INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

Sustainable Cooling Technologies for Data Centers

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Rapid growth of data center market

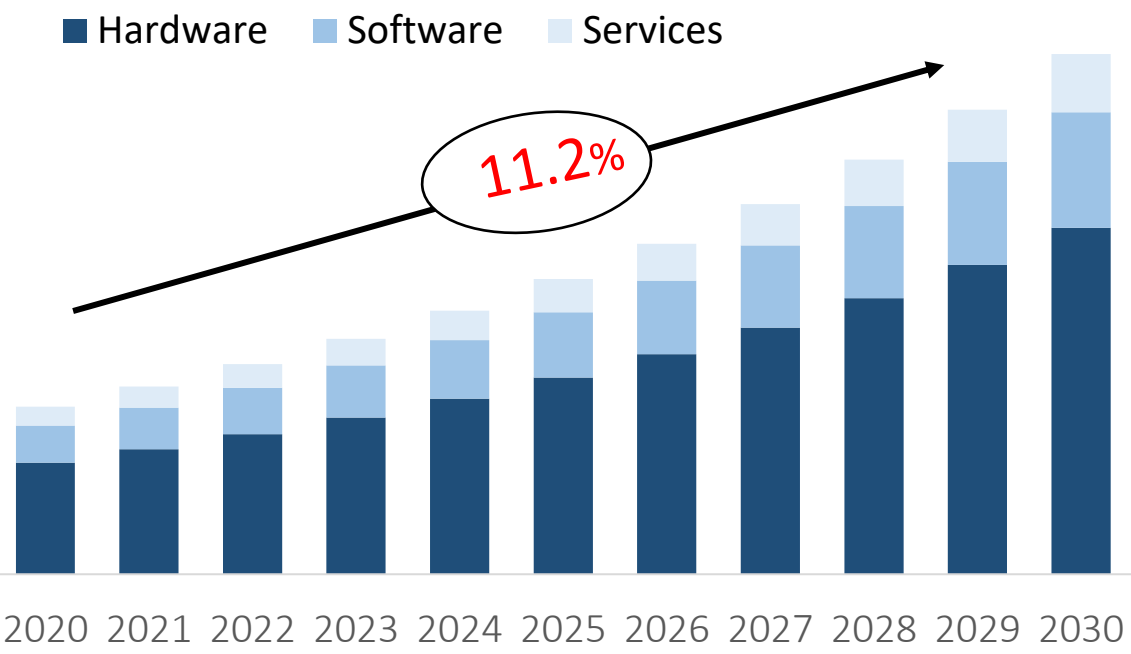
- **Data center supports artificial intelligence, IoT, big data analysis……**

Artificial intelligence

Industrial IoT

Big data analysis

Data center market composition

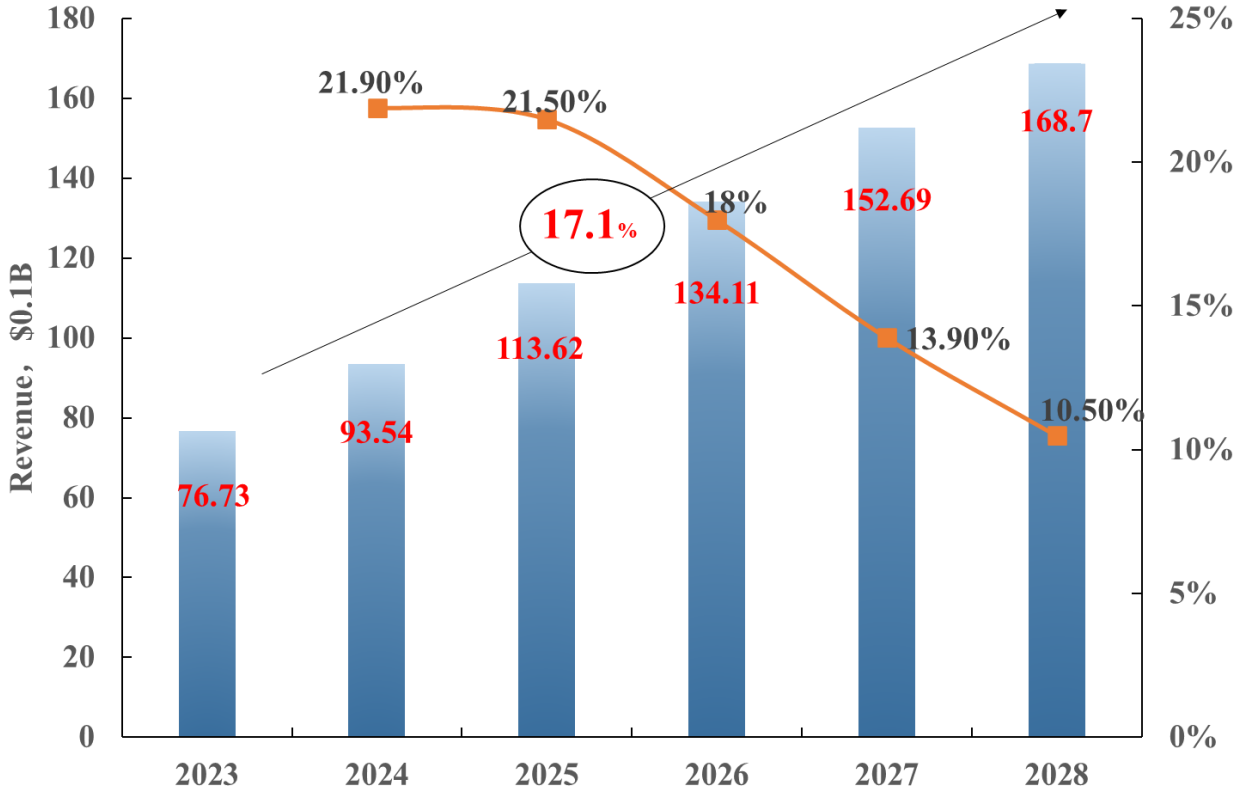


- **Market projections indicate a compound annual growth rate of 11.2%**

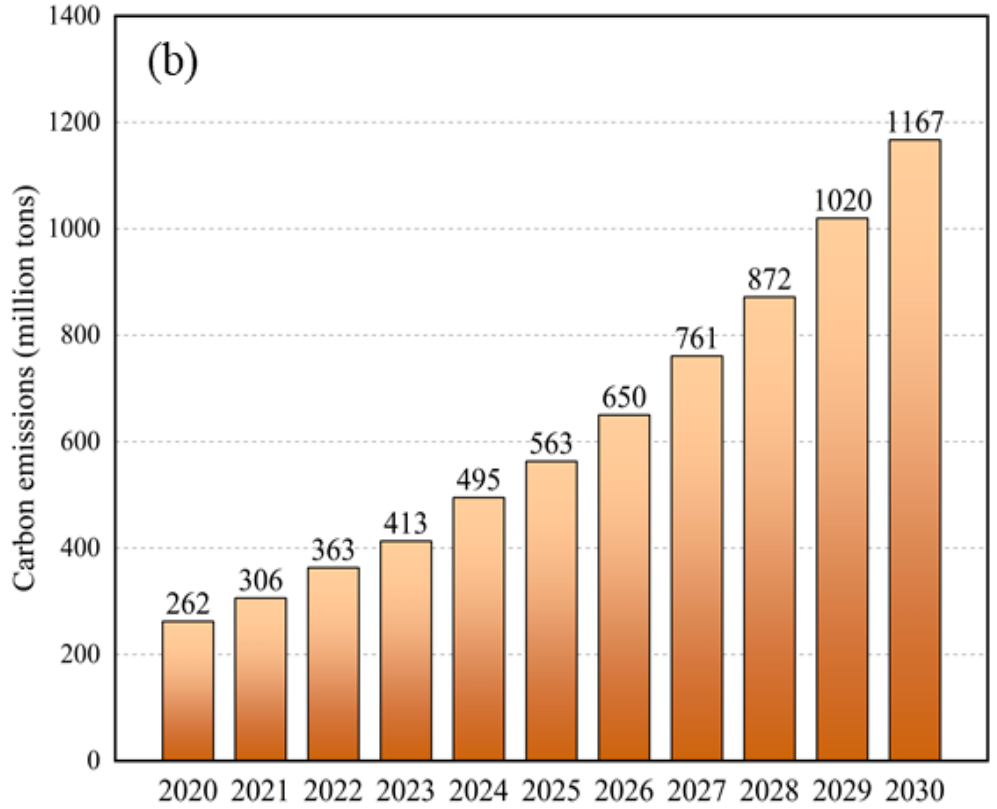
Data Center Market Size, Share, & Trends Analysis Report

