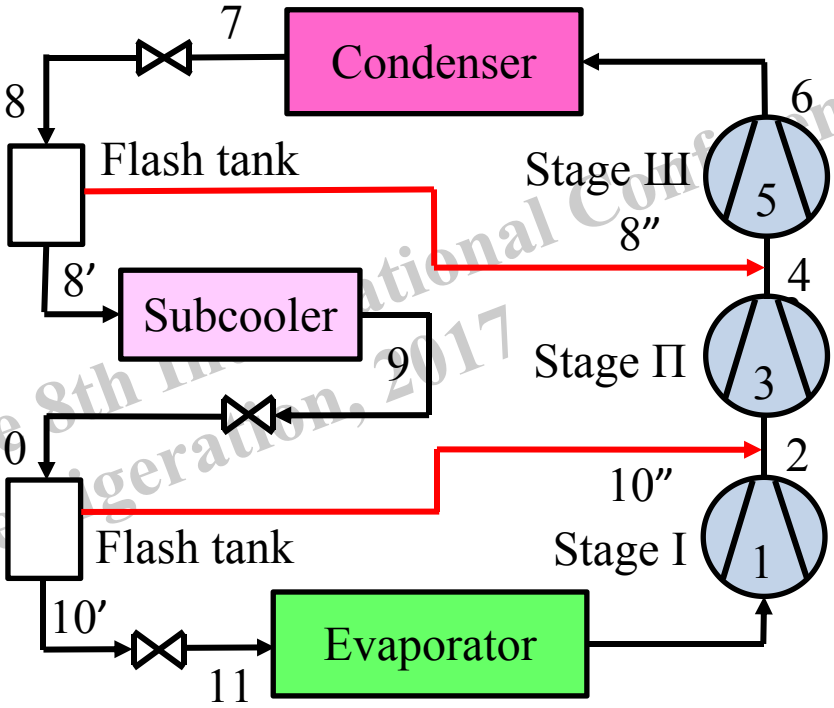


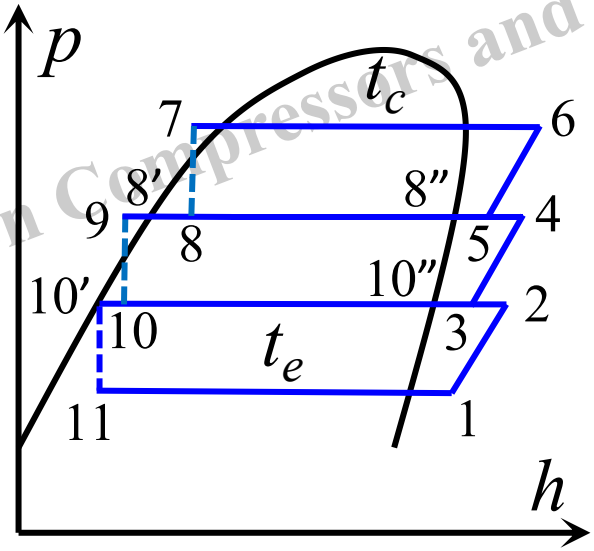


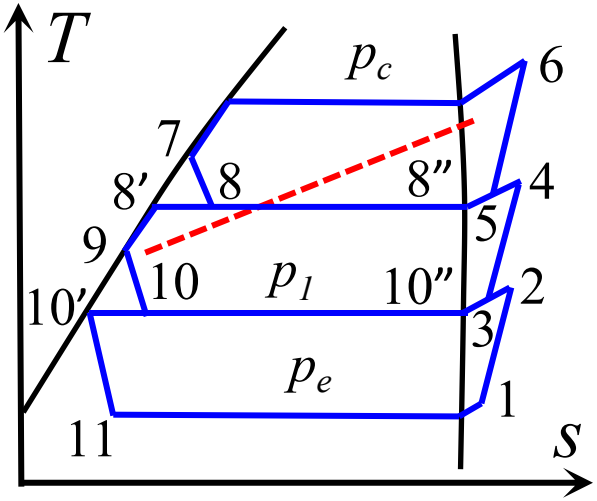


Severe cold region

- Three stage compression cycle

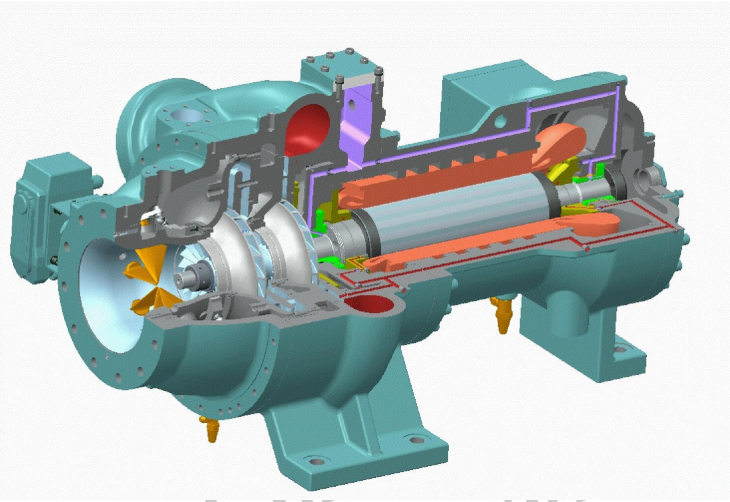


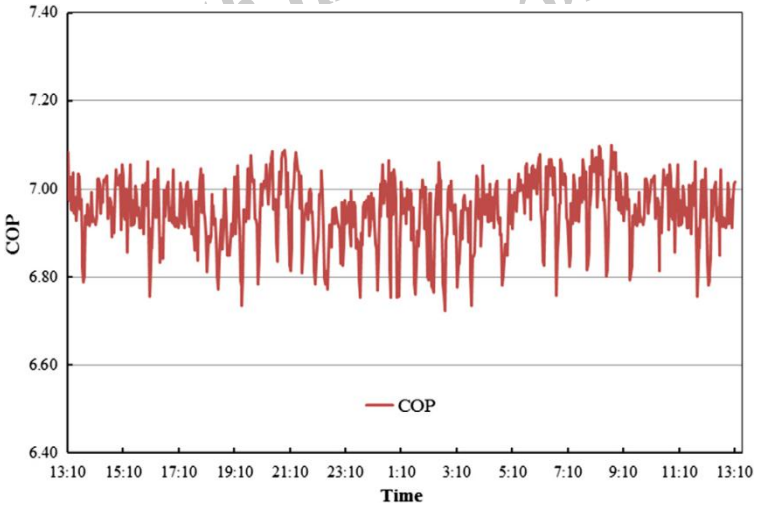


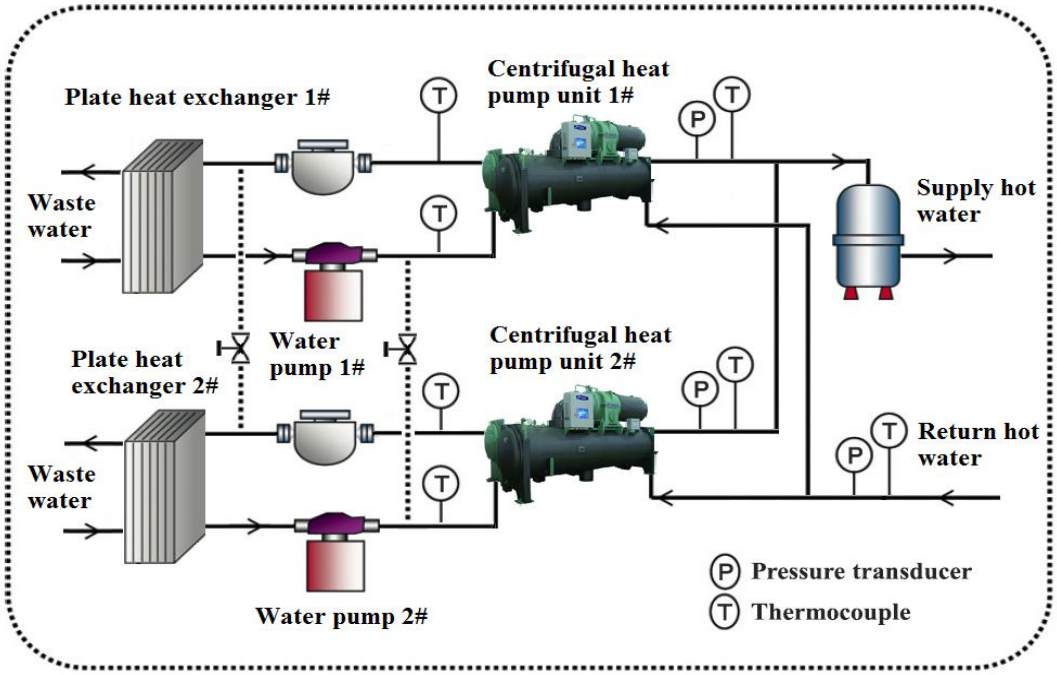


