IEA Annex 59
Low temperature heating &
high temperature cooling

Reducing cooling energy by system innovation

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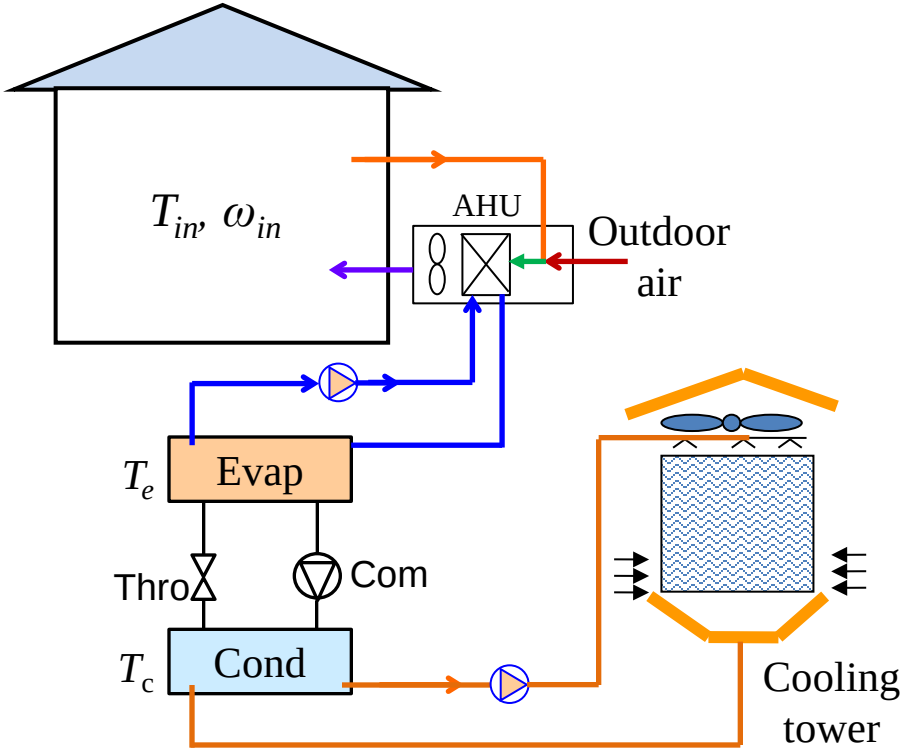
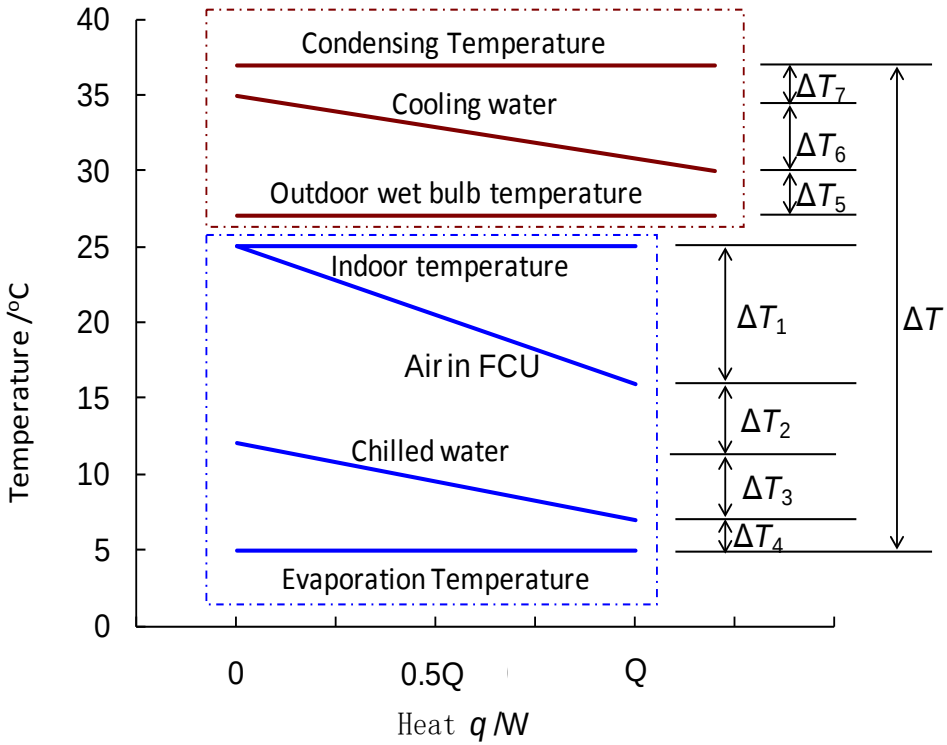
Where is the energy lost through cooling?

- **Indoor→ chilled water → chiller → cooling water → cooling tower → outdoor**





Where is the energy lost through cooling?

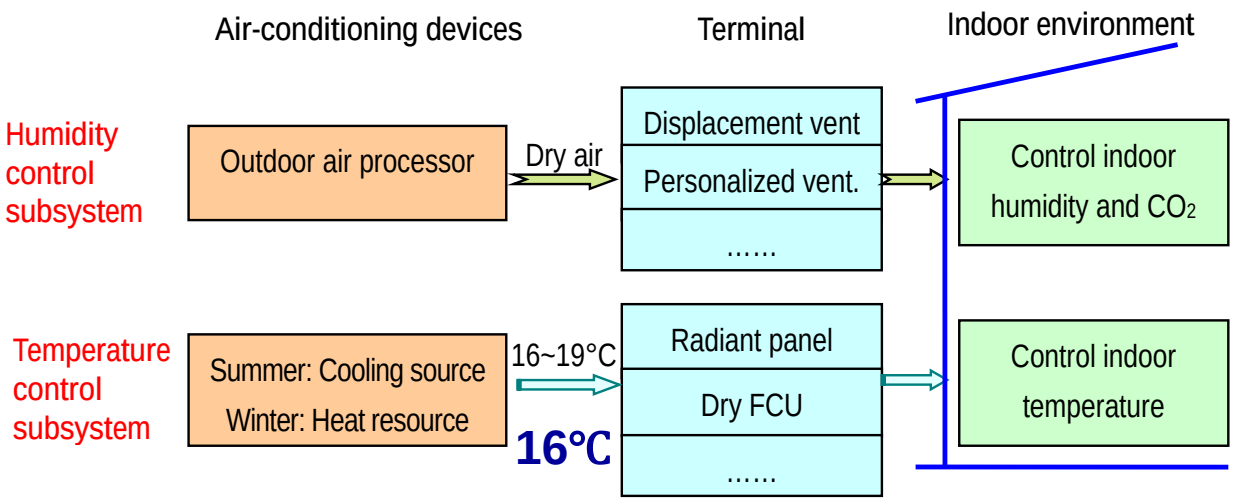
- The real demand for space cooling is just raising the heat Q for 3K from 25℃ indoor to 28 ℃ outdoor, the required work is 3Q [WK]
- However the chiller does lift up the heat Q from 5 ℃ at the evaporator to 40 ℃ at the condenser, the actual work is 35Q [WK], as many as 11 times!
- The additional 32Q have been paid for completing the heat transfer process as well as heat flux mixed with different temperature during the heat transportation process from indoor to outdoor
- The other reason is that dehumidification required. To make moisture condensation, low temperature below dew point as the cooling source is needed

An Innovation of space cooling system

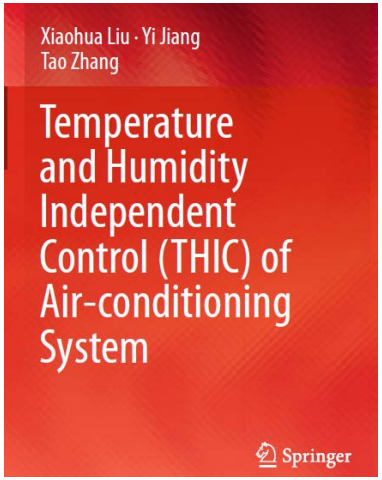
- **Separate humidity control from temperature control: THIC**
  - **An independent air system added to remove latent heat for humidity control**
  - **Temperature can then be controlled by a high temperature cooling source (eg. 15℃ to 20℃) to remove sensible heat only**
  - **As sensible heat normally takes more than 70% of the total heat load, high efficiency cooling source can be used to remove sensible heat**
    - **Underground water or underground heat exchanger if ground temperature is below 15℃**
    - **Evaporate cooling can also provide cooling source if the dew point outdoor is below 15℃**
    - **COP for compression chiller can be achieved at 9 ~ 10 comparing with 5~6 at normal state**
- **Reduce the temperature difference between indoor space and cooling source so to raise required cooling source temperatures as high as possible**
- **Reduce the power of fans and pumps by improvement of the heat delivering system**

An Innovation of space cooling system

- **Separate humidity control from temperature control (THIC)**
  - ***Humidity control* as well as *indoor air quality*: Dried outdoor air**
  - ***Temperature control*: High temperature cooling source (or low temperature heating source in winter)**



Operating principle of the THIC air-conditioning system



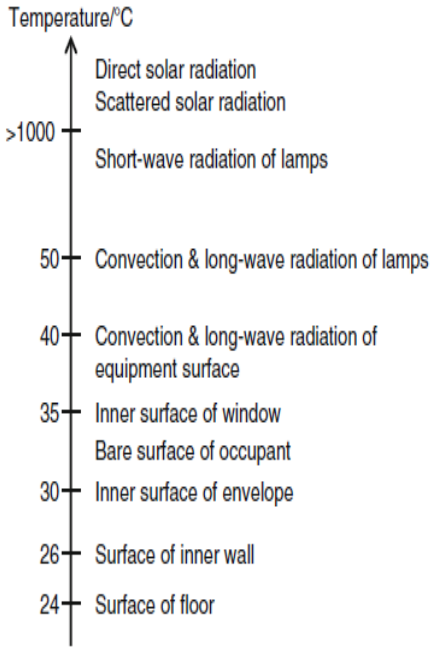
* ***Liu XH***, *Jiang Y, et al*. **Temperature and Humidity independent Control (THIC) of Air-conditioning System**. Berlin: Springer Press, 2014

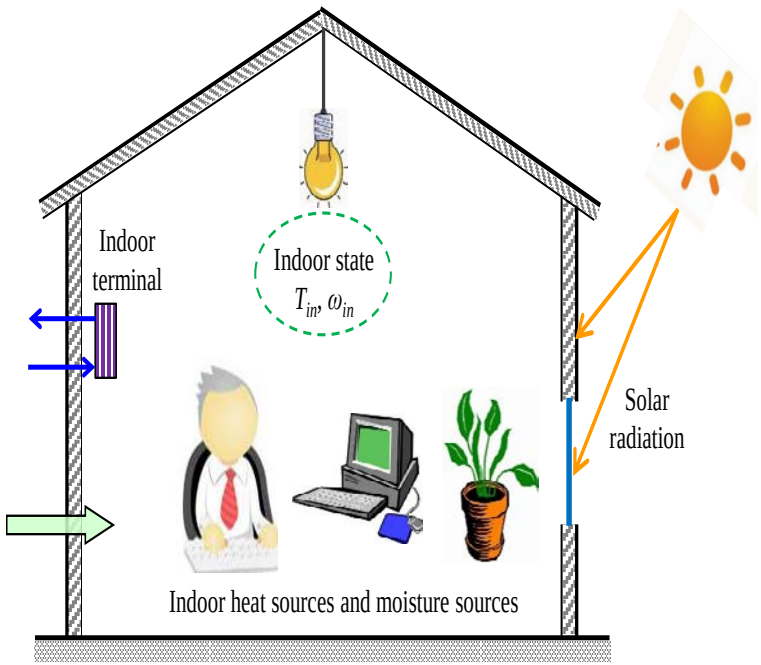
Sensible heat removal for Temp. control

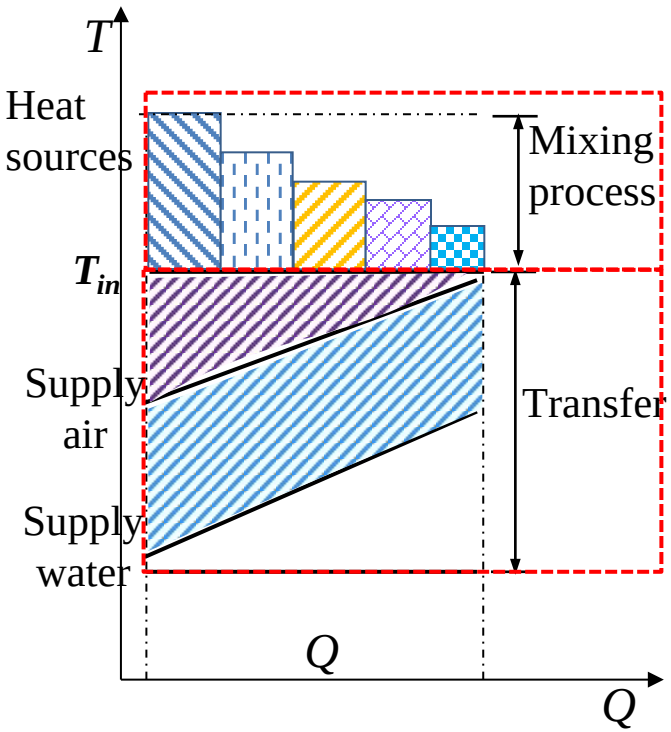
- In more than 40% of cooling applications in the world the outdoor dew point is below 15℃. Moisture can be removed by air exchange with outdoor. Space cooling is just to remove sensible heat
- To raise the cooling source temperature for high efficiency cooling, the key approach is to reduce the Δt during heat delivering process
  - Avoid the mixing loss of heat collection process at indoor terminals
  - Avoid Δt loss of heat exchange process
  - Avoid the mixing loss of heat fluxes with different temperature