1 Fast expansion of DC cooling demand and emission

Global data center cooling market size



Global carbon emissions from data centers

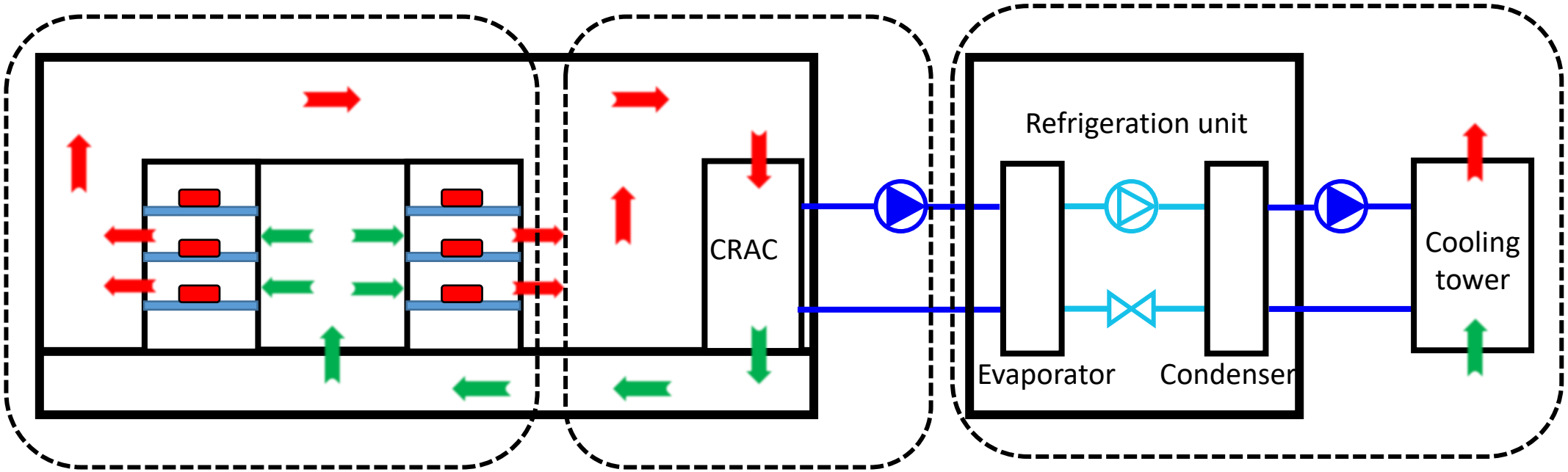


Increased utilization of data centers →

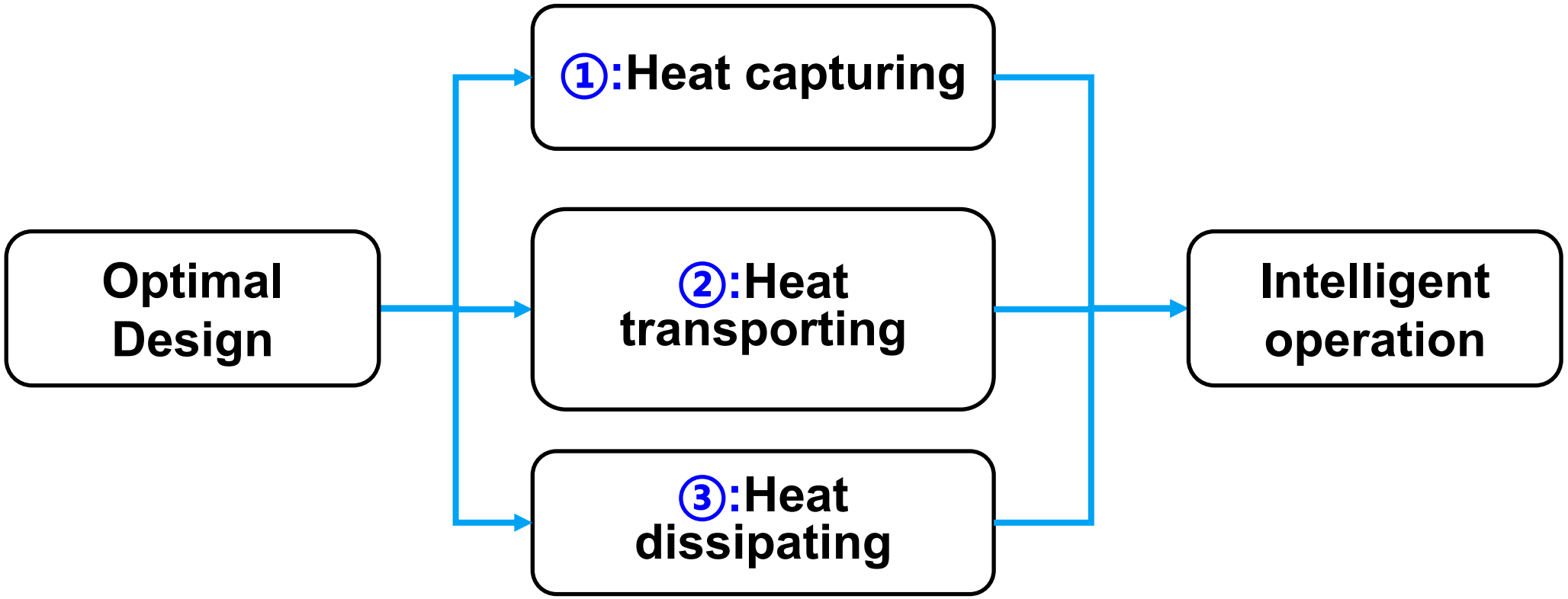
Elevated energy consumption and carbon emissions

China Data Center Industry Development White Paper (2023) and Data Centers and Data Transmission Networks