Severe cold region

Centrifugal heat pump with multi-stage compression





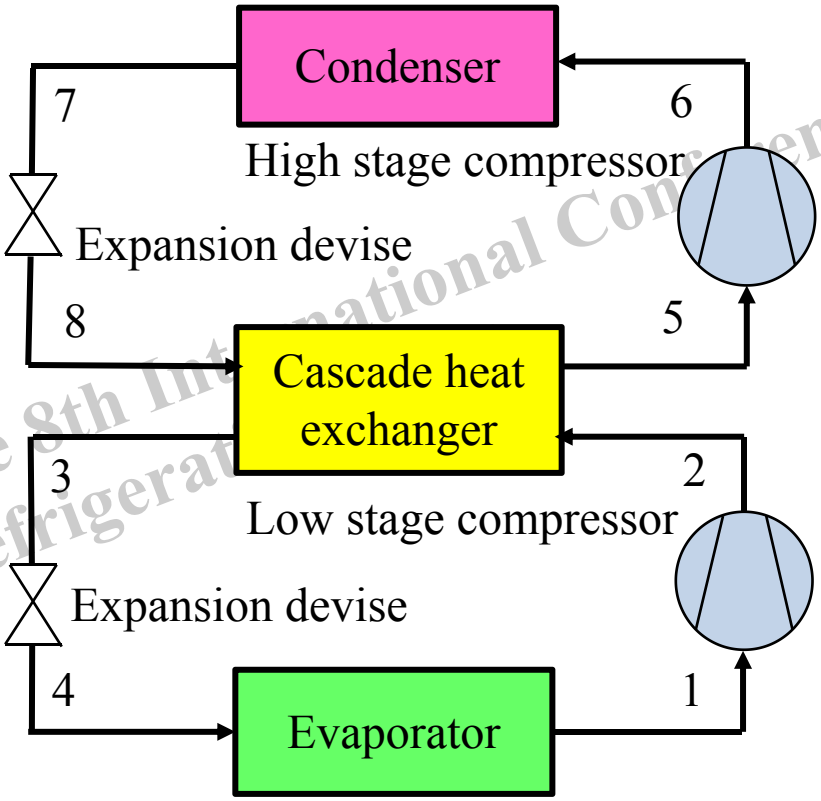


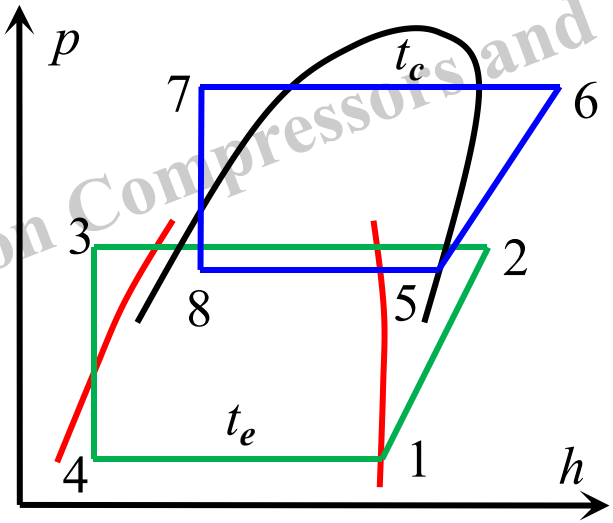
- The hot water supply and return temperatures were 45.1 °C and 35.6 °C respectively.
- COP of centrifugal heat pump were 6.95.