Terminal handling process

- **Task: collecting heat and moisture from sources**



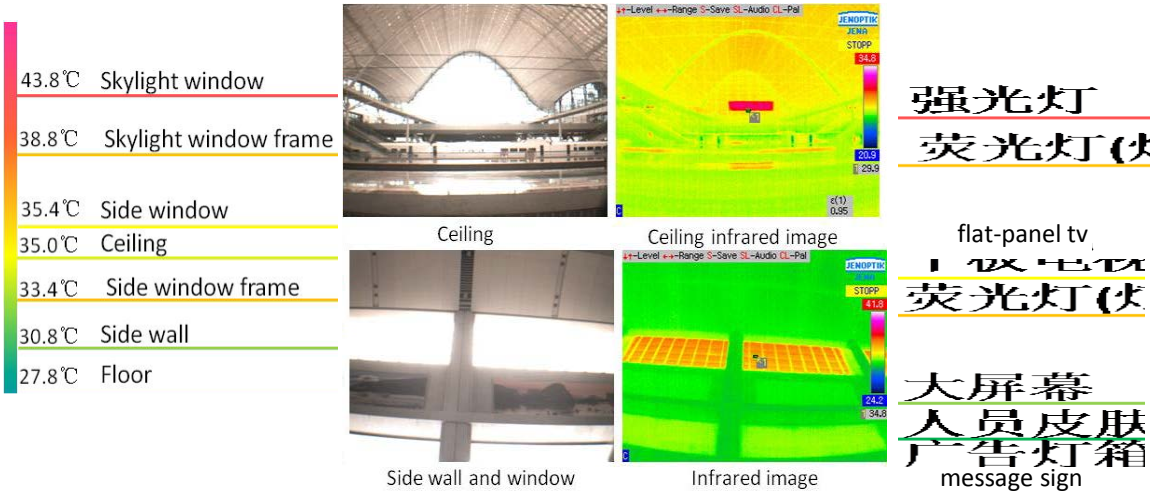




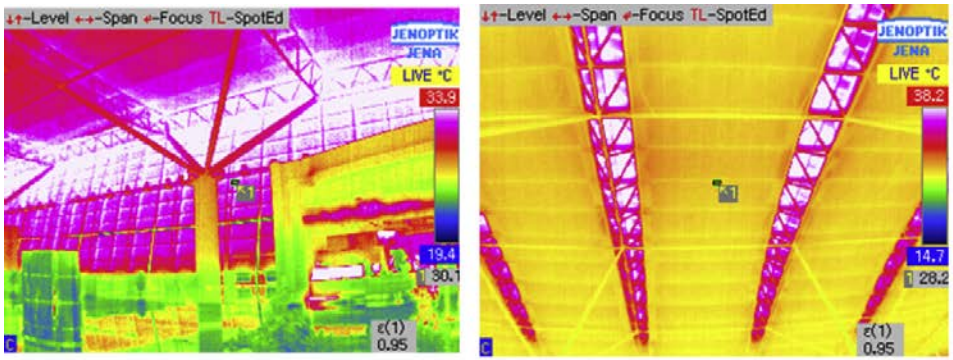
Avoid mixing loss of heat collection process at indoor terminals!

Terminal handling process

■ Heat sources with different temperatures



- Heat sources' temp. varying in the range of 26~40ºC, or even higher



- Significant mixing loss from heat sources to indoor air

Direct solar radiation

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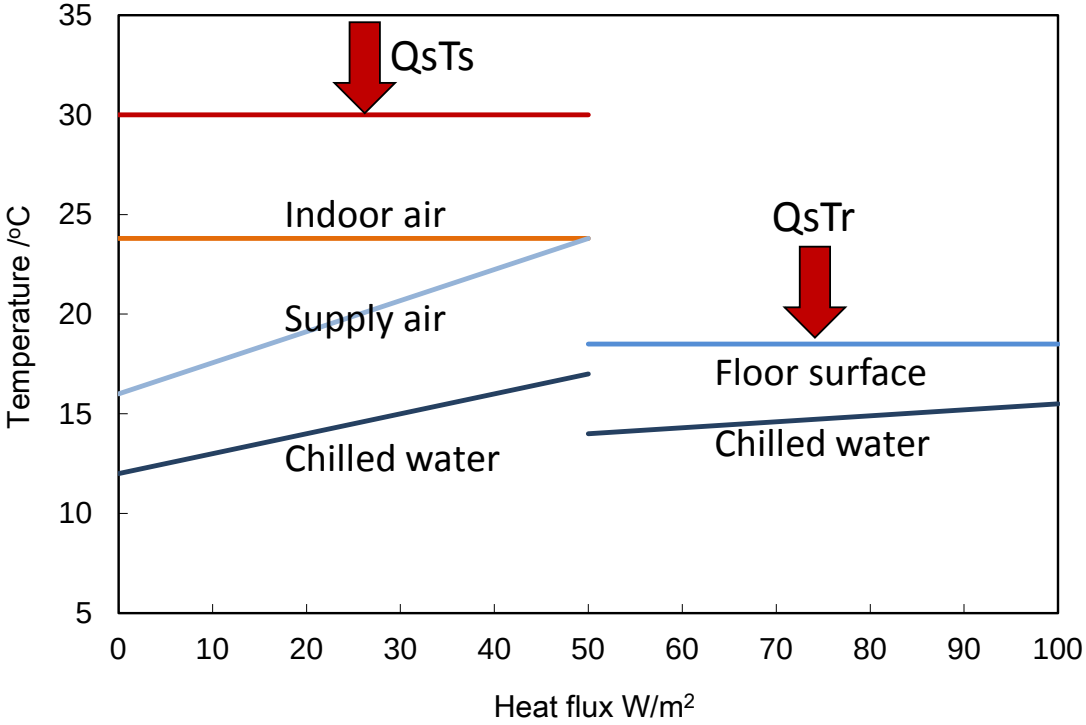
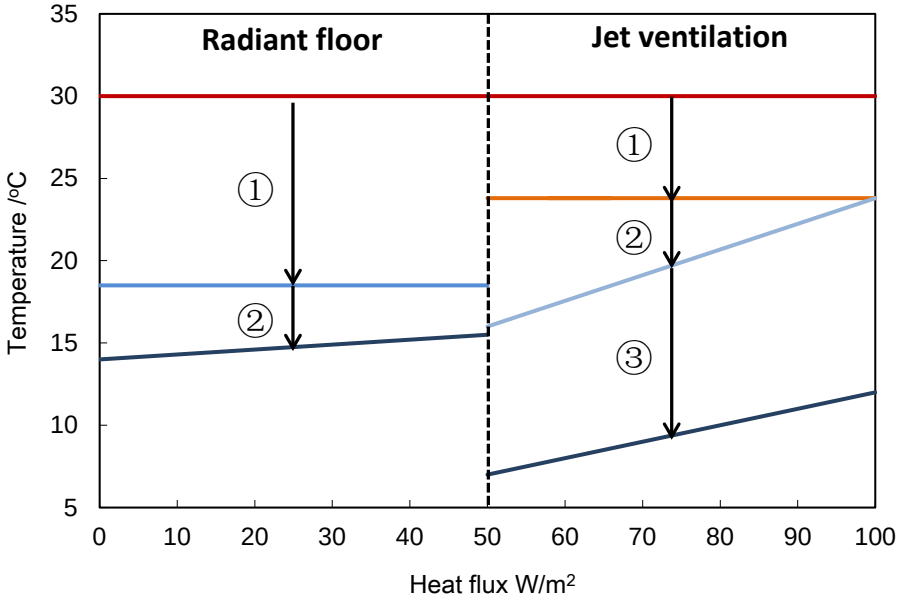


Terminal handling process

> Simplify heat transfer process from heat sources to chilled water



Heat sources $\xrightarrow{①}$ Radiant floor surface $\xrightarrow{②}$ Chilled water

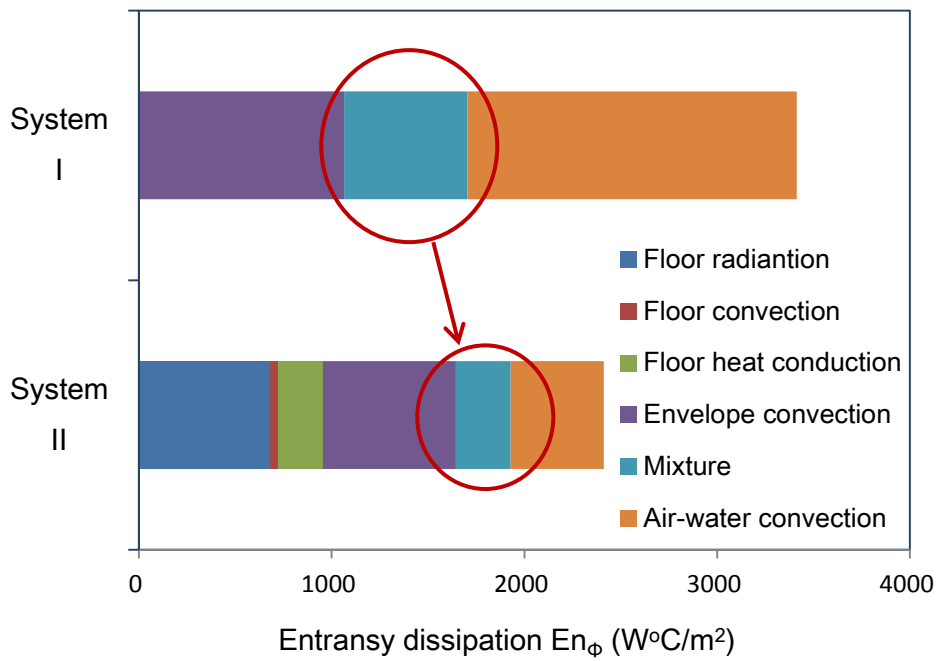
Heat sources $\xrightarrow{①}$ Indoor air $\xrightarrow{②}$ Supply air $\xrightarrow{③}$ Chilled water

Terminal handling process

> Reducing indoor mixing loss

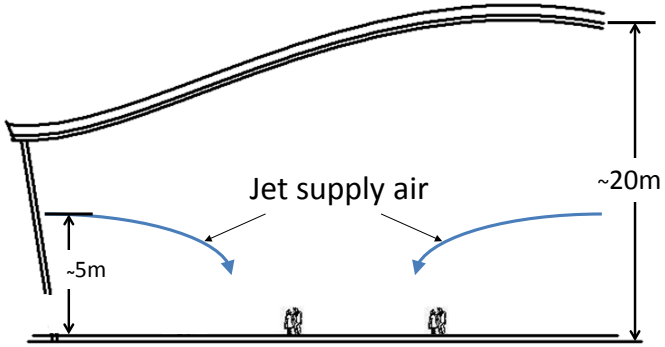
> Decrease temperature gradient in space ∇T

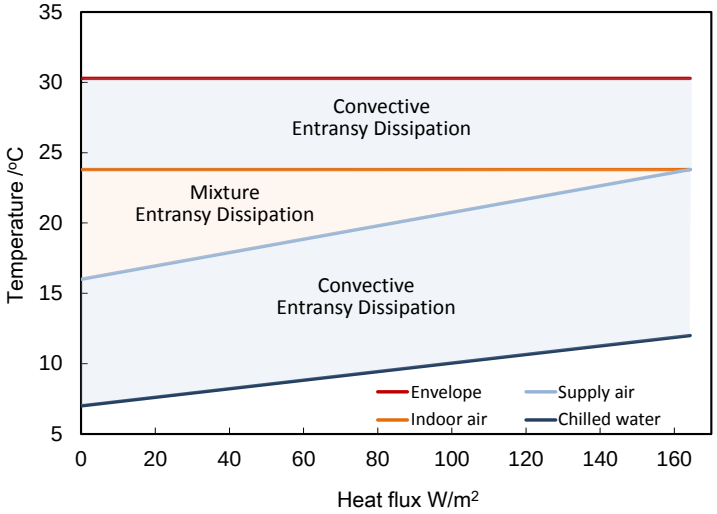
> Avoid fluid mixture of high temperature with low temperature