2 Typical Configurations of Data Center Cooling Systems



- Pathways for sustainable cooling of data centers

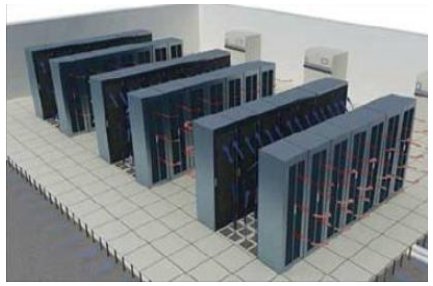


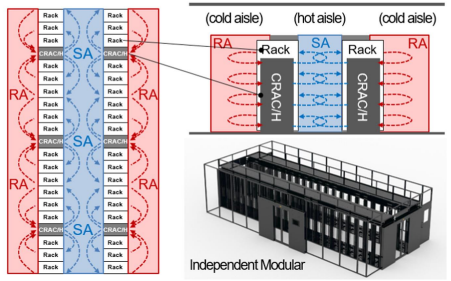
Contents

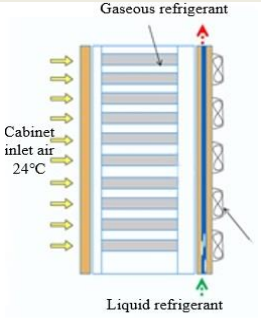
3.1 Heat capturing

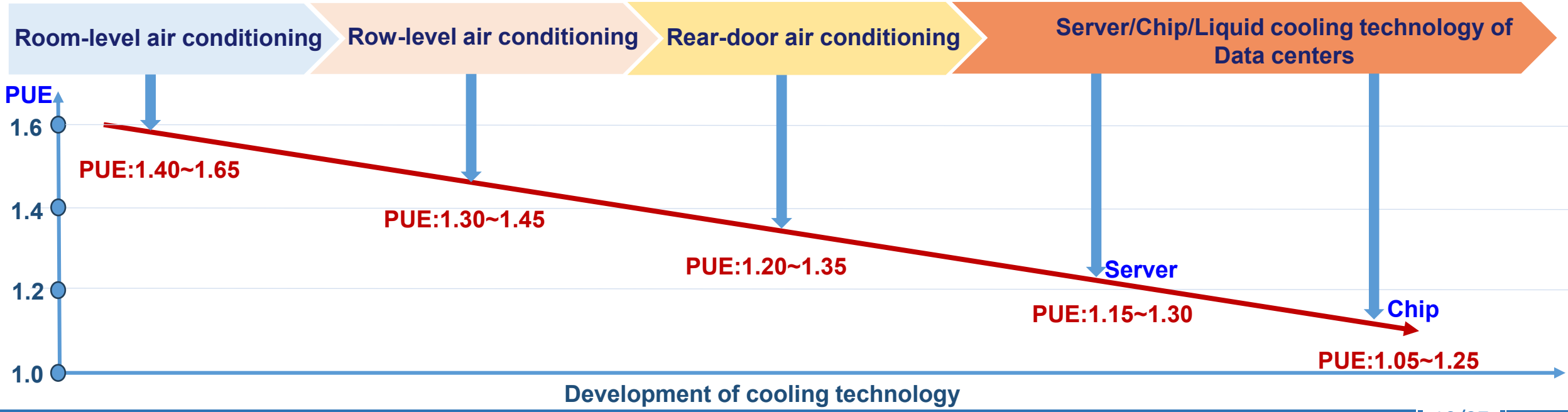
Target: **1) Decrease the heat exergy degradation** (by heat transfer or mixture), and

2) Enhance the heat transfer intensity

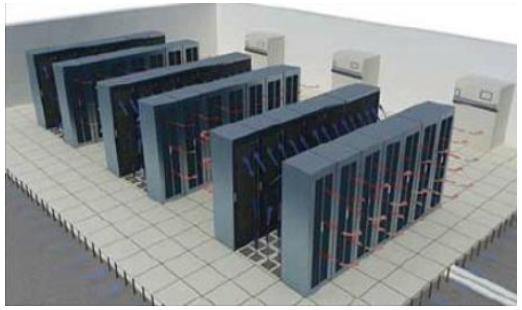




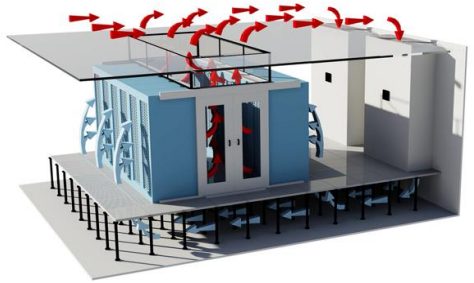




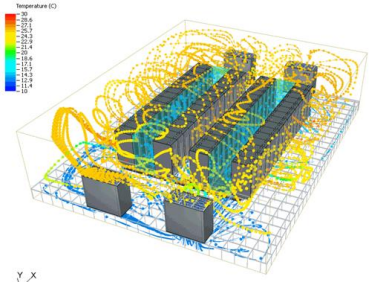
①Room-level air conditioning



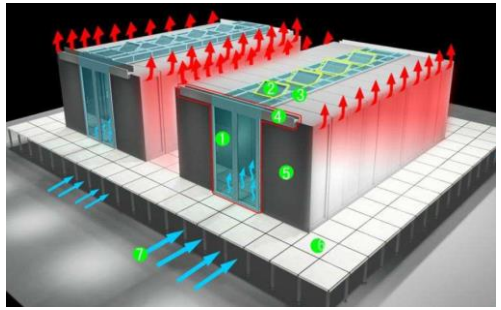
Hot aisle/cold aisle
without containment