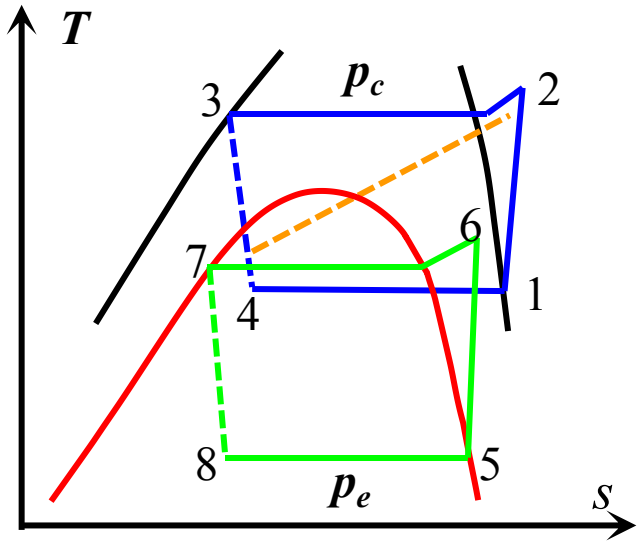
Bin Hu, Hua Liu, R.Z. Wang, et al. A High-Efficient Centrifugal Heat Pump with Industrial Waste Heat Recovery for District Heating[J]. Applied Thermal Engineering. 2017, 125: 359–365