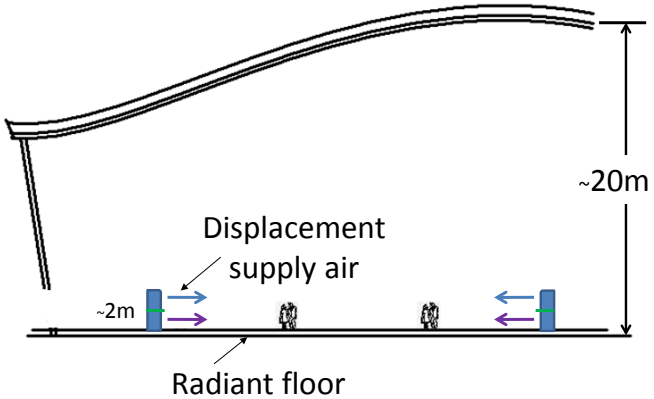
Terminal handling process

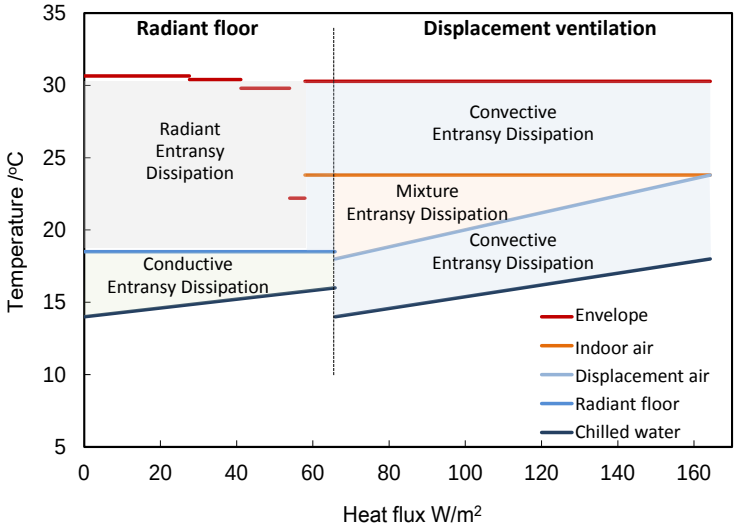
Jet ventilation





Radiant floor



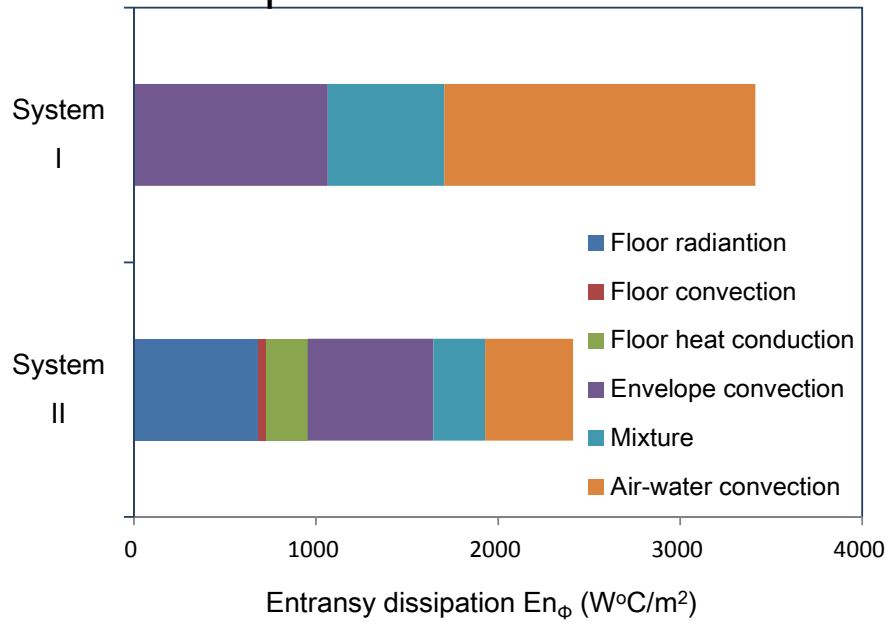


Terminal handling process

Entransy dissipation comparison

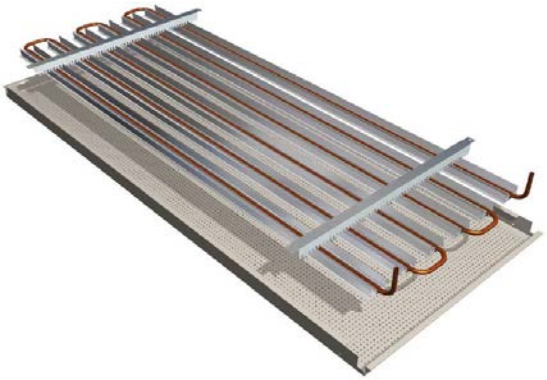
> Total entransy dissipation of System II (2411 (W·ºC)/m^2)) is less than that of System I (3413 (W·ºC)/m^2))

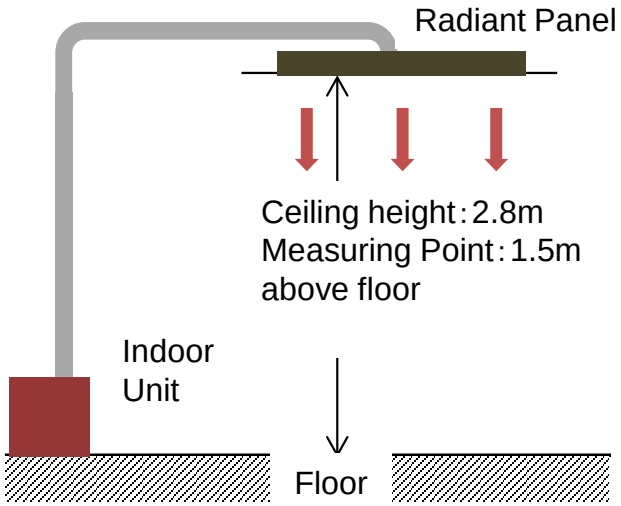
> Reduced entransy dissipation (1002 (W·ºC)/m^2)) by system II equals to rising 6.3ºC of chilled water temperature.

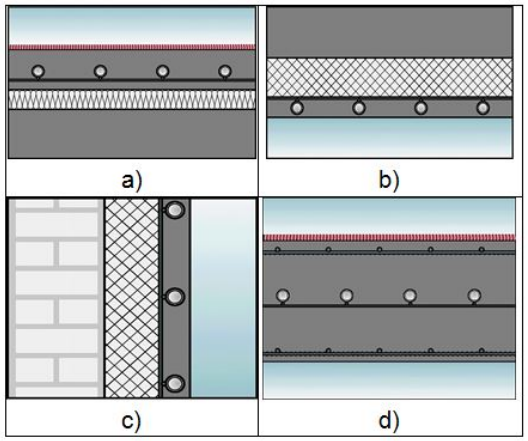


Terminals with low mixing loss

■ Radiant panels, radiant floor, TABs







Embedded radiant systems: a) Floor, b) Ceiling, c) Wall, d) TABS

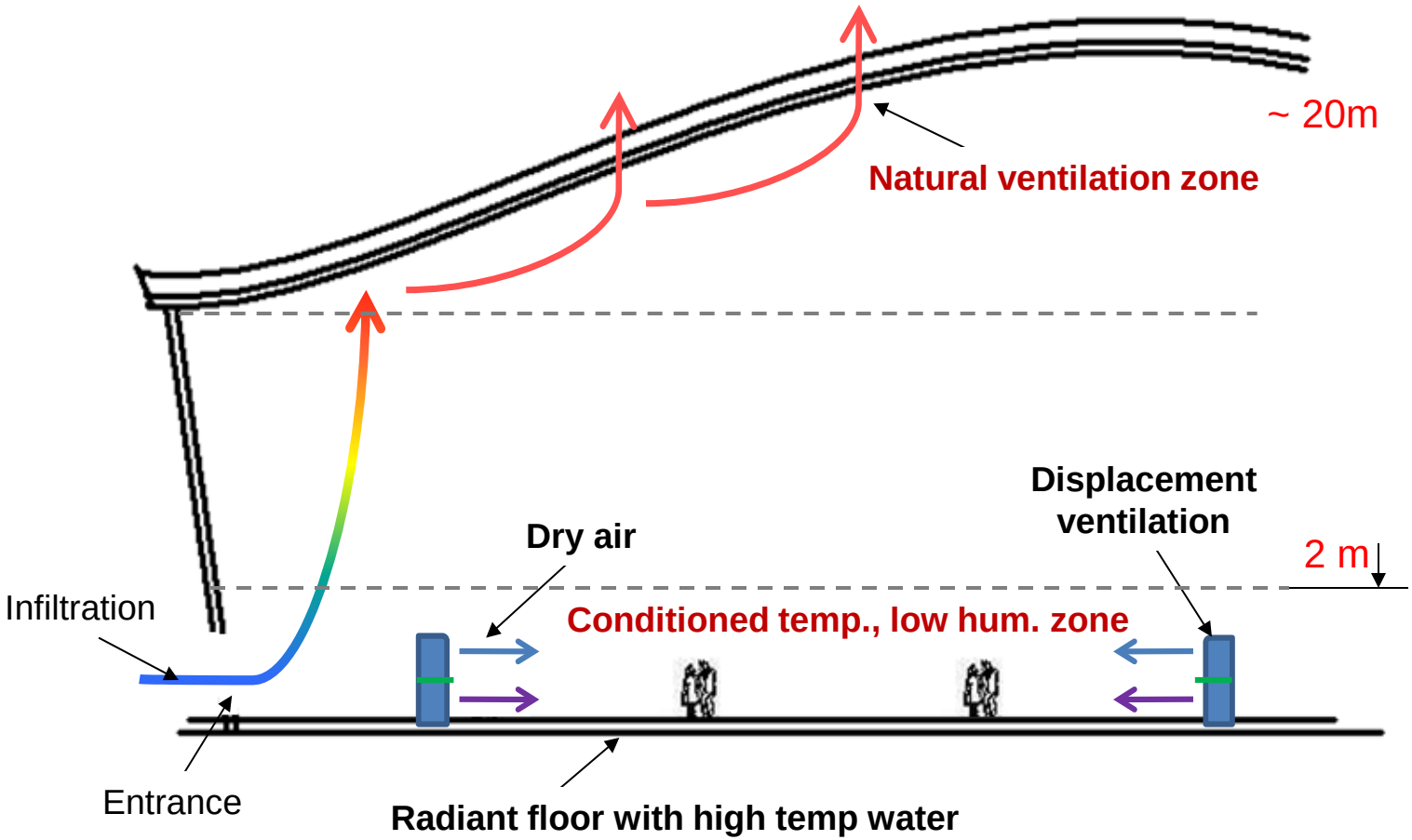
Application

- Terminal 3 of Xi'an airport
  - **Area: 258,000m^2, with a maximum height of 36.5m**
  - **Coming into service since May 2012**
- The first terminal adopting radiant cooling/heating in China
  - **Radiant cooling, displacement ventilation, liquid desiccant …**

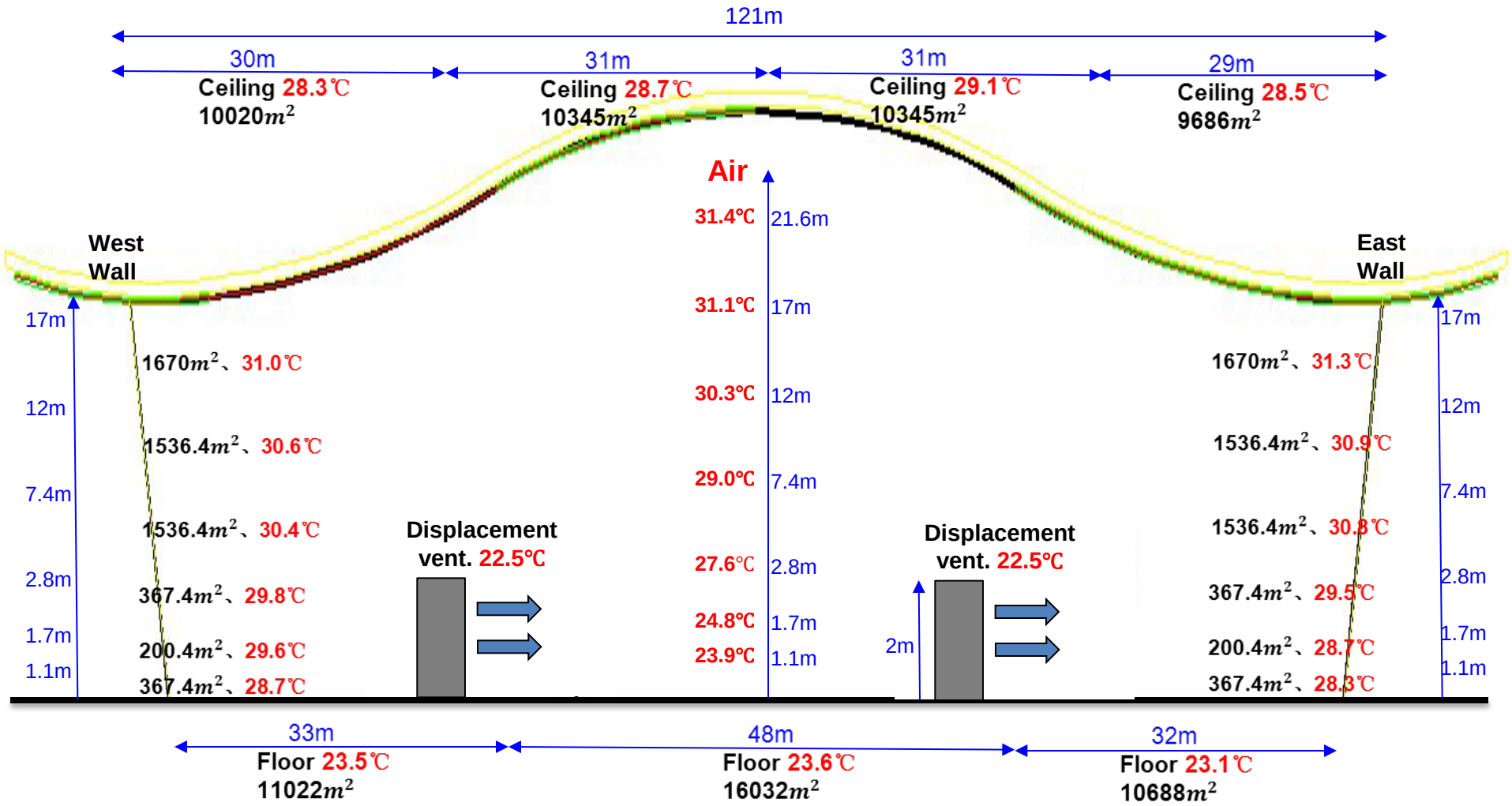
AC system (summer)