Underfloor air supply
with hot aisle closure

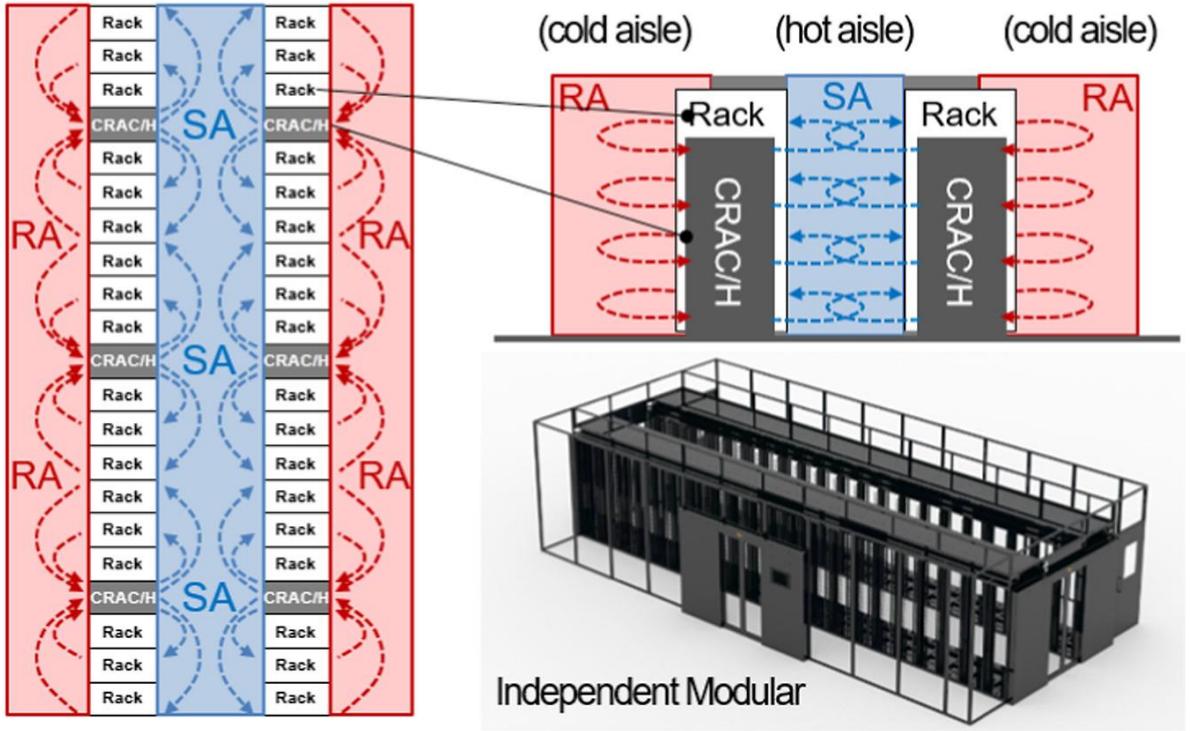


Airflow management



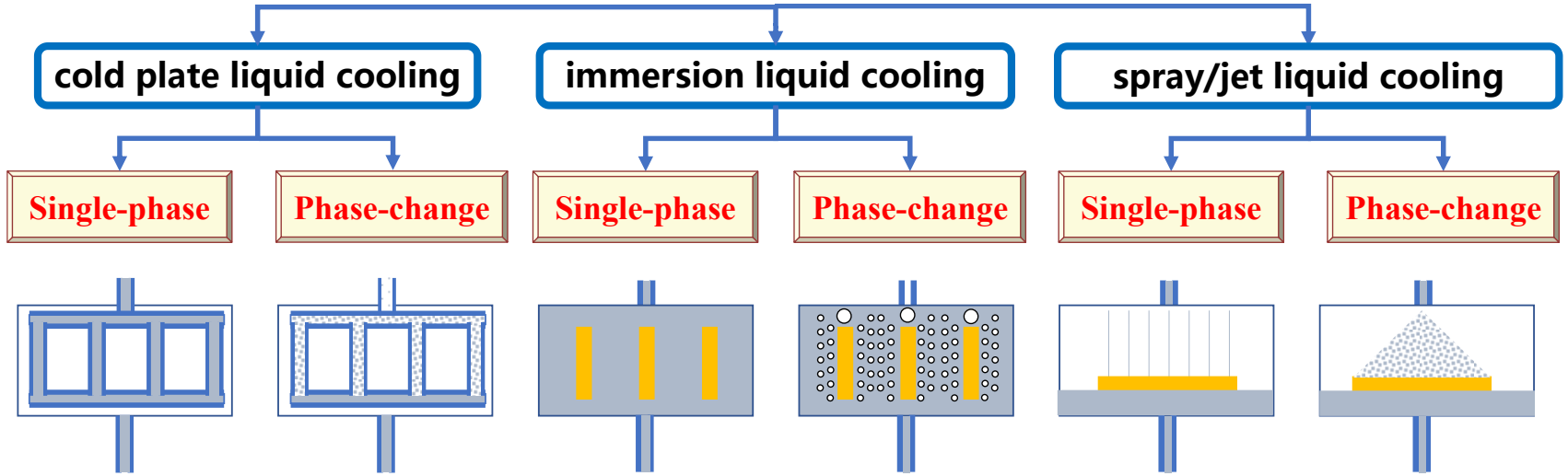
Underfloor air supply
with cold aisle closure

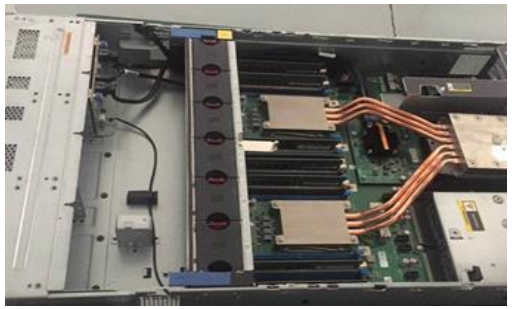
②Row-level air conditioning



minimizes airflow distance, enables precise demand-driven cooling, and consequently enhances energy efficiency

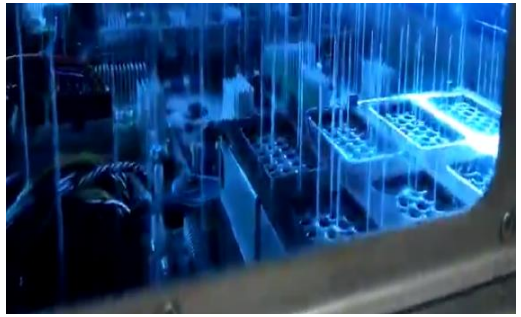
③Liquid cooling technology of data centers





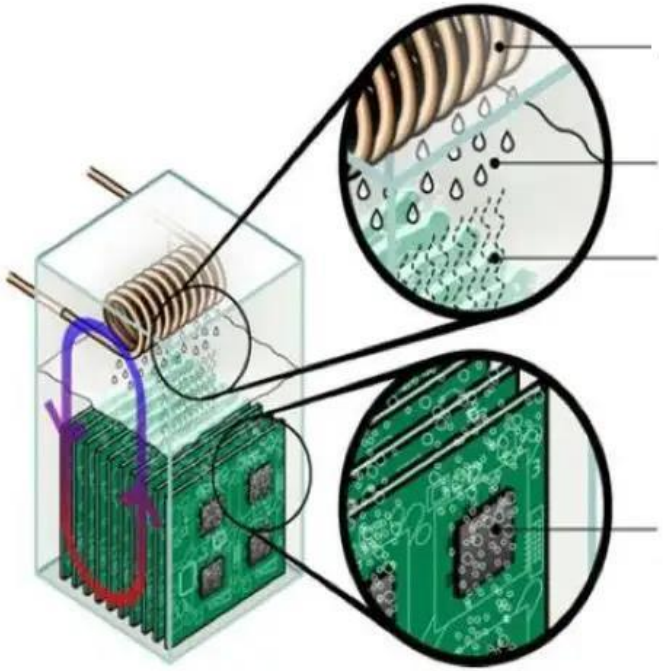
Cold plate

Immersion liquid cooling



Spray liquid cooling

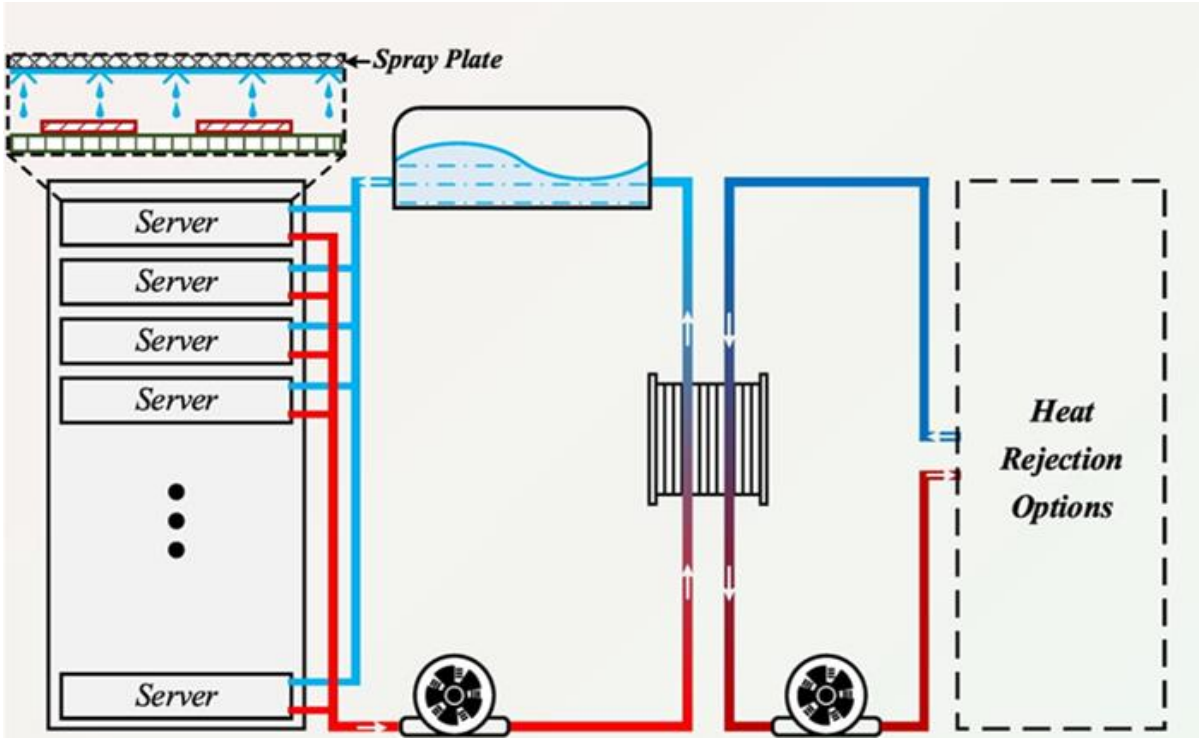
Two-phase immersion liquid cooling



- Eliminating airflow-dependent cooling infrastructure
- Achieving near-theoretical energy efficiency limits
- Supporting ultra-high power density deployments