Severe cold region

- Cascade heat pump system

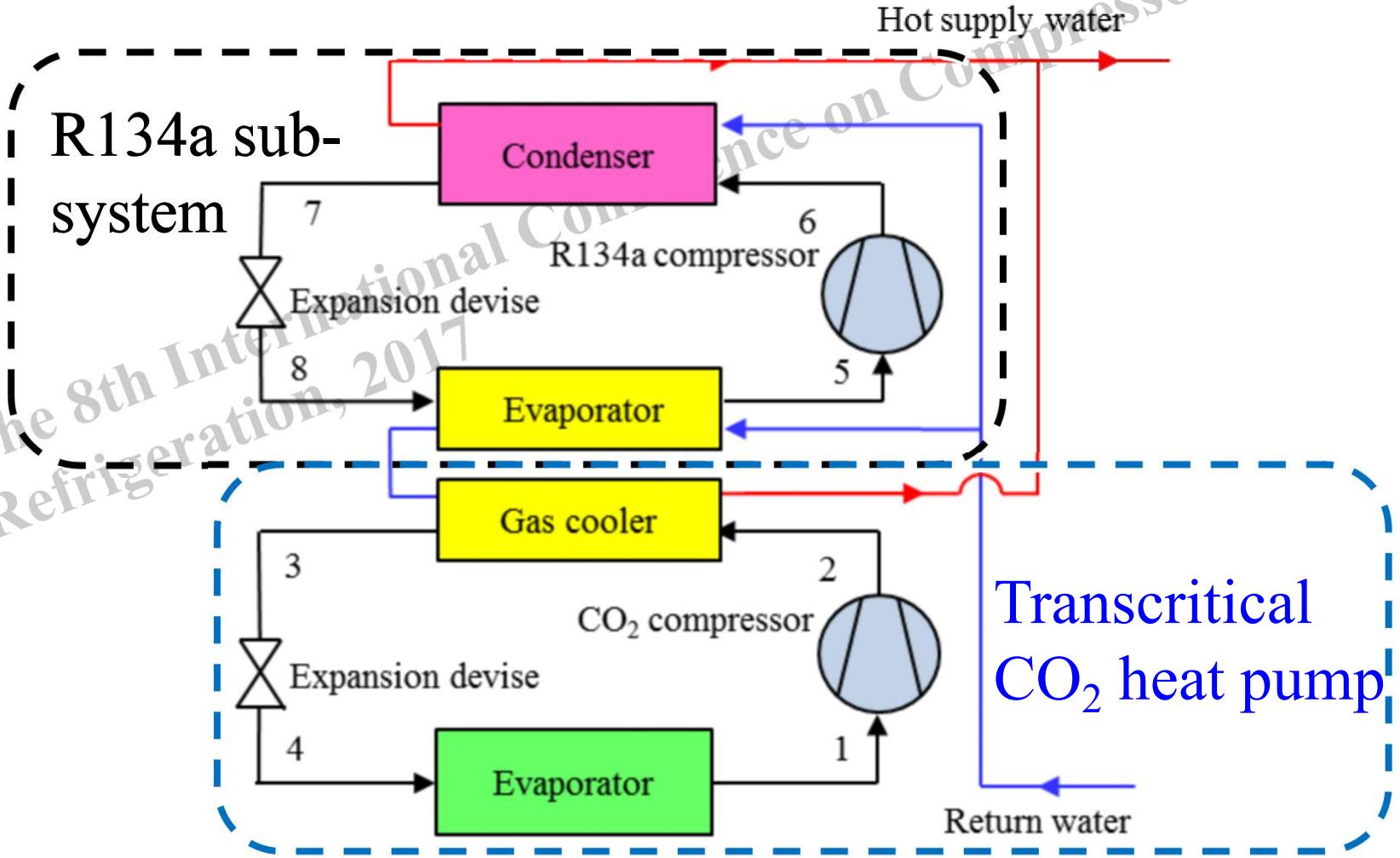






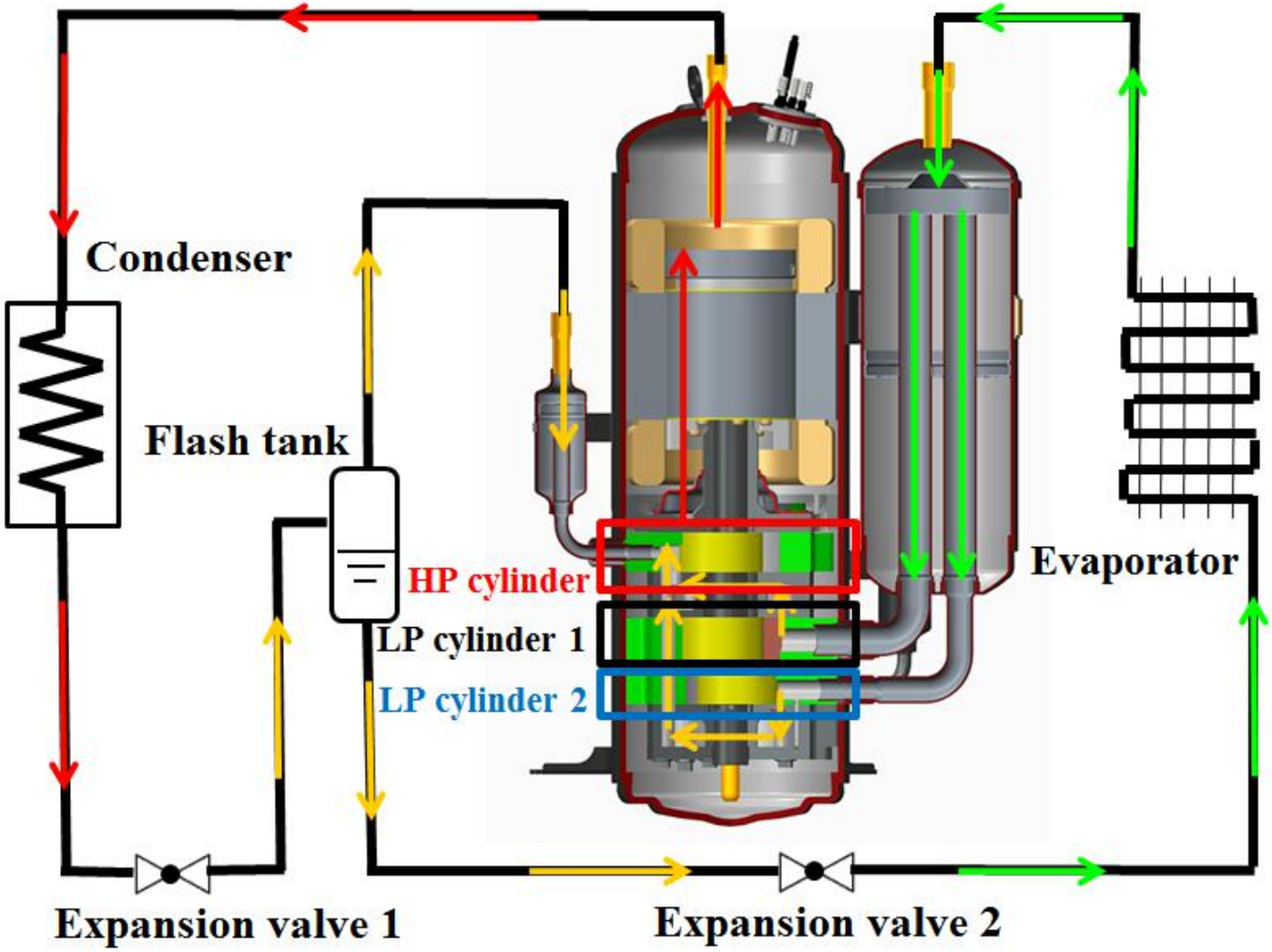
Severe cold region

- Combined transcritical CO_2 and R134a heat pump



Severe cold region

Heat pump system with two-stage variable volume ratio compressor

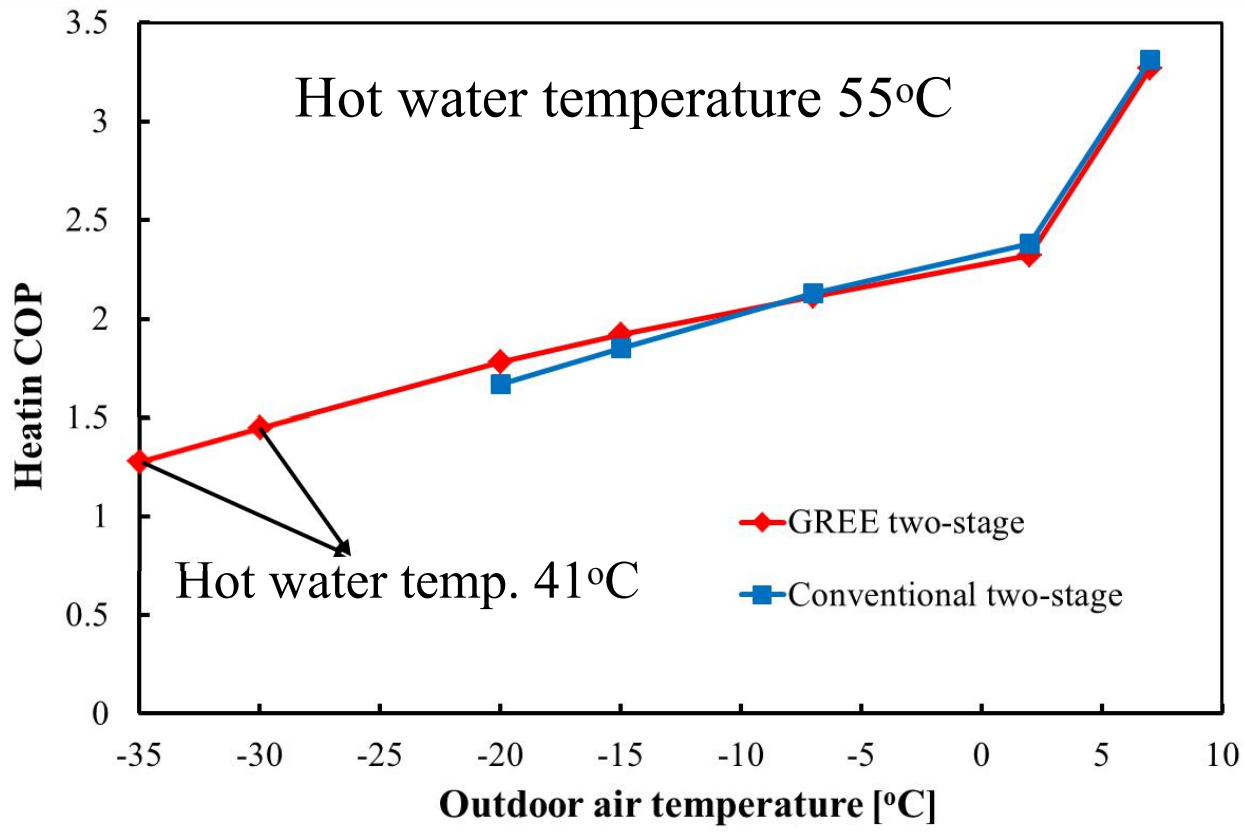


Air source heat pump with two-stage variable volume ratio compressor. http://news.ehvacr.com/people /2016/1121/99877.html