■ Large space area

➢ **Stratified air conditioning in summer**



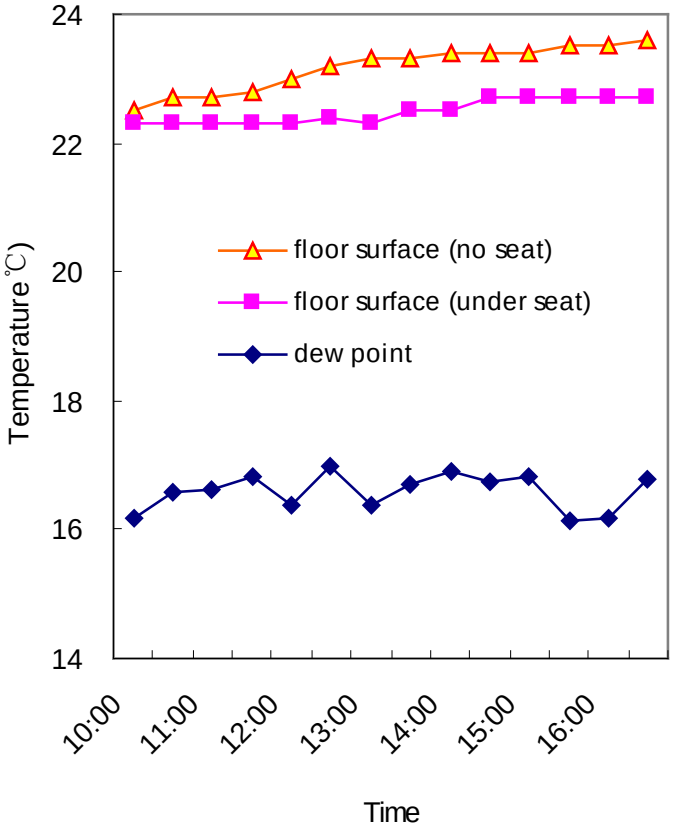
Terminal handling process



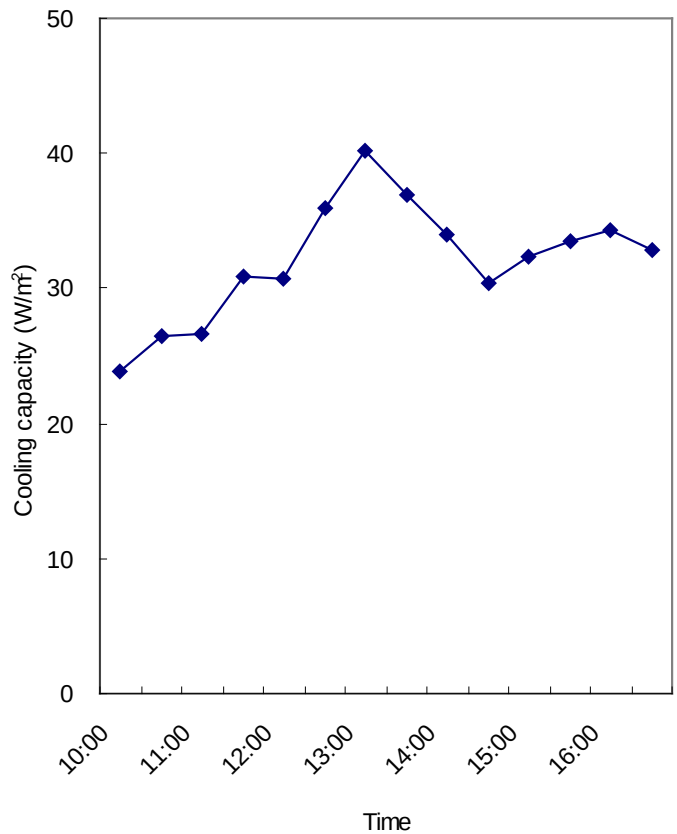
Measured temperatures

Application

■ Radiant floor for cooling (without solar)



Temperatures



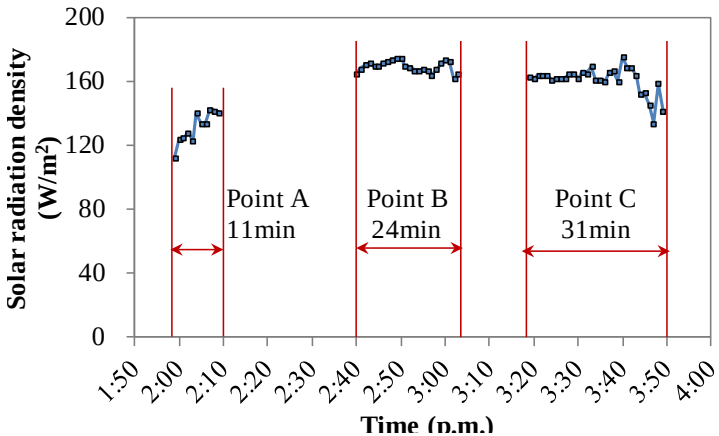
Cooling capacity

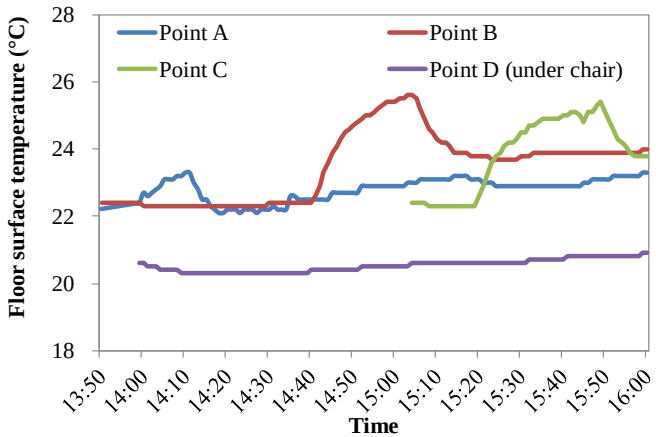
(20~40W/m^2)

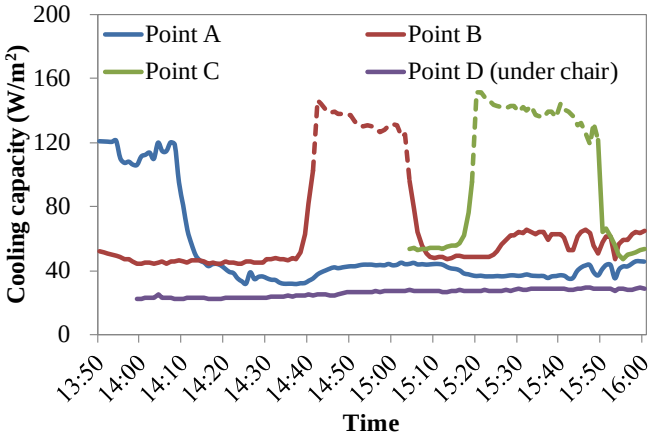
Application

■ Radiant floor for cooling (with solar)

➢ **Solar radiation on floor: High intensity, transient process**





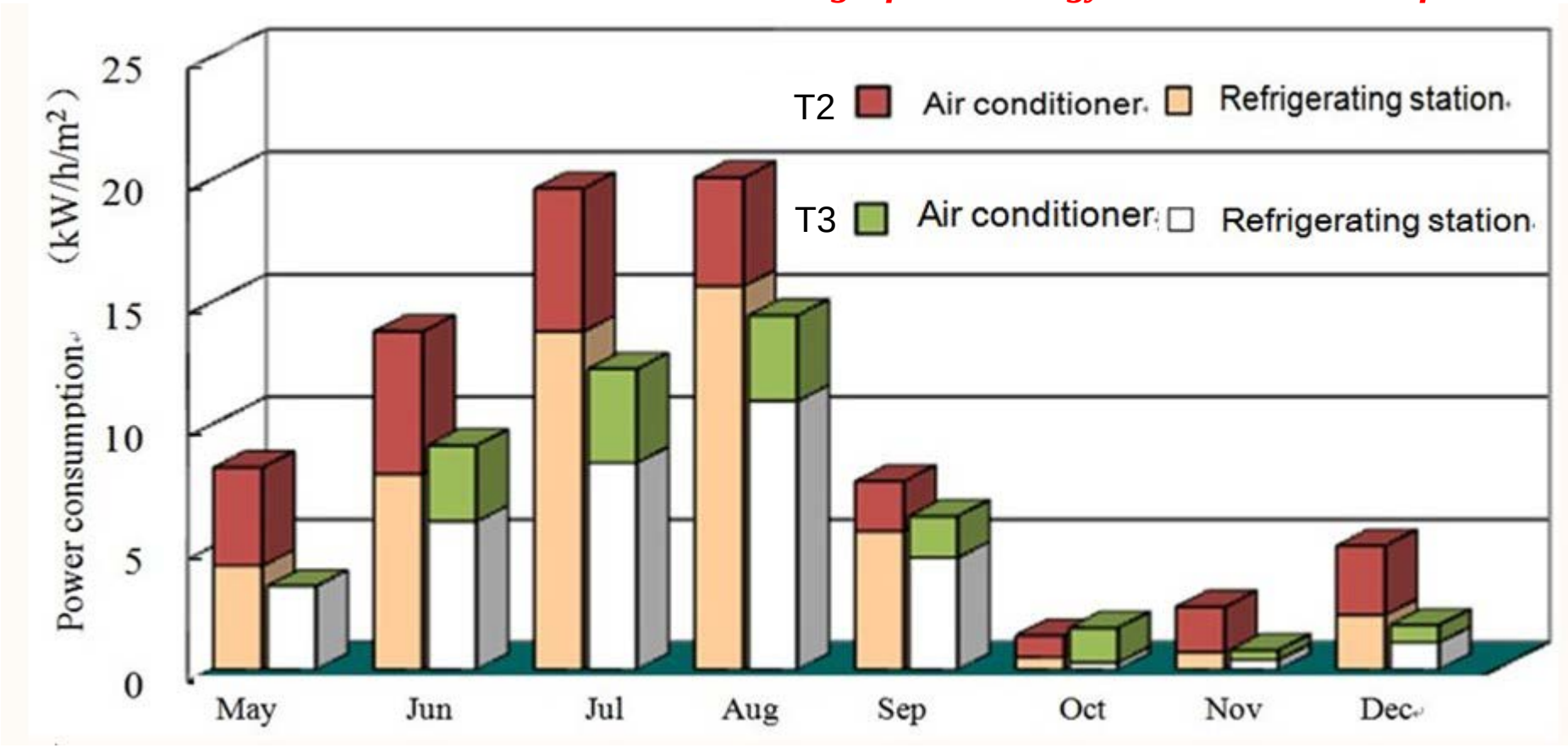


Cooling capacity could be higher than 100W/m2 with direct solar radiation

Application

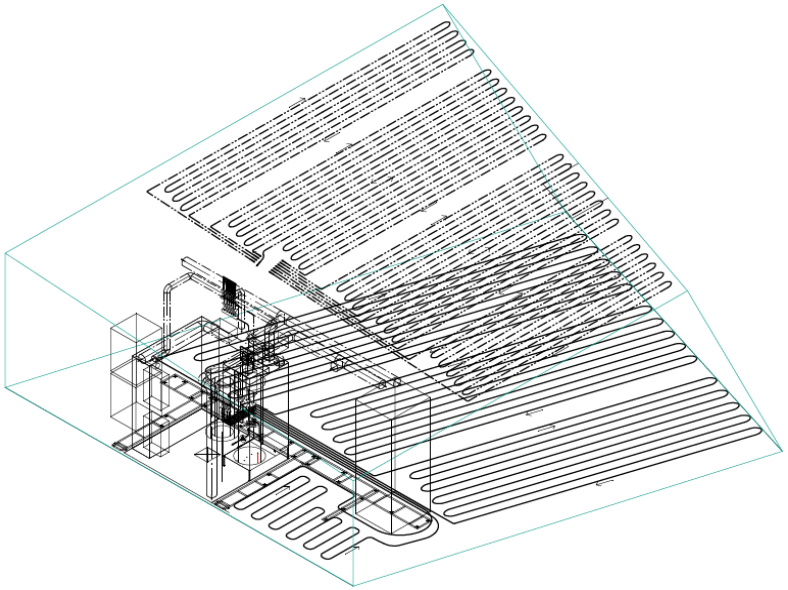
■ Power consumption

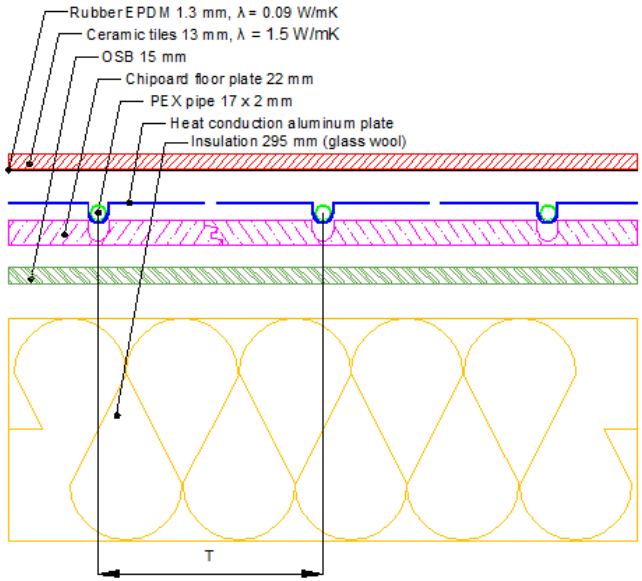
Significant energy conservation benefits



Application

■ Radiant terminal in a solar house (Denmark)