Spray/Jet liquid cooling

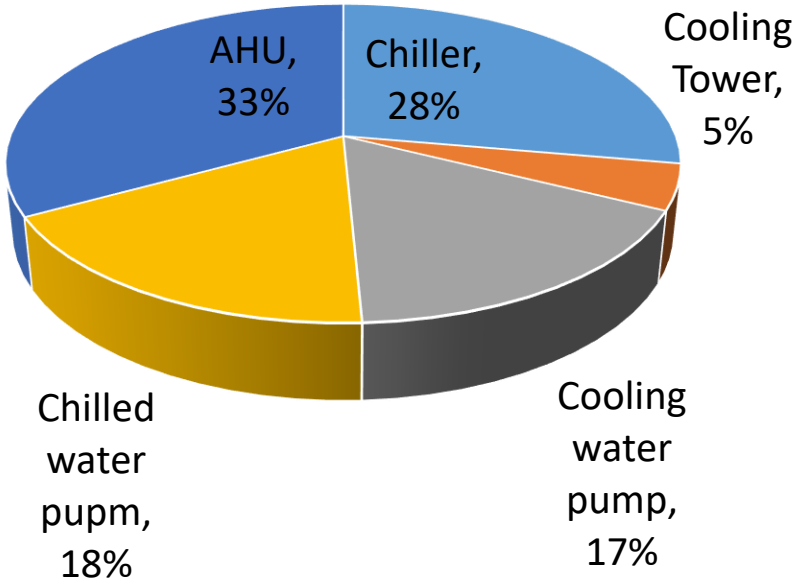
- Targeted spraying based on localized heat flux density
- **Reduces coolant consumption**
- Decreases structural floor loading



Comparison of different Liquid cooling technologies

	Cold plate	Immersion	Spray/Jet
PUE	★★★★☆	★★★★★	★★★★☆
Capital Expenditure	★★★★☆	★★☆☆☆	★★★☆☆
Space Utilization Efficiency	★★★★☆	★★★★★	★★★★☆
Technology Maturity	★★★★★	★★★☆☆	★★☆☆☆
Max Thermal Load per Rack	★★★☆☆	★★★★★	★★★★☆
Retrofit Compatibility	★★★★☆	★☆☆☆☆	★★☆☆☆

3.2 Heat transporting



The energy consumption proportion of Heat transport within data centers' annual total energy usage is continuously rising

Target: 1) **Minimize transport power required**, and
2) **Use environmental friendly coolant**

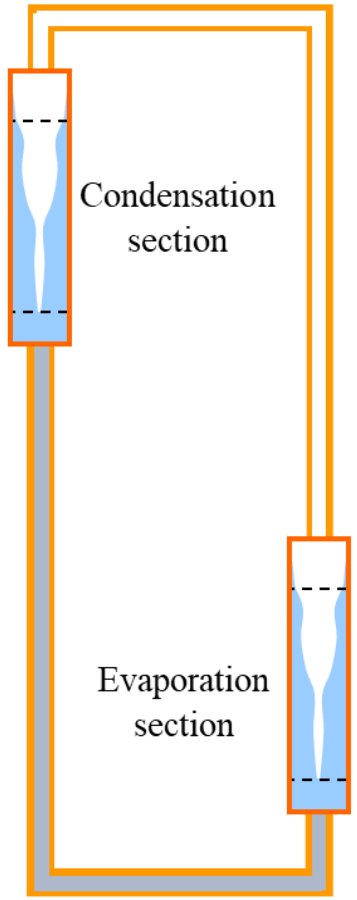
$$Q = \dot{m}Cp(T_i - T_o)$$

$$P = \dot{m}\Delta H$$

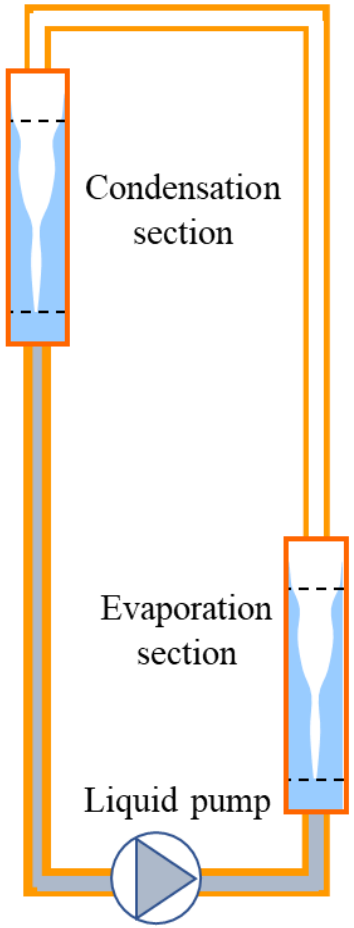
→ **Larger heat transfer temperature differentials** increase exergy destruction
→ **Lower flow rates** reduce fluid transport energy consumption

→ **Refrigerants' lower viscosity** versus water, coupled with vapor-liquid density differences, enable reduced transport energy
→ **Higher fluid density** permits smaller piping diameters, conserving space

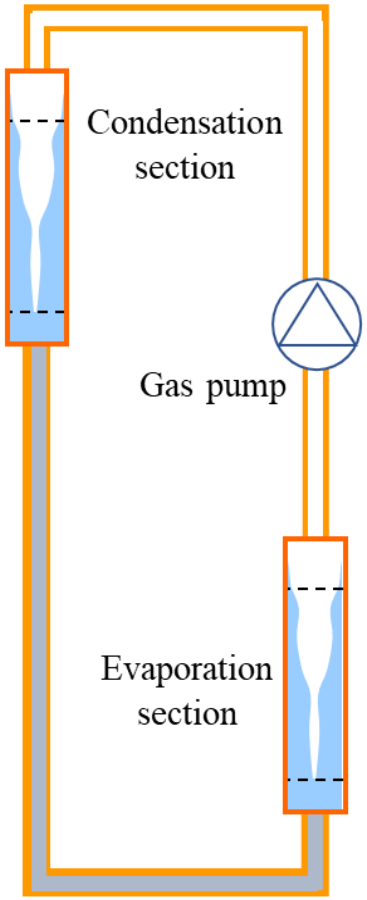
Heat pipe loop



(a) Gravity-driven(thermosyphon)



(b) Liquid pump driven



(c) Gas pump driven

Gravity-driven(thermosyphon)

Utilizes gravity potential and density differential as circulation driving force.

Liquid pump driven

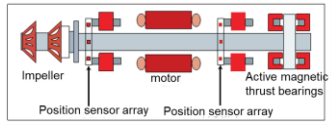
Utilizes liquid pump as circulation driving force; cavitation prevention required.

Gas pump driven

Utilizes vapor compressor as circulation driving force; liquid slugging prevention required.

3.3 Heat dissipating

Integrated system architecture



⑤ High-Efficiency Chillers

→**Magnetic bearing variable frequency** drive chillers
→Water/air-cooled VFD chillers
→Low condenser water temperature operation

⑥High-Efficiency Customized Terminal Units

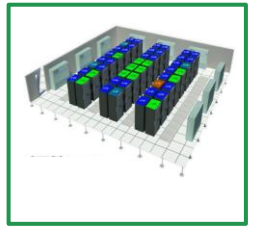
→Electronically commutated (EC) fans
→Fresh air / full recirculation mode

⑦ Packaged Cooling Plant System

→ Prefabricated modular units
→ Unitary integrated cooling plant
→ Integrated building management system