Severe cold region

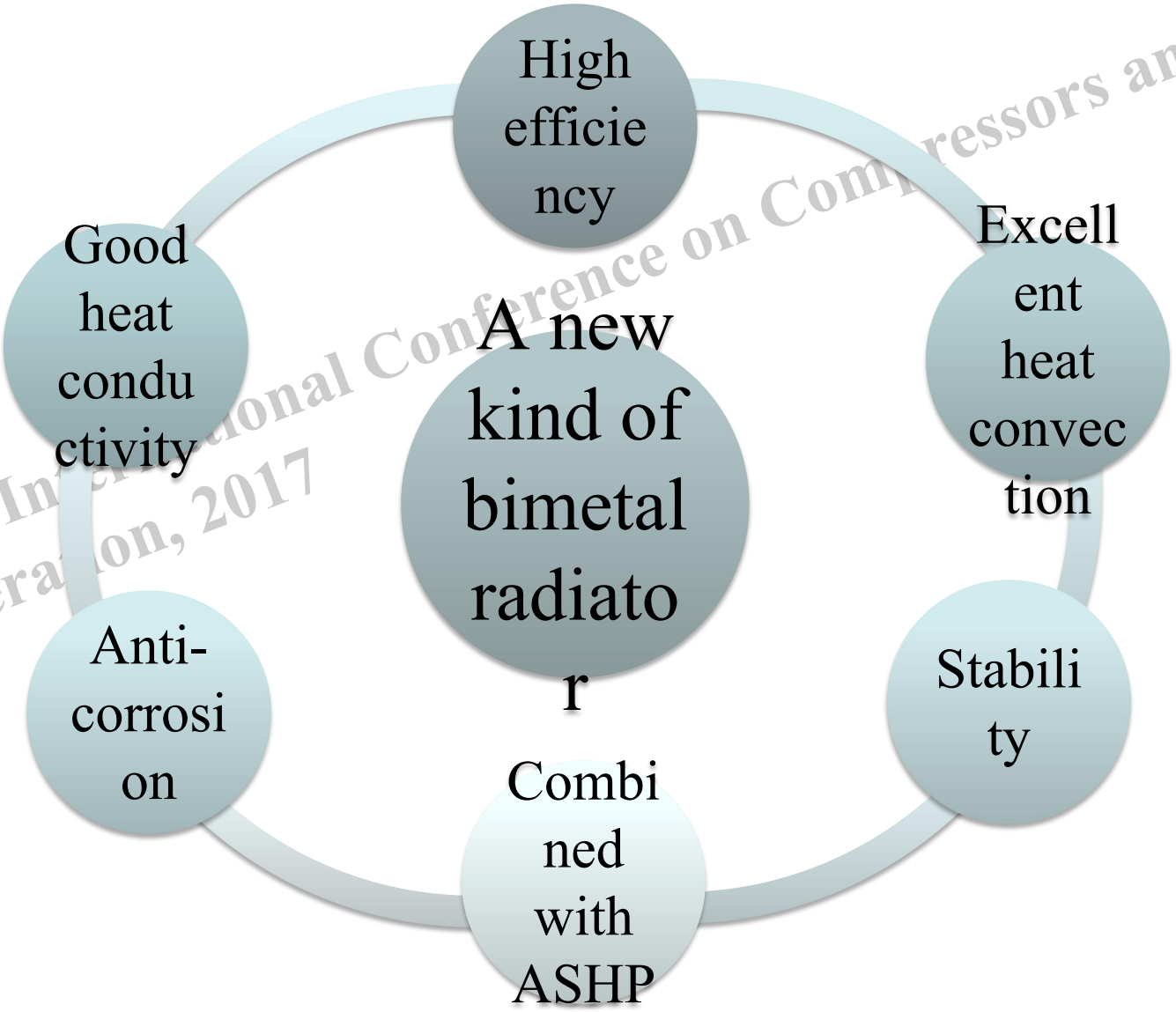
- The two-stage variable volume ratio compressor has three cylinders (high pressure cylinder, low pressure cylinder1 and low pressure cylinder 2)
- The compressor can operate in a wide-range of ambient temperature(-35℃ to 54℃).
- When the outdoor air temperature is -20°C, the heating COP of such two-stage heat pump is 6.5% higher than conventional two-stage heat pumps.
- The heating COP of such two-stage heat pump can be kept at 1.5 when the outdoor air temperature is -30°C.