Application

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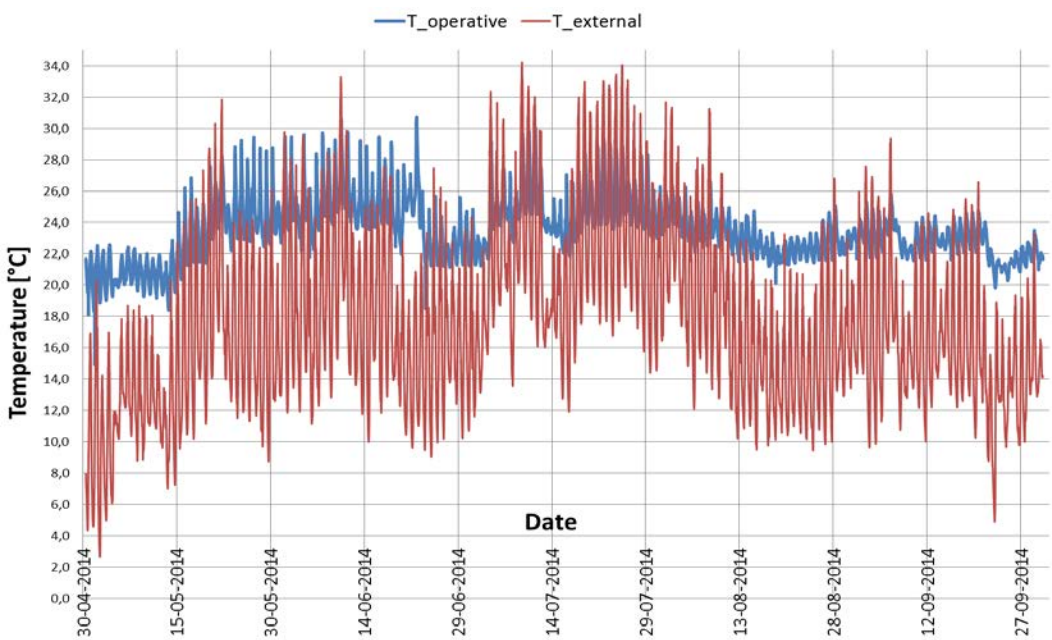
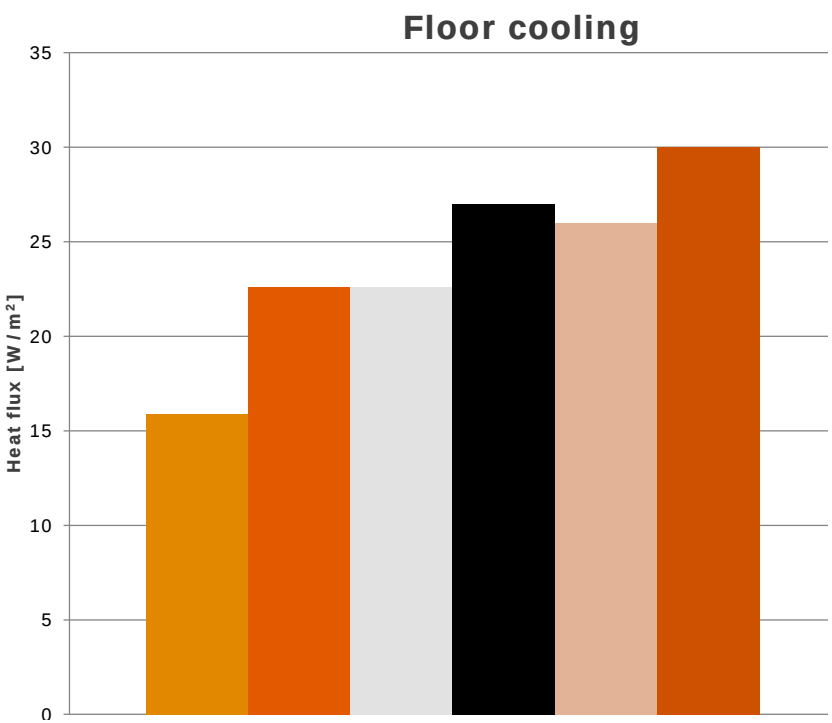


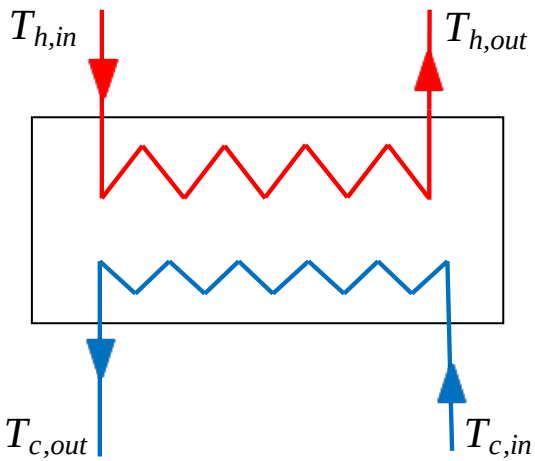
Operative temperature and external air temperature during the cooling season

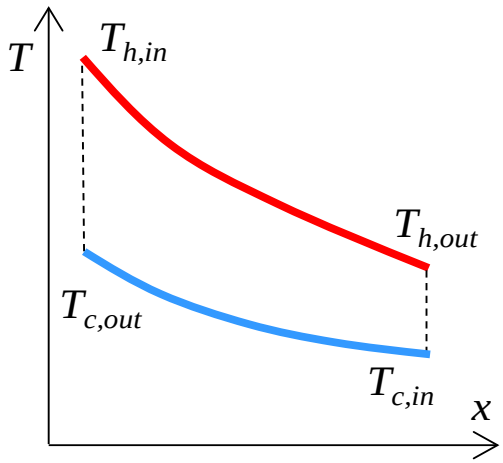


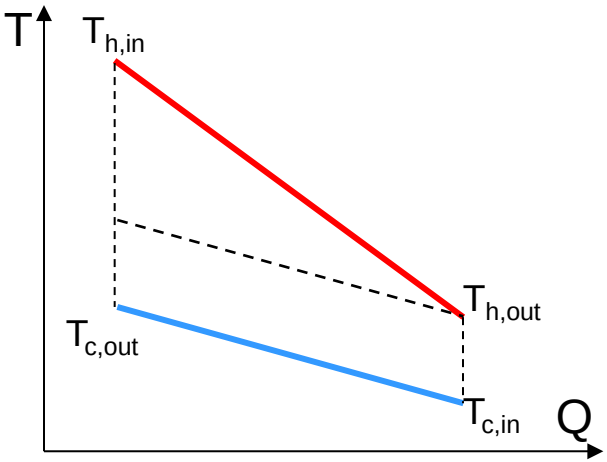
Cooling capacity

Avoid Δt loss of heat exchange process

- **Direct connection of the cooling source with indoor terminals**
- **Enlarge the heat transfer ability and adjust the flow rates at both sides so to ensure the Δt uniformed along the heat exchange process**



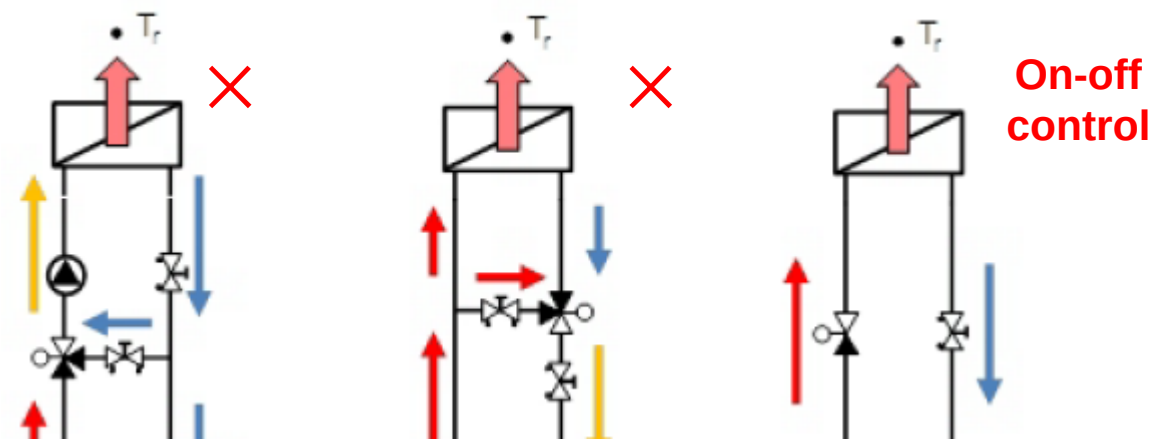




Unmatched flow rates

Avoid Δt loss of heat exchange process

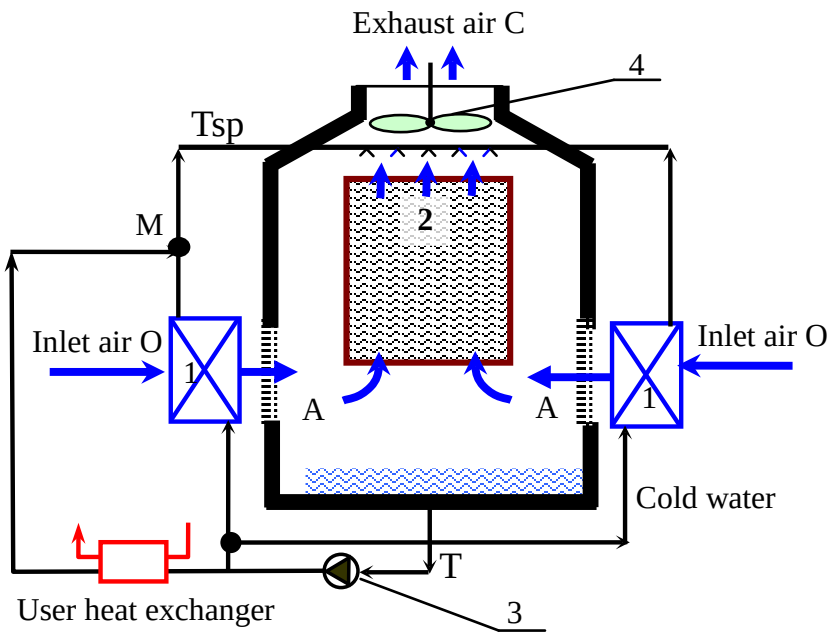
- **4~5 K temperature difference for water circulation**
- **On-off control for each indoor terminal (radiative) to obtain near linear control performance**
- **Careful design of the water piping system to avoid large pump power consumed**
  - **Remove most of control valves and other resistance device in water loops except on-off control valve**
  - **Pressure drop: 10~15 m H_2O for total water loop circulation**

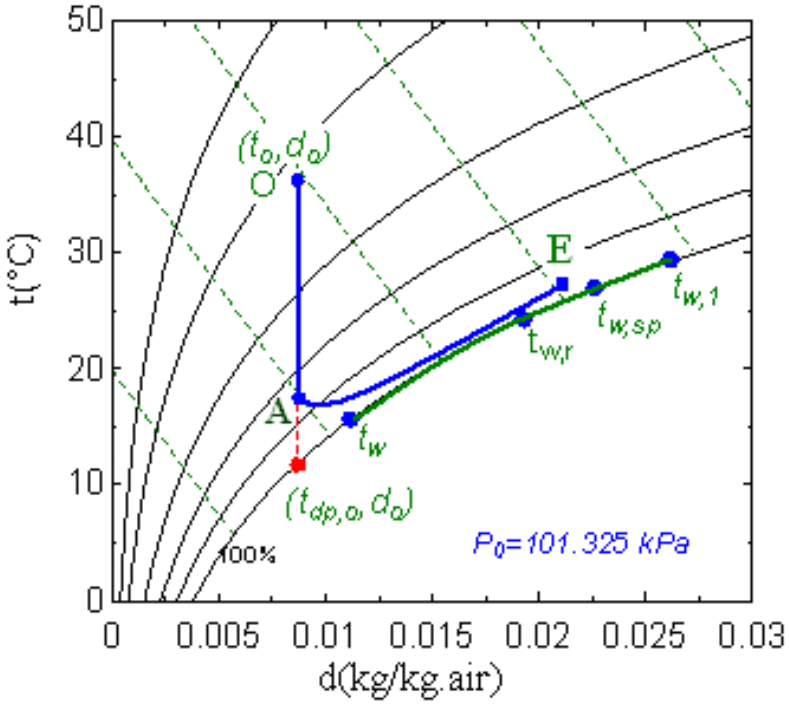


Case study

■ Evaporative cooling as cooling source

➢ **Outlet water temperature 15~19℃ to remove sensible heat**





- **Key parts: countercurrent air cooler/packing tower**
- **Design idea: matched flow rates and parameters**

Case study

■ Evaporative cooling as cooling source

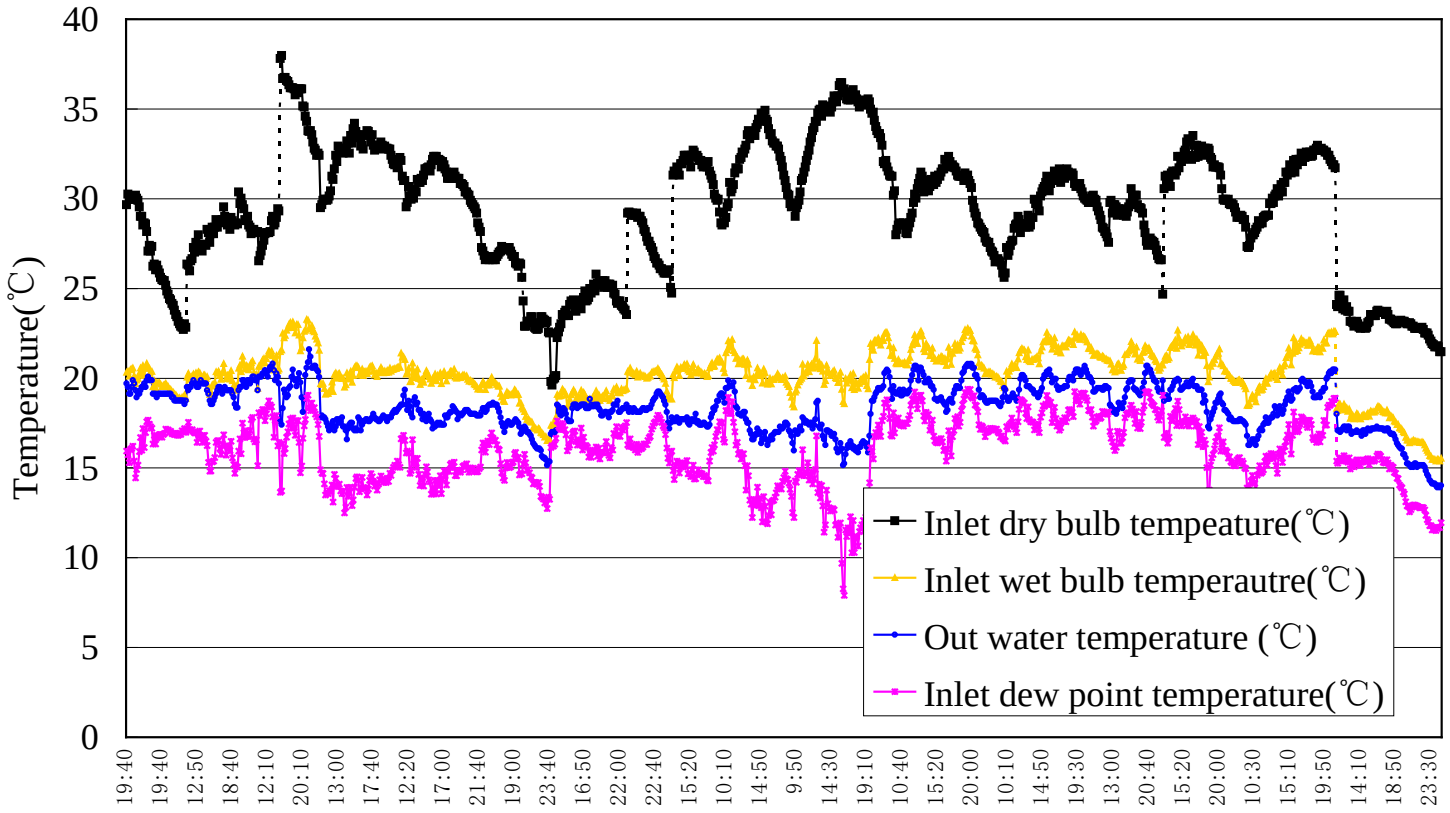
❖ Installed in Shihezi Kai Rui Building, now four years well-running.