⑧ AI-Driven Energy Management Platform

→ All-variable speed drive configuration
→ Free cooling; redundant hot standby

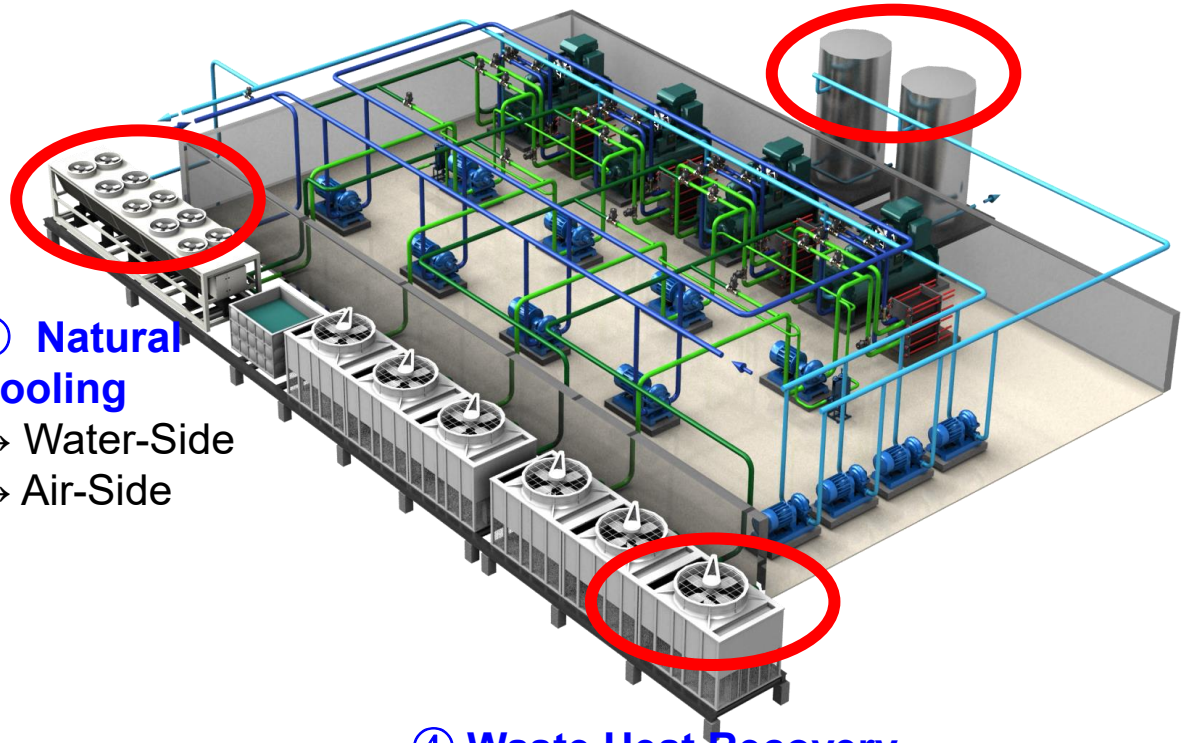


③ Evaporative cooling

→ reduction of cooling source temperature

② Thermal Energy Storage

→Ice-based thermal energy storage
→Water-based sensible thermal energy storage



① Natural Cooling

→ Water-Side
→ Air-Side

④ Waste Heat Recovery

→ Condenser Heat Recovery System
→ Total Heat Recovery

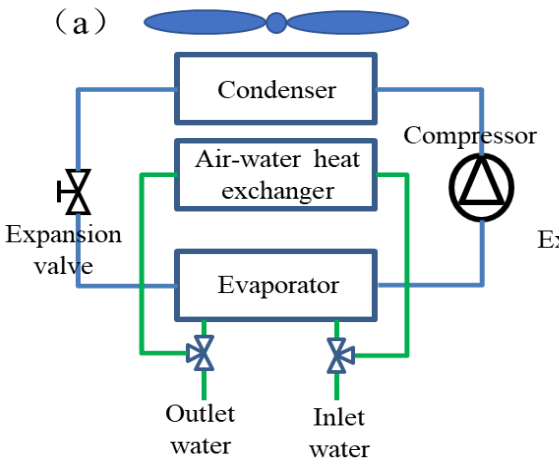
① Natural cooling

Types of natural cooling system

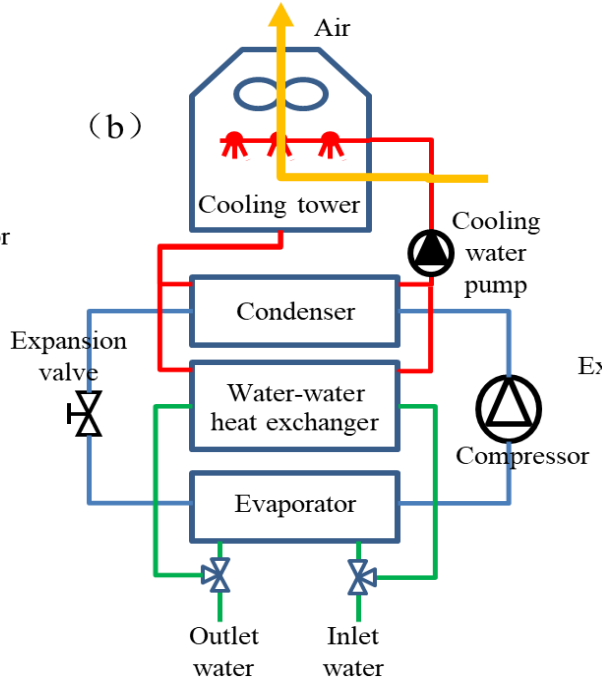
Classification	Type
Air-side	Direct Indirect
Water-side	Direct water-cooling Air-cooling Cooling tower /evaporative cooling
Heat pipe	By driving force By system By outdoor cooling

Advantages:

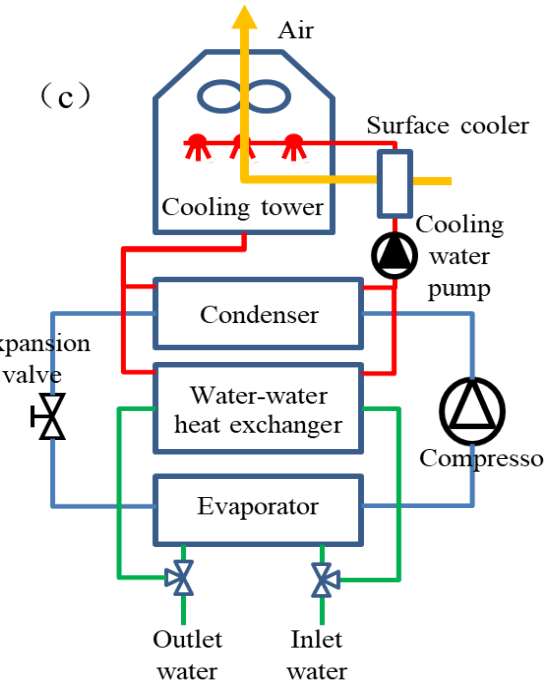
- Environmental Sustainability
- Economic Viability