Severe cold region

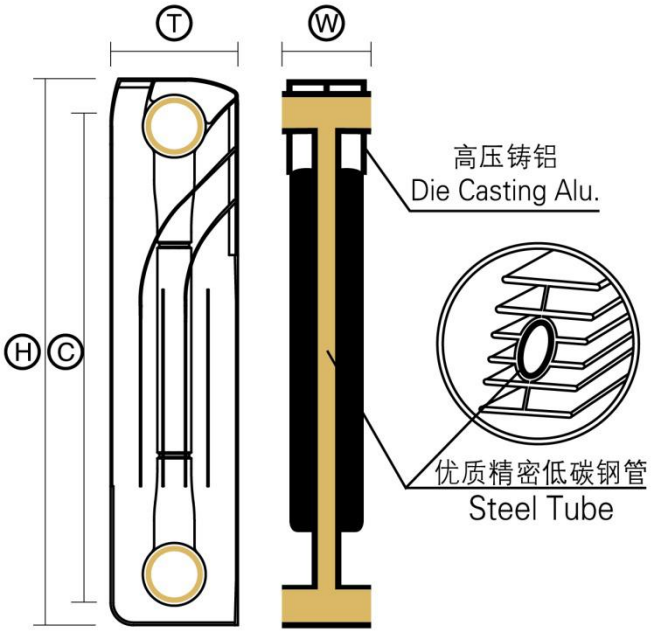


Heating COP of GREE and conventional two-stage heat pumps

Severe cold region



Severe cold region



(a) A picture of bimetal radiator **(b) Structure of bimetal radiator**

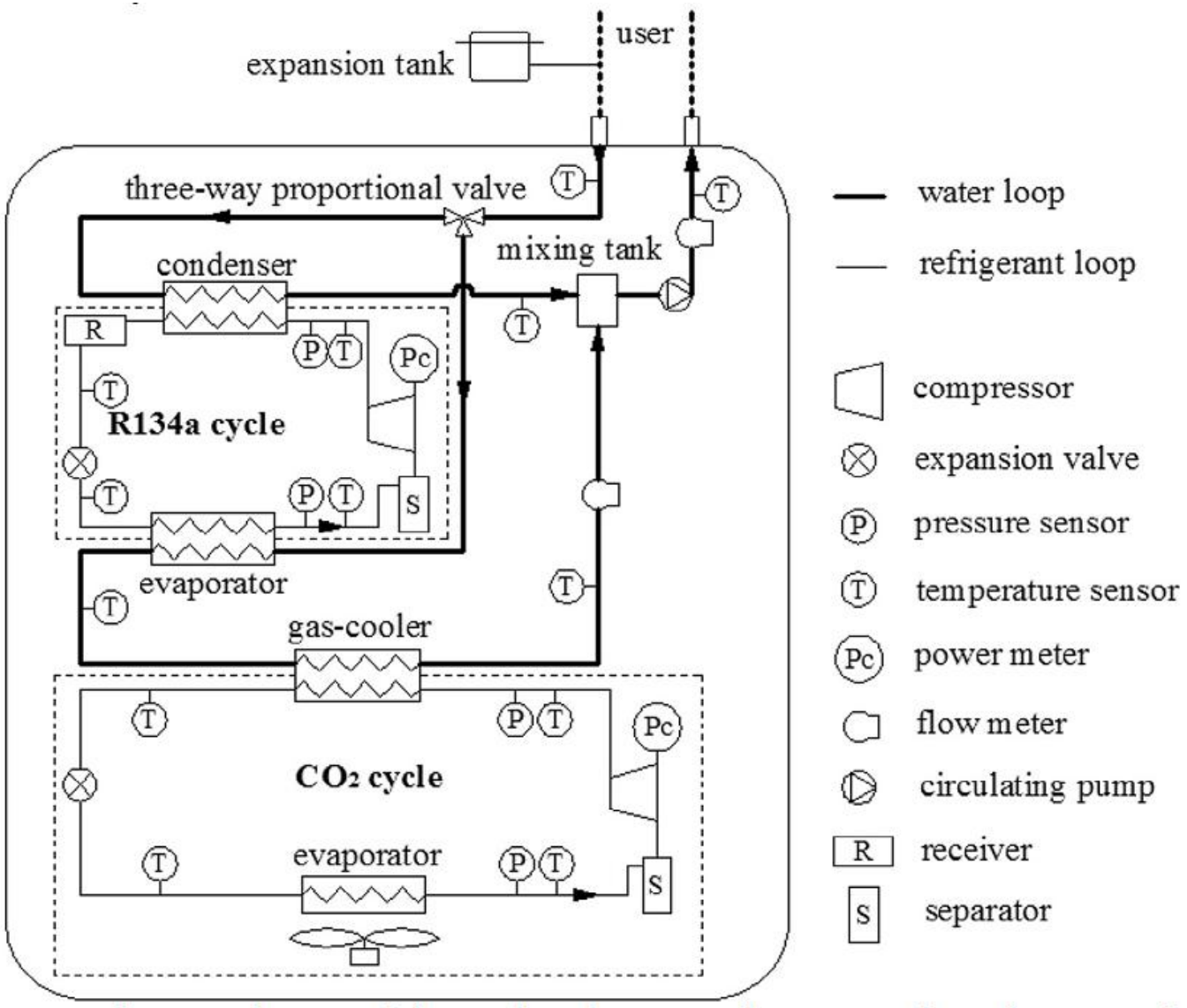
A new kind of Unbeatable bimetal radiator

- Both natural and forced convection heat transfer are adapted.
- The supply water temperature can be as low as 40°C.
- maximize the heating output by heat conduction and convection.