❖ Shihezi outdoor design air state: dry bulb 32.8℃, wet bulb 21.5 ℃.

❖Designed water out temperature 18.5 ℃, cooling Energy output 120kW.

Case study

■ Evaporative cooling as cooling source



- Out water Temperature **lower than inlet Wet Bulb Temperature**.
- Tested **COP** (sensible heat removed/power of fan and pump) **higher than 10.**

Case study

■ Evaporative cooling as cooling source

➢ **Applications in the dry region (Xinjiang province, China)**

Shihezi Kai Rui Building

Aksu People's Hospital

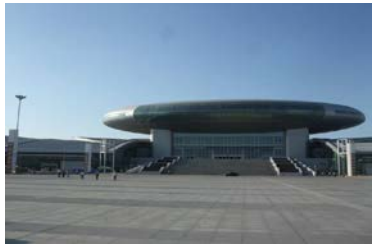
Xinjiang Chinese Medicine Hospital

Xinjiang Medical University Hospital

Xinjiang air force hospital

Office building of Xinjiang medicine hospital

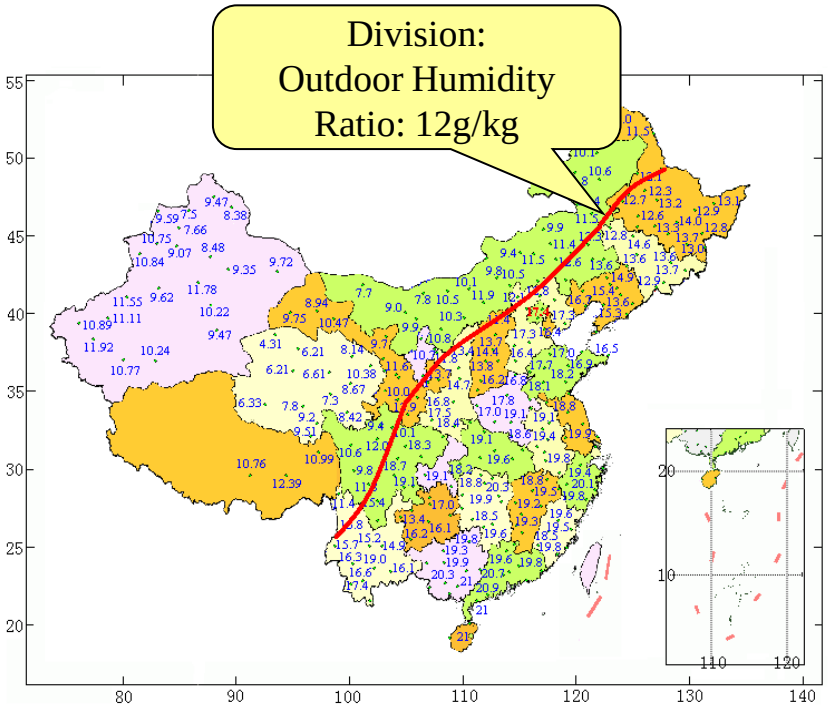
Changji medicine hospital



Xinjiang international exhibition center

Suitable region for evaporative cooling

- **Climate condition: dew point ≤15℃**
- **System requirement:**
  - **Low Δt loss terminals with on-off control**
  - **Large water circulation with minimal pressure drop**



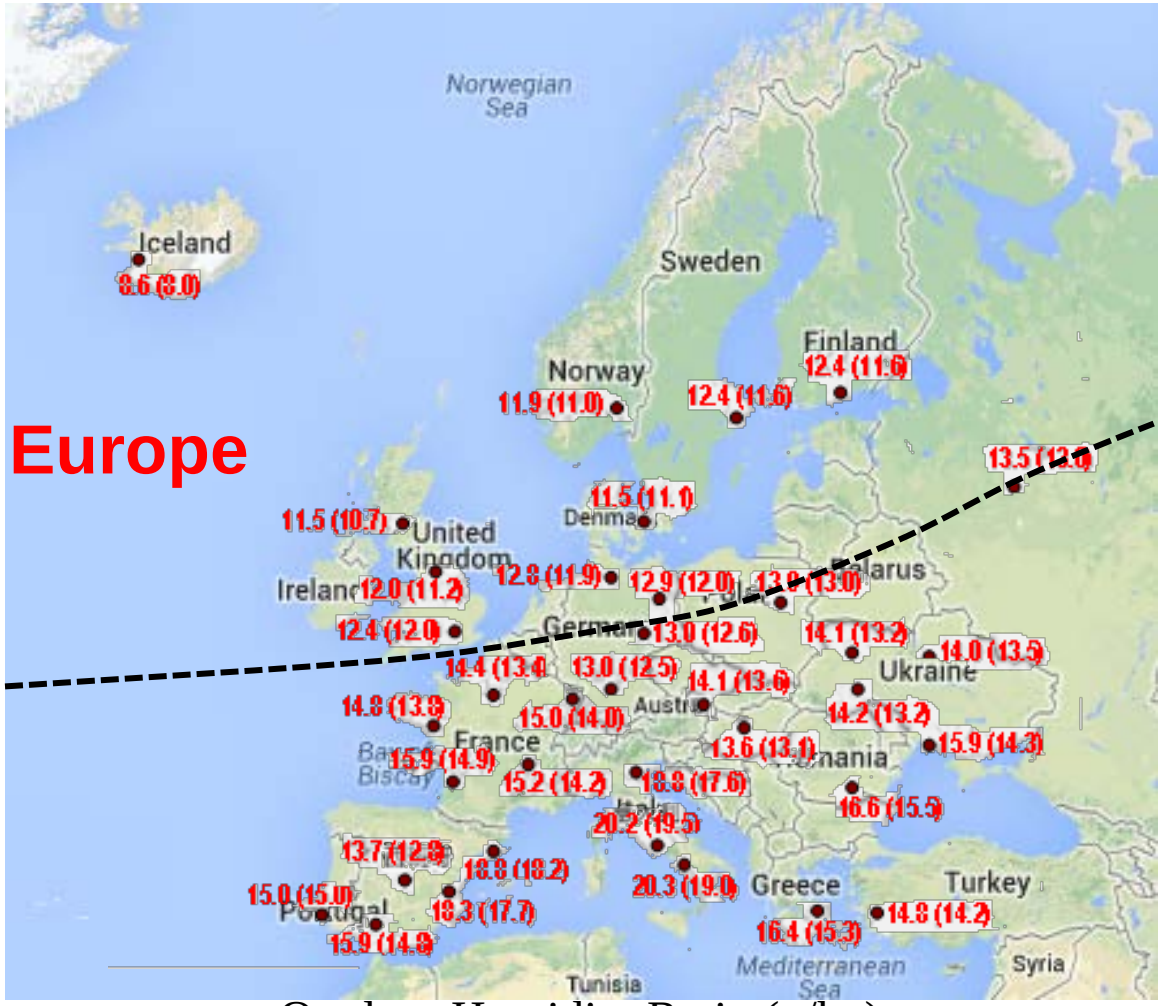
West China

West U.S.

Suitable region for evaporative cooling

- **Climate condition: dew point ≤15℃**

North Europe

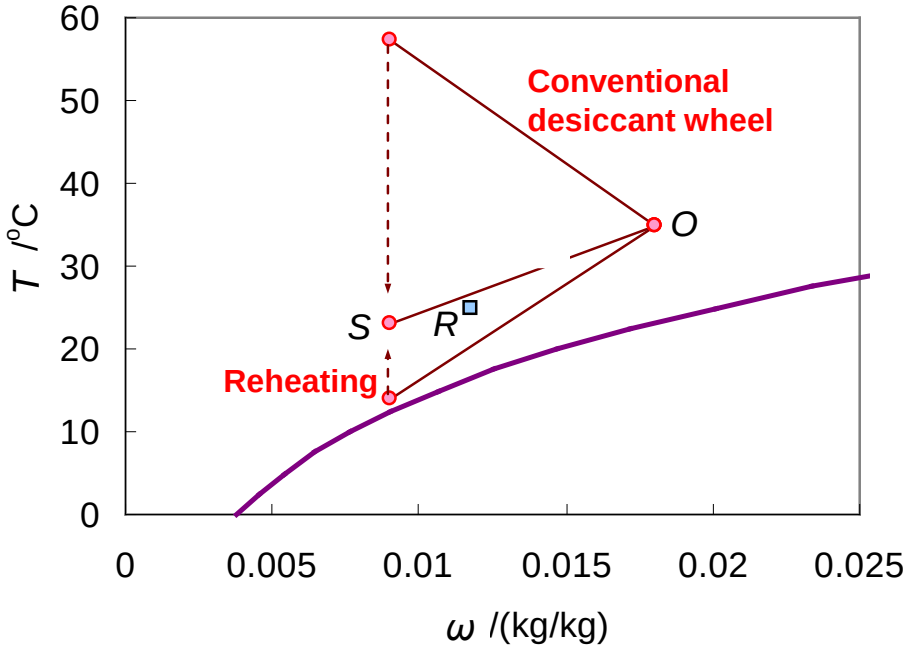


Outdoor Humidity Ratio (g/kg)

Efficient dehumidification process

For moist region: humidity control is part of the task in space cooling

- **Weak point of dehumidification by condensation:**
  - **Require the cooling source below dew point**
  - **Reheat, or mix with higher temperature environment**

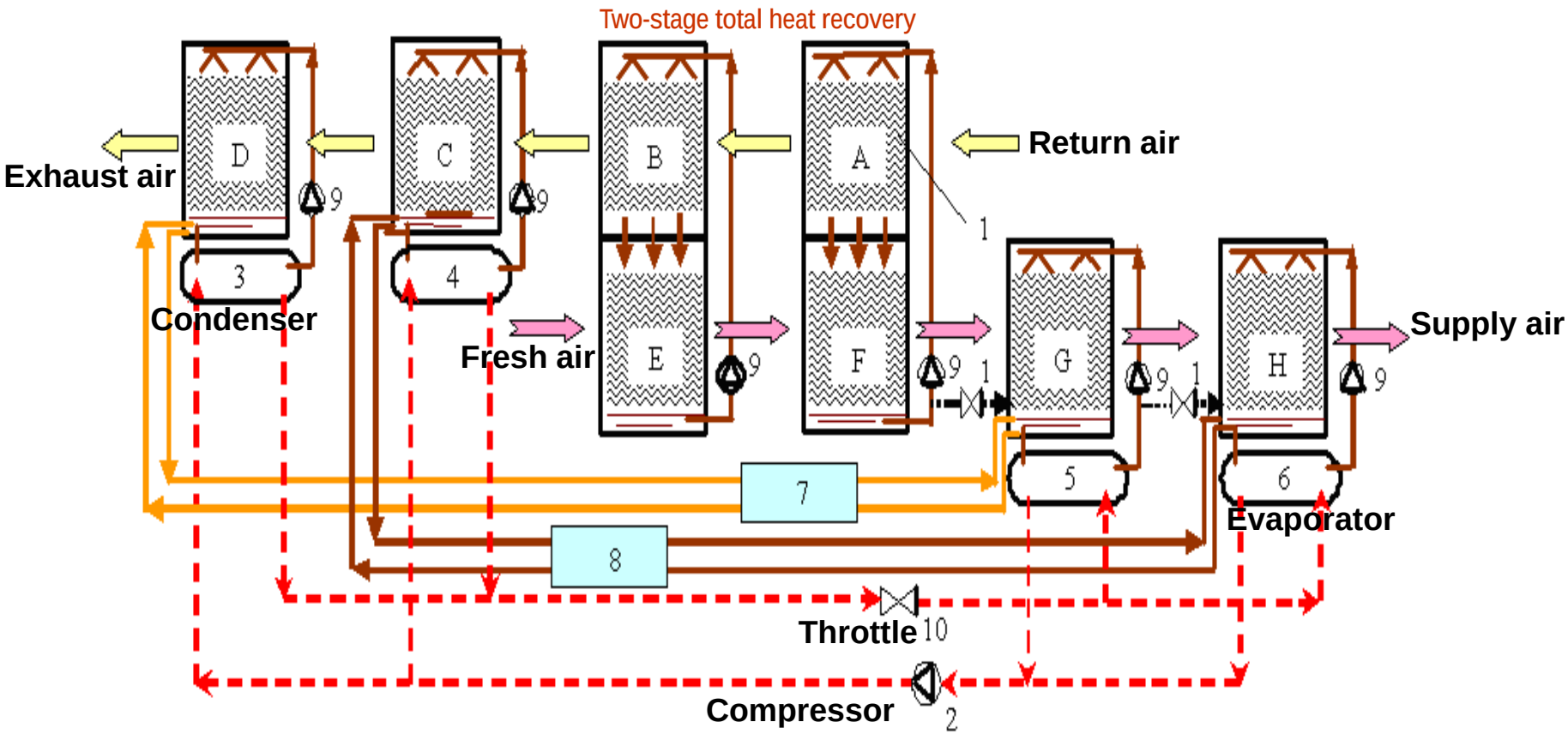


New approaches for dehumidification are required!