Air-cooled chillers
Dry-bulb temperature



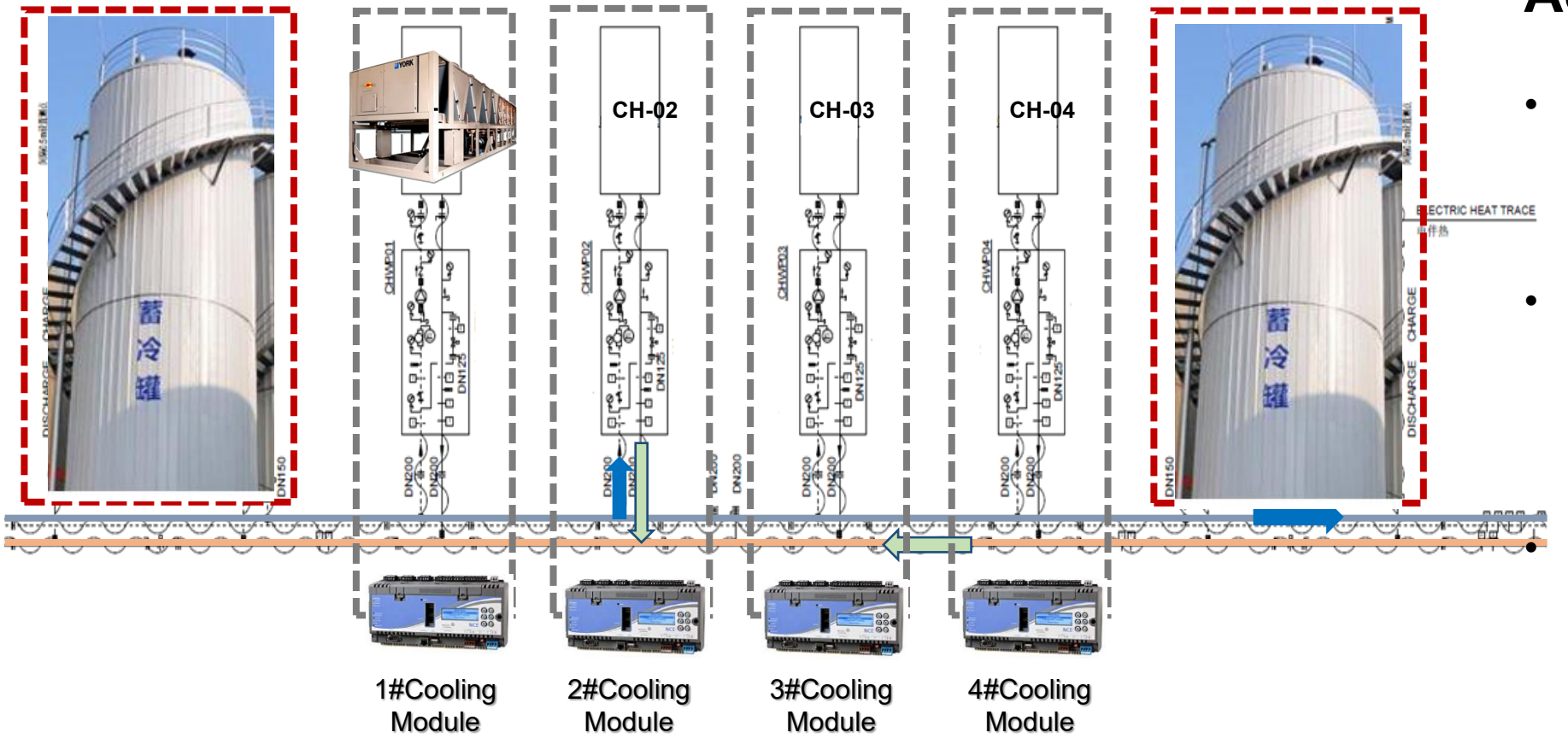
Chiller + Direct
evaporative cooling
Wet-bulb temperature



Chiller + Indirect
evaporative cooling
Dew-point temperature

Active/natural cooling integrated systems

② Data Center Cooling Thermal Storage

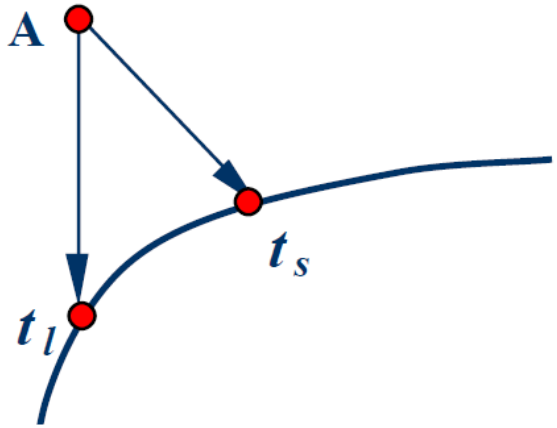


Advantages:

- **Increasing Cooling Capacity**: Enhances the operational resilience of data center cooling systems
- **Customer-Side Energy Storage**: Improves grid reliability and increases renewable energy utilization rate
- **Time-of-Use Electricity Pricing**: Reduces operational costs

③ Evaporative cooling: reduction of cooling source temperature

Typical Evaporative Cooling Heat Transfer Process



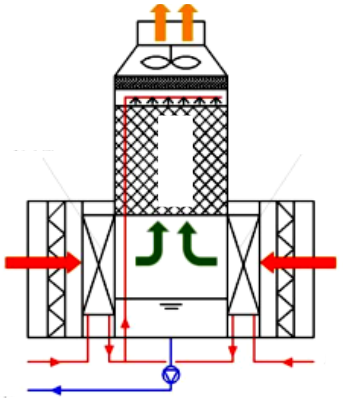
→ Heat removal via water evaporation

→ Direct evaporative cooling (*ts*) / Dew-point evaporative cooling (*tl*)

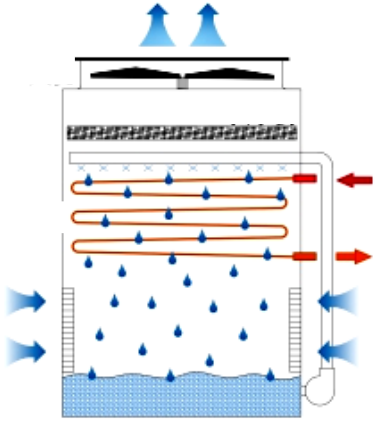
→ Generates chilled air/water or condenses refrigerant (evaporative condensation)

Internally-cooled indirect evaporative air handling unit

Externally-cooled indirect evaporative air handling unit



Indirect evaporative chiller



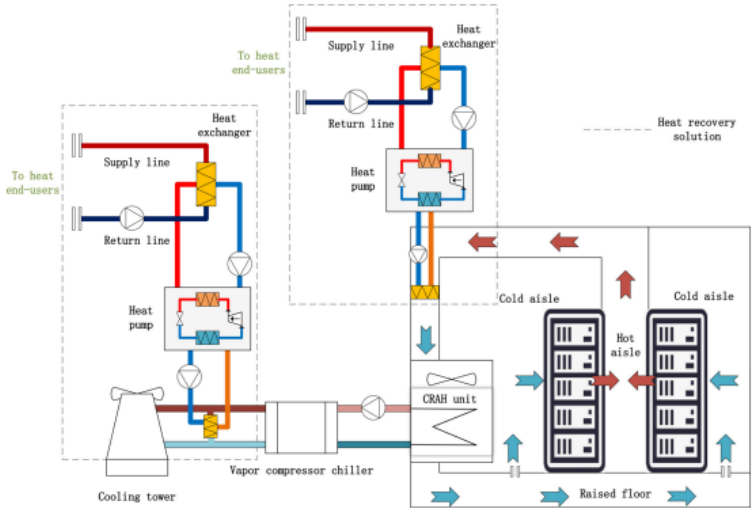
Evaporative condenser unit

④ Data Center Waste Heat Recovery Technologies

Various heat sources

Air Cooling Thermal Sources: High-temperature exhaust air, condenser water, chilled water

Liquid Cooling Thermal Sources: Coolant return flow, process cooling liquid



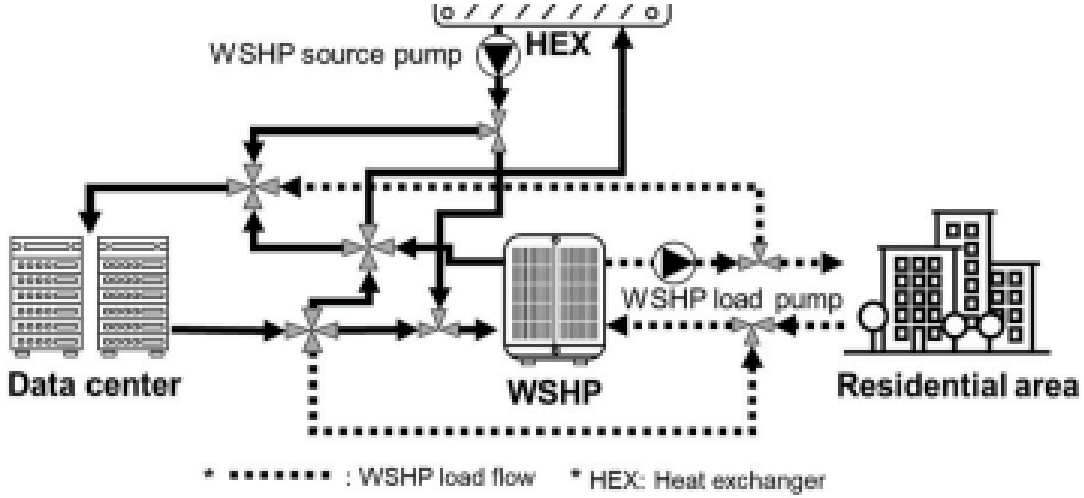
Air Cooling Thermal Sources

Various heat sinks

District Heating: Supplies hot water/space heating

Organic Rankine Cycle (ORC) Power Generation: Directly offsets electricity consumption

Supplementary Cooling: Waste heat-driven refrigeration compensating cooling load



District Heating

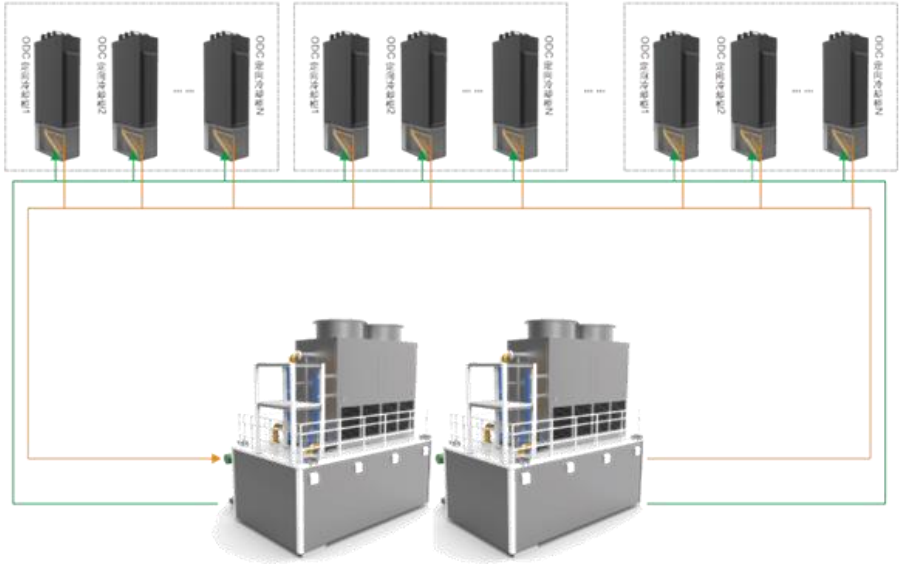
Integrated Cooling Plant- Qingpu, Shanghai

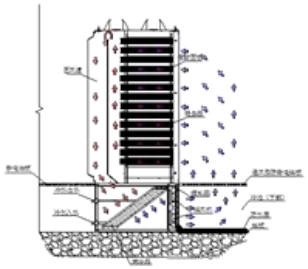
Cooling System Architecture：

→ **Dual-loop system design** with two cooling plants operating in parallel to provide mutual hot standby capability

→ Implementation of **closed-circuit cooling towers** enabling valve-free **free cooling** operation

→ **Customized rack-level cooling terminals with 22 C elevated supply temperature and balanced hot aisle closure**





Global Coefficient of Performance (GCOP) for the entire cooling system and **Annual Coefficient of Performance (ACOP)** for the integrated cooling plants are **6.95** and **8.77**

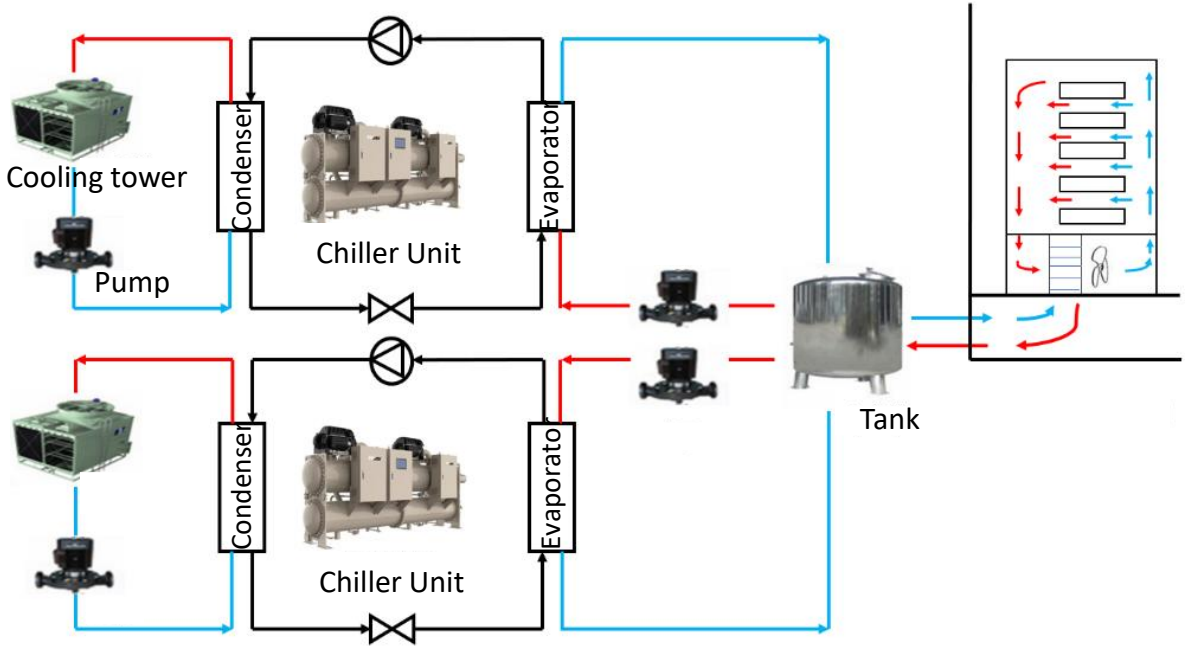
Magnetic Bearing Centrifugal Chillers - Beijing

Cooling System Architecture:

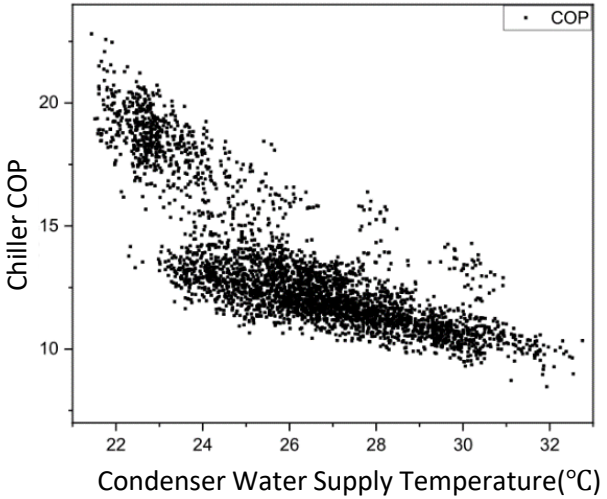
→ The cooling system employs **two magnetic bearing centrifugal chillers**

→ **Rack-level cooling** terminals minimizing indoor energy consumption

→ **A custom-engineered oil-based heat transfer fluid** with enhanced thermal efficiency and IT equipment safety



Magnetic bearing chillers achieved significant **noise reduction (≤75 dB(A))** .The calculated seasonal average **Coefficient of Performance (COP)** reached **12.69**



1 Background

2 Principle

3 Sustainable Cooling Technology

4 **Conclusions**

Conclusions

- The rapid expansion of data centers drives massive electricity consumption, resulting in significant greenhouse gas (GHG) emissions
- To address the intensified heat generation from super servers, more powerful cooling systems are imperative
- Developing sustainable cooling solutions demands a comprehensive approach — from efficient heat capturing to low-energy heat transport and optimized heat dissipation mechanisms

Thanks