Jiangsu Unbeatable Radiator Co. Ltd. http://www.unbeatable.cn/

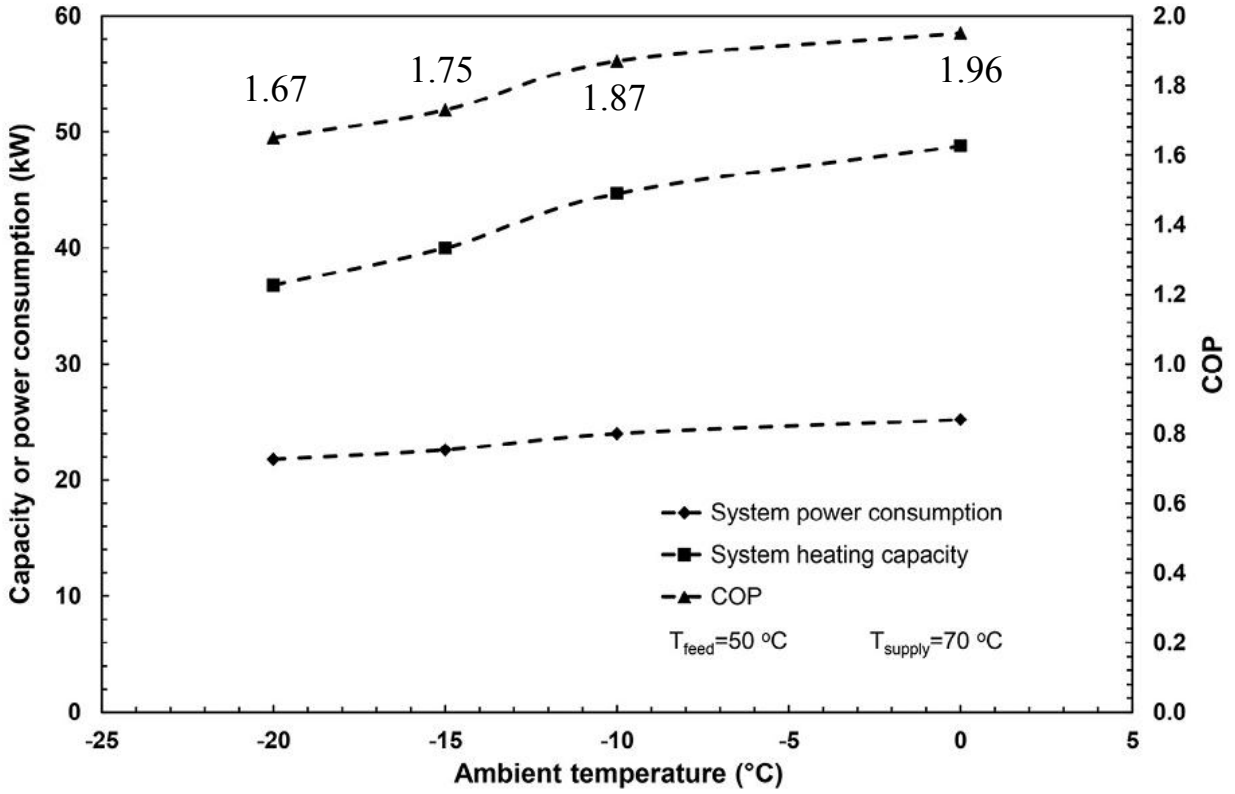
Severe cold region

XJTU:
Schematic of the combined R134a and transcritical CO_2 heat pump (CRTCHP)



Song Y, Li D, Cao F, et al. Investigation of the Optimal Intermediate Water Temperature in a Combined R134a and Transcritical CO_2 Heat Pump for Space Heating[J]. International Journal of Refrigeration, 2017.

Severe cold region



System performance of CRTCHP with the feed and supply water temp. of 50 and 70°C

- Heating capacity and power consumption decreased by 26 % and 12% when ambient temperature decreased from 0 to -20°C.
- The heating capacity decreases slower than total power consumption.

Song Y, Li D, Cao F, et al. Investigation of the Optimal Intermediate Water Temperature in a Combined R134a and Transcritical CO_2 Heat Pump for Space Heating[J]. International Journal of Refrigeration, 2017.

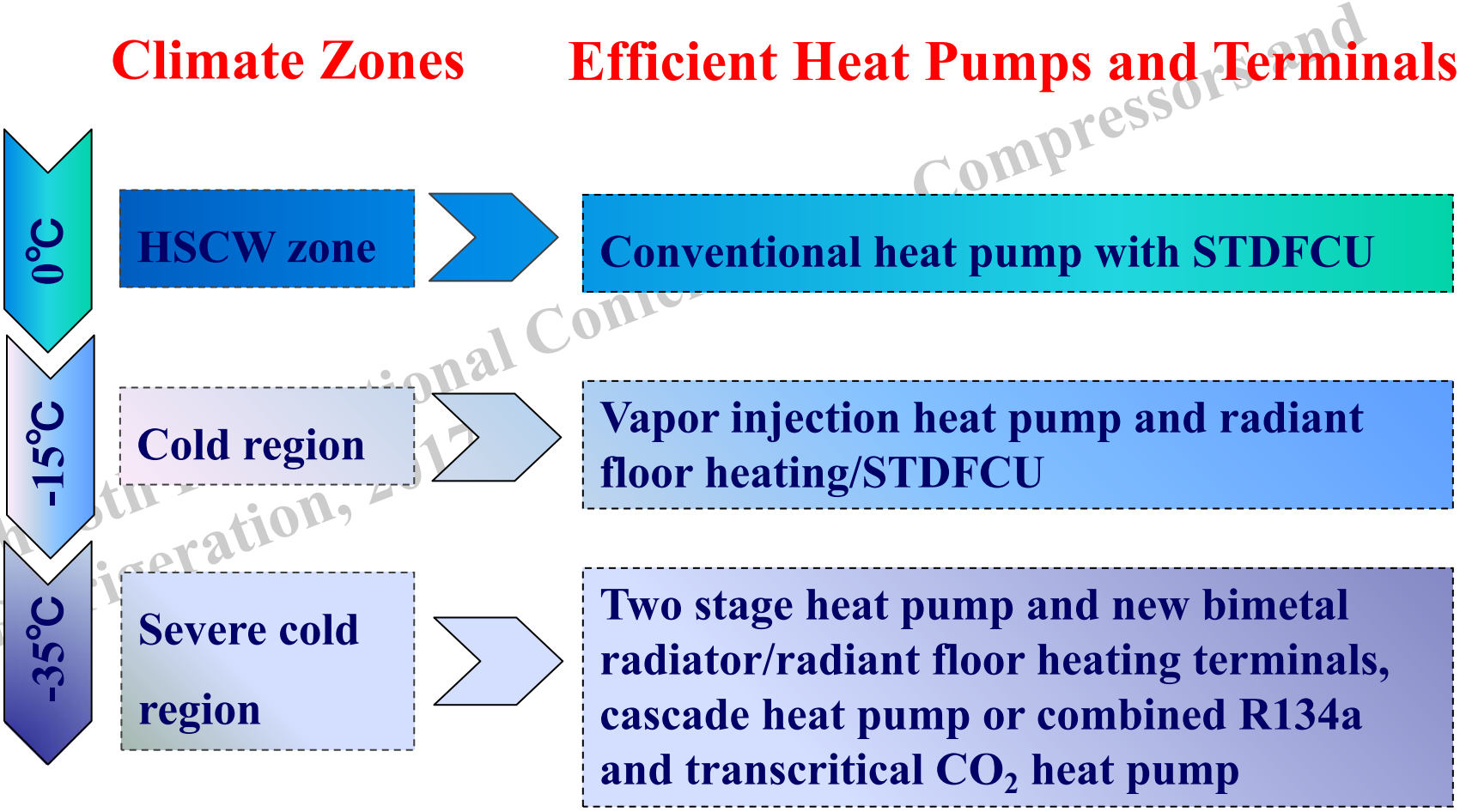
Severe cold region

- An application case is located in Shunyi district of Beijing.
- The original heating method is coal-fired boiler combined radiator.
- The coal-fired boiler is replaced with the combined R134a and transcritical CO_2 heat pump.
- Radiators and heating pipeline inside the building is kept.
- Suitable defrosting method is necessary in operating.