Efficient dehumidification process

■ New approaches for dehumidification

➢ **Liquid desiccant dehumidification**

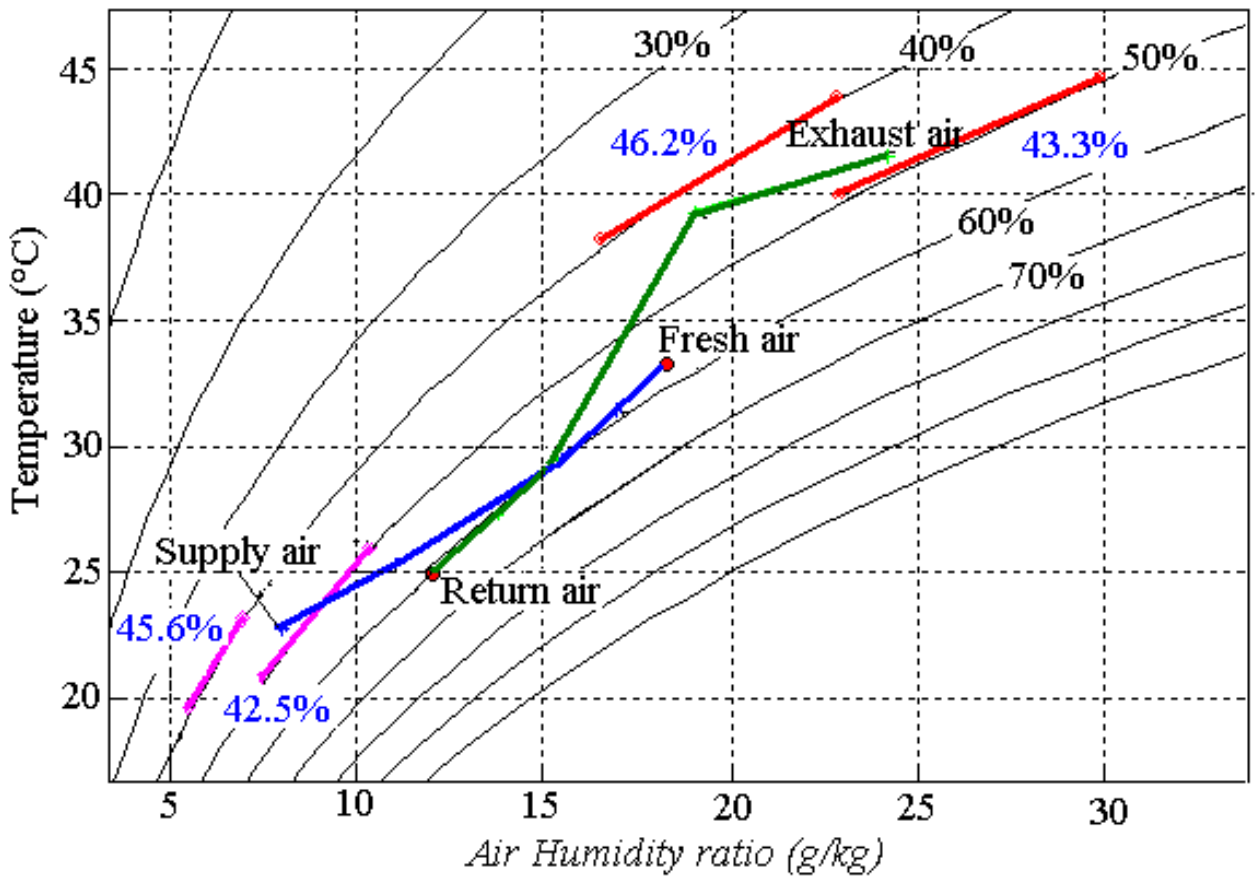


□ Multi-stage process for dehumidification, matched parameters

Efficient dehumidification process

■ New approaches for dehumidification

➢ **Liquid desiccant dehumidification**



- Close to the iso-relative humidity line instead of isenthalpic line

Efficient dehumidification process

■ New approaches for dehumidification

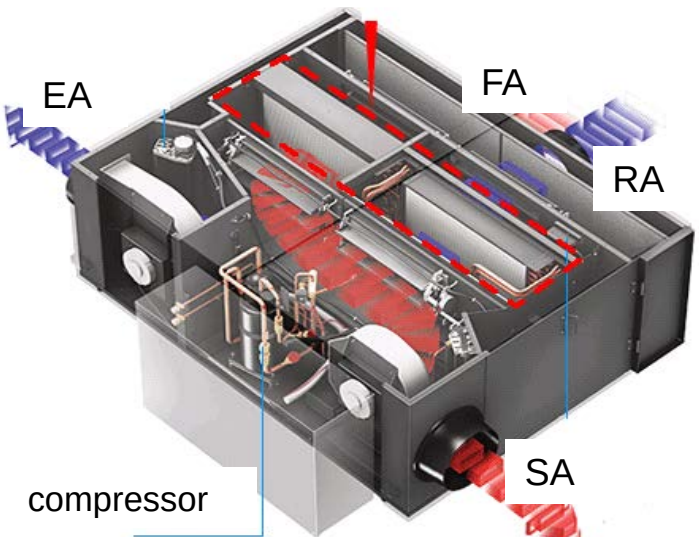
➢ **Liquid desiccant dehumidification**

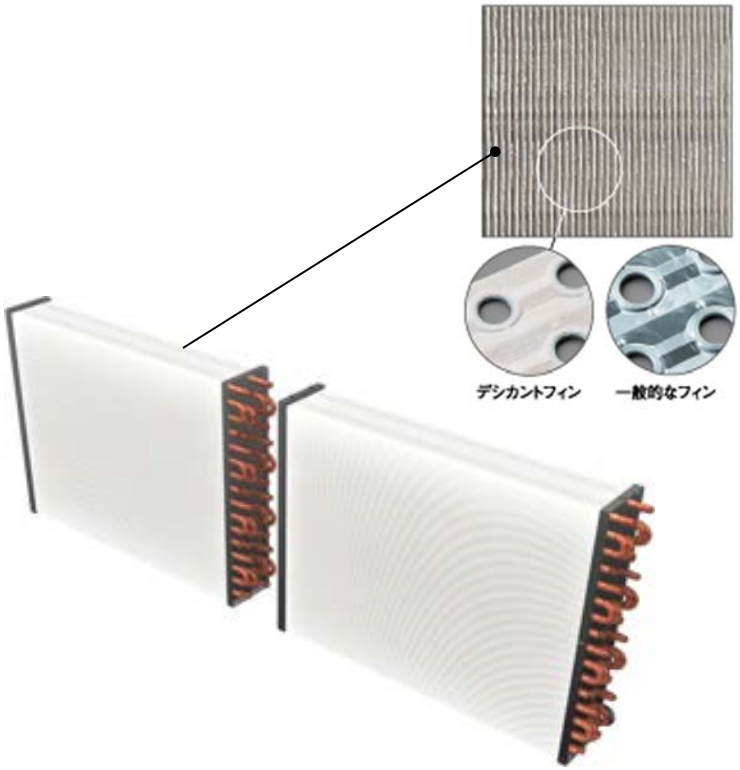
	Cooling Dehumidify	Deep Dehumidify		Total Heat Recovery	Humidify	
Fresh air t (°C)	36.0	22.8	22.8	35.9	6.4	4.3
Fresh air d (g/kg)	24.6	8.6	8.6	26.7	2.1	1.6
Supply air t (°C)	17.3	16.1	11.9	30.4	22.5	25.6
Supply air d (g/kg)	8.6	5.1	3.4	19.5	7.2	10.7
Return air t (°C)	26.0	33.2	26.3	26.1	20.5	22.1
Return air d (g/kg)	12.2	18.3	16.3	12.1	4.0	5.1
Exhaust air t (°C)	39.1	43.9	42.2	32.6	7.0	6.6
Exhaust air d (g/kg)	37.3	23.4	24.1	20.3	2.7	2.9
COP	5.00	2.32	1.74	62.5%	6.2	4.6

Efficient dehumidification process

■ New approaches for dehumidification

➢ **Solid desiccant dehumidification *(DESICA, Japan)***



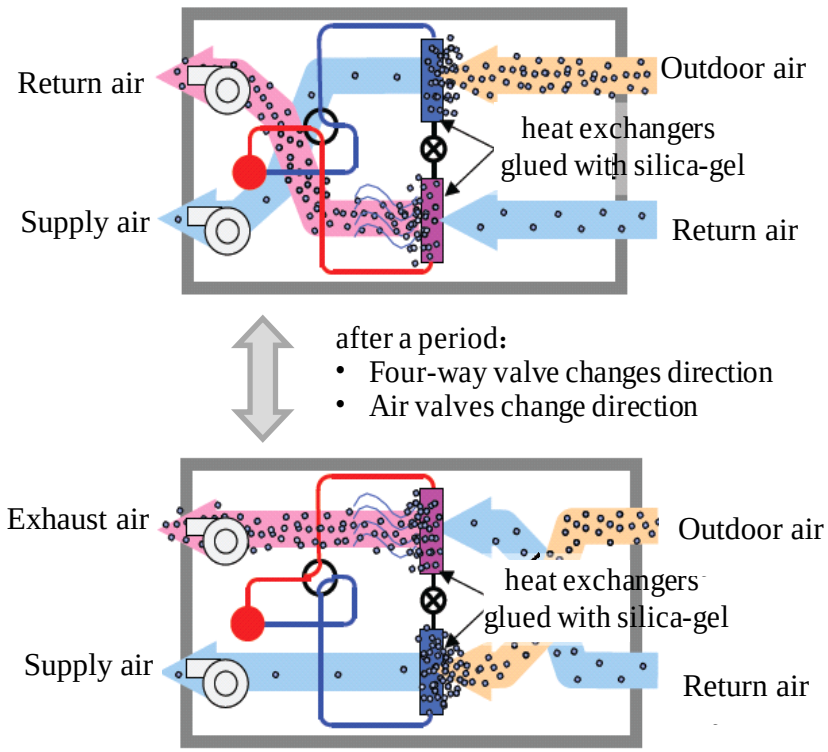


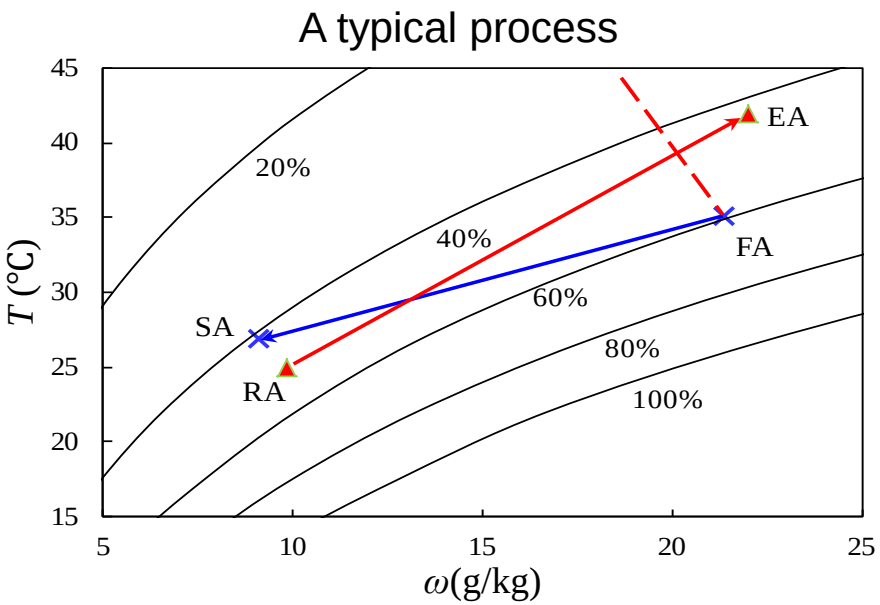
□ Heat pump utilized for internal cooling in dehumidification

Efficient dehumidification process

■ New approaches for dehumidification

➢ **Solid desiccant dehumidification *(DESICA, Japan)***

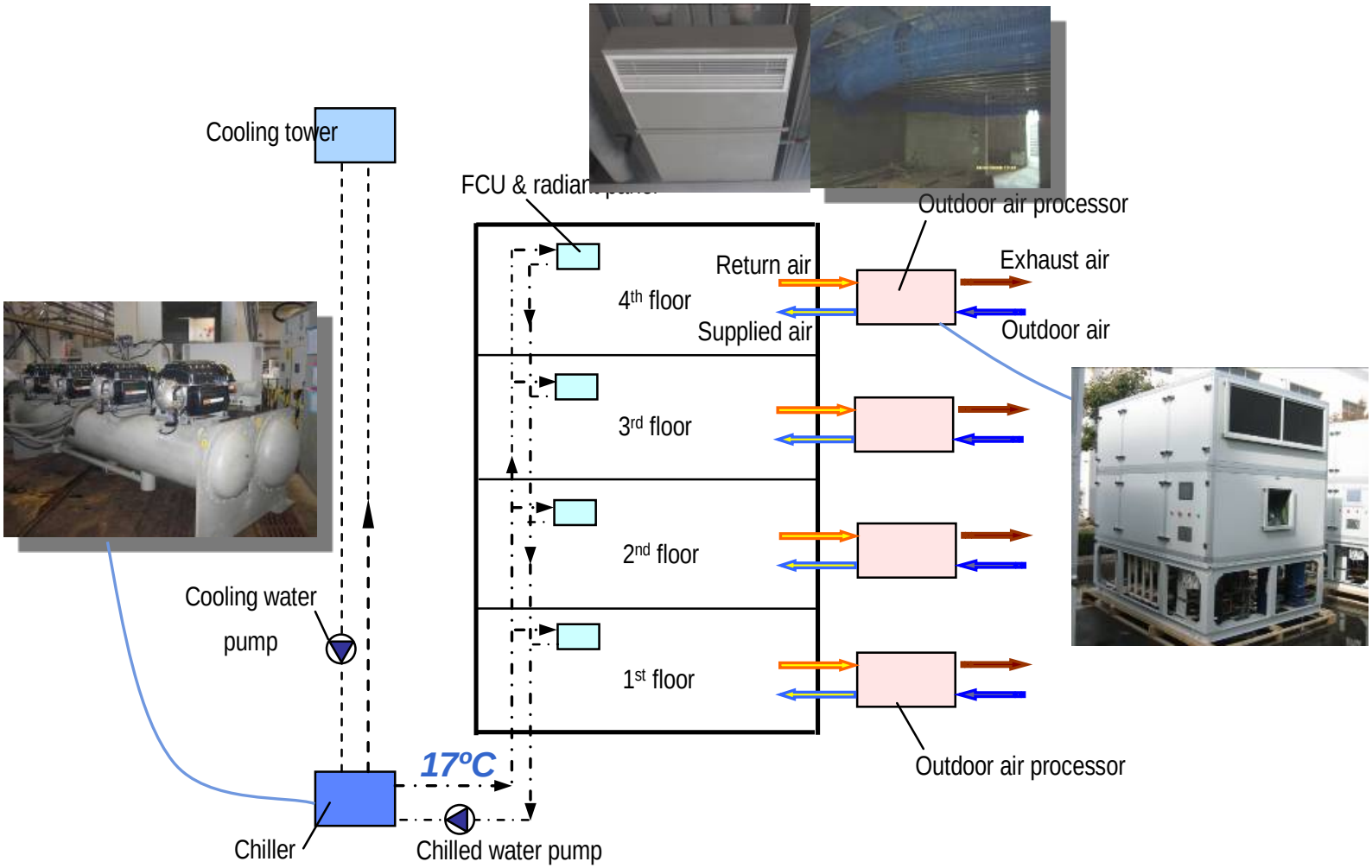




- ☐ Close to the iso-relative humidity line instead of isenthalpic line
- ☐ ***COP* is as high as 4.0**

Application——Liquid desiccant

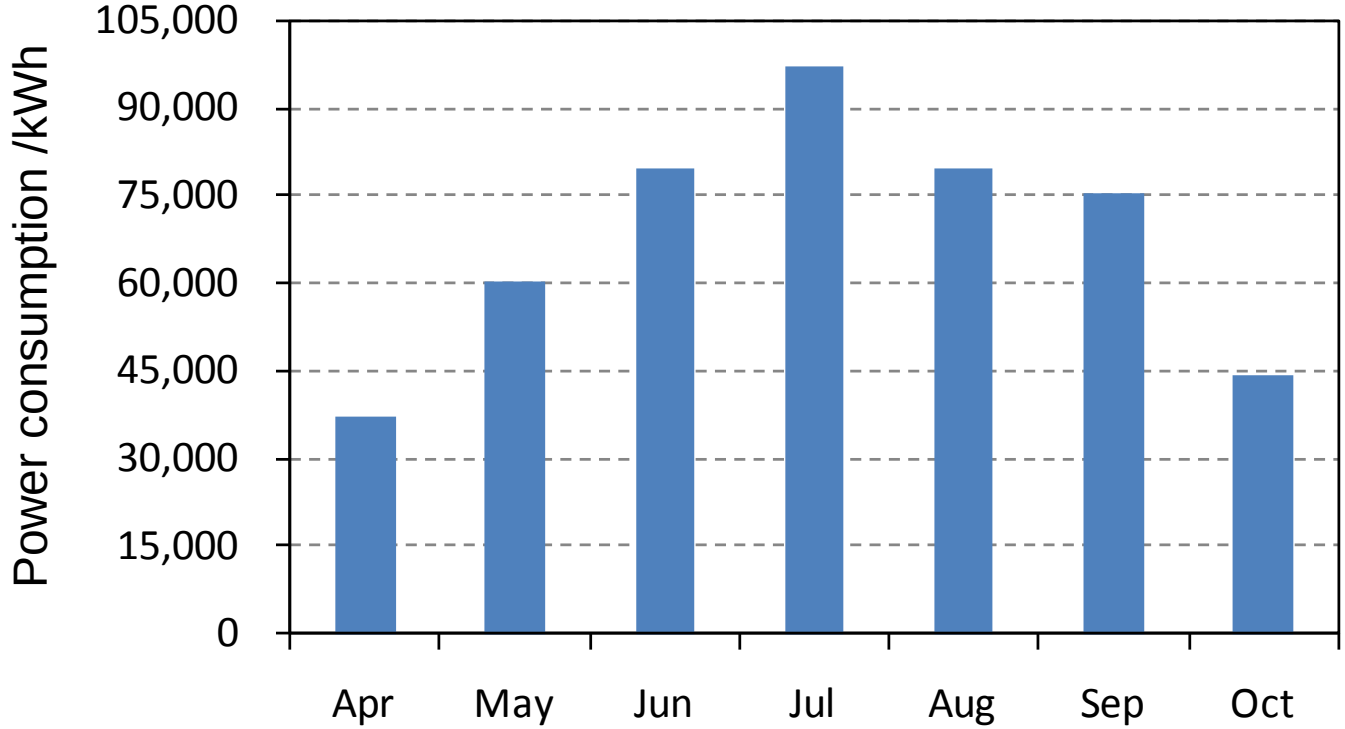
■ Temperature and Humidity Independent control system



Application——Liquid desiccant

	Outdoor air process		Chilled water process					Entire system
	OAHU	Fan	Chiller	Chilled water pump	Cooling water pump	Cooling tower	Fan Coil Unit	
Cooling capacity /kW	773.0		446.1					1219.1
Energy consump /kW	166.9	20.0	52.5	30.6	14.6	3.7	19.4	307.7
COP	4.3 (OAHU=4.6)		3.7 (Chiller=8.5)					4.0

Application——Liquid desiccant

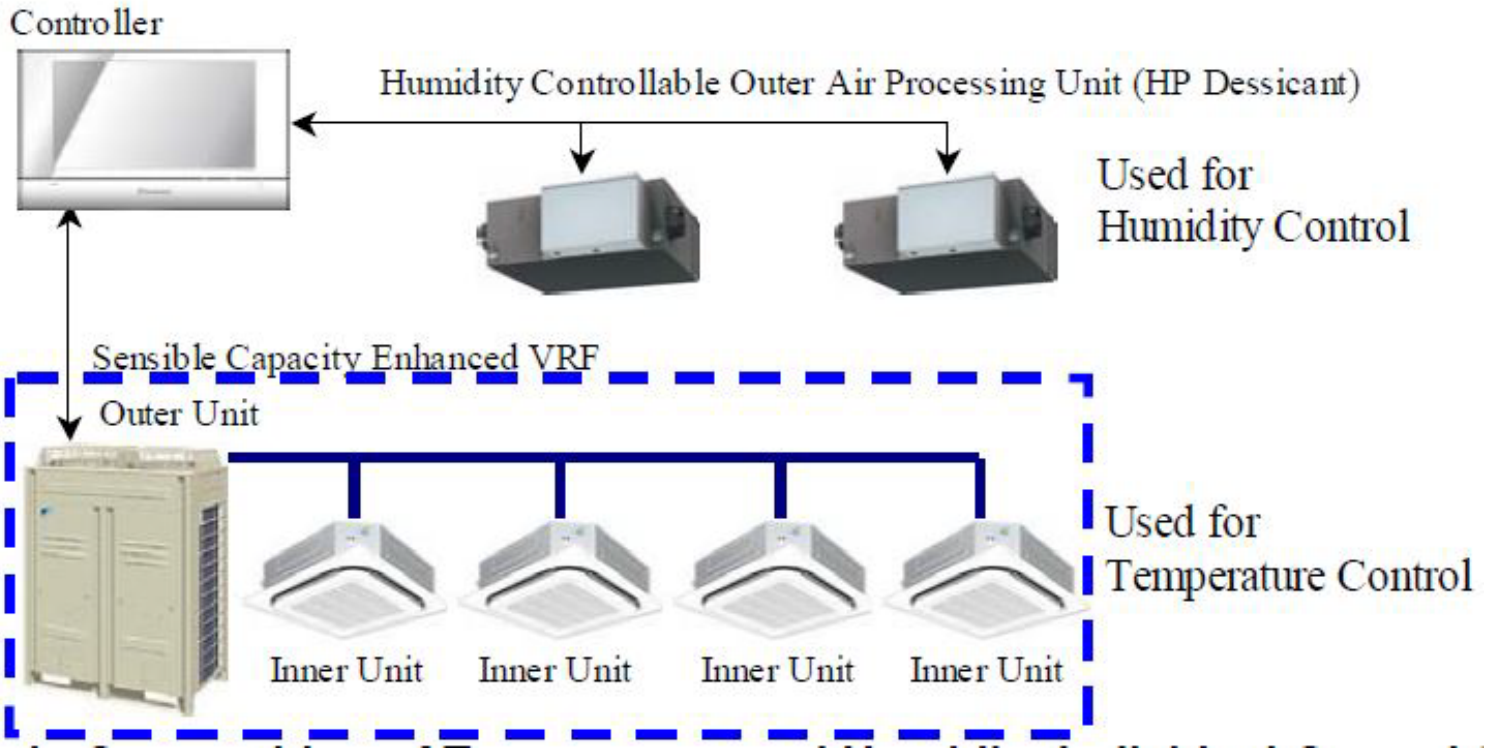


Annual power consumption: 32kWh/(m^2 AC area)
Common building in Shenzhen: ~50kWh/(m^2 AC area)
Energy saving: ~30%

Application——DESICA

Office building in Japan

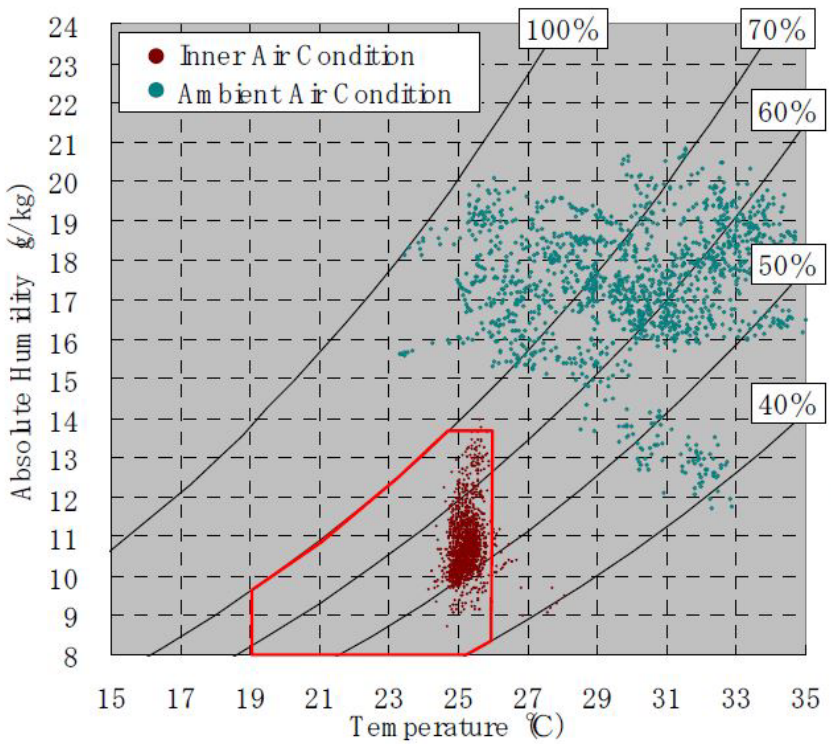
DESICA for humidity control and VRF for temp. control



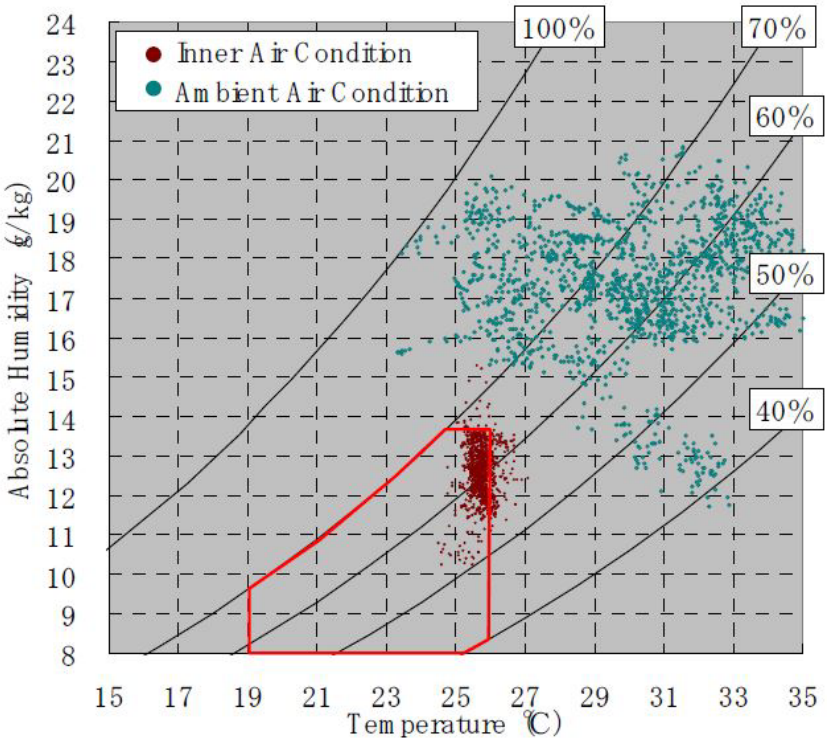
Application——DESICA

Office building in Japan

DESICA for humidity control and VRF for temp. control