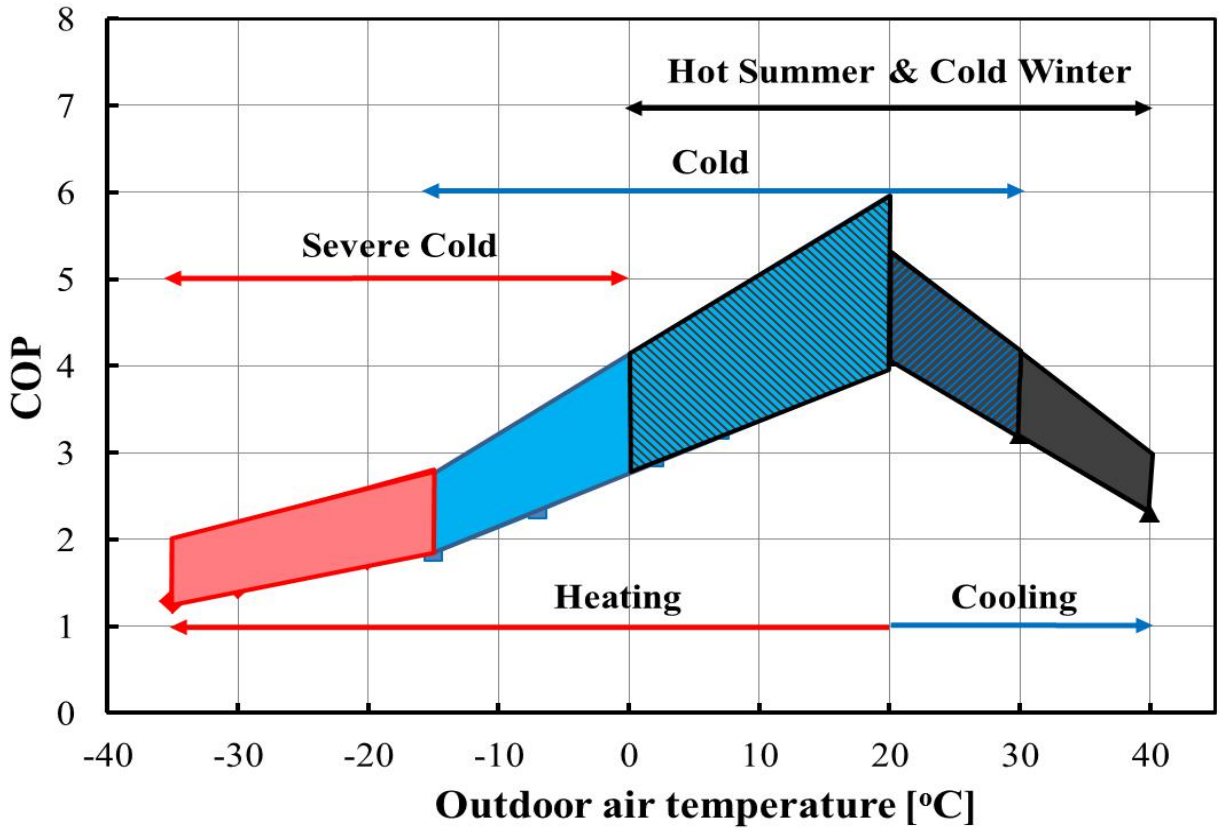
Beijing Comfort technology. http://www.jiafukeji.com/.

Outline

Conclusions and perspectives



Conclusions and perspectives



COP of favorable heat pump system for different climate zone

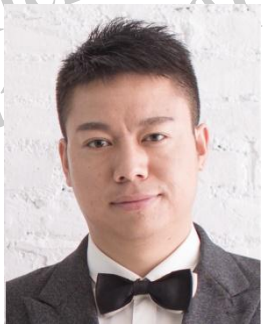
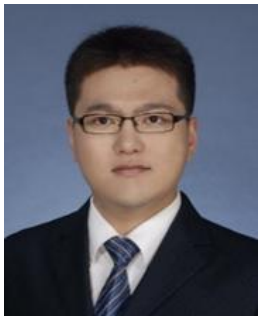
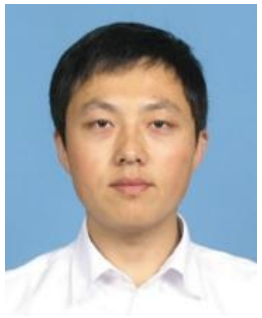
Conclusions and perspectives

- For hot-summer and cold-winter zone, the conventional heat pump can meet the requirement of heating in winter and cooling in summer as long as the suitable terminal is selected, such as STDFCU.
- In cold region, vapor injection heat pump and radiant floor heating/STDFCU is the best heating combination.
- For severe cold region, the two-stage heat pump and new bimetal radiator may be a promising heating method.
- The cascade heat pump or combined R134a and transcritical CO_2 heat pump with radiator is also an competitive sulution for north China.

Acknowledgements

- This work was supported by: National key research & development program of China (2016YFB0601200). The authors are grateful of GREE Electric Appliances, INC for offering the test data.

- **Other contributors**

					
LiWei Wang	Bin Hu	Long Jiang	Shuai Du	ZhenYuan Xu	QuanWen Pan

Thank you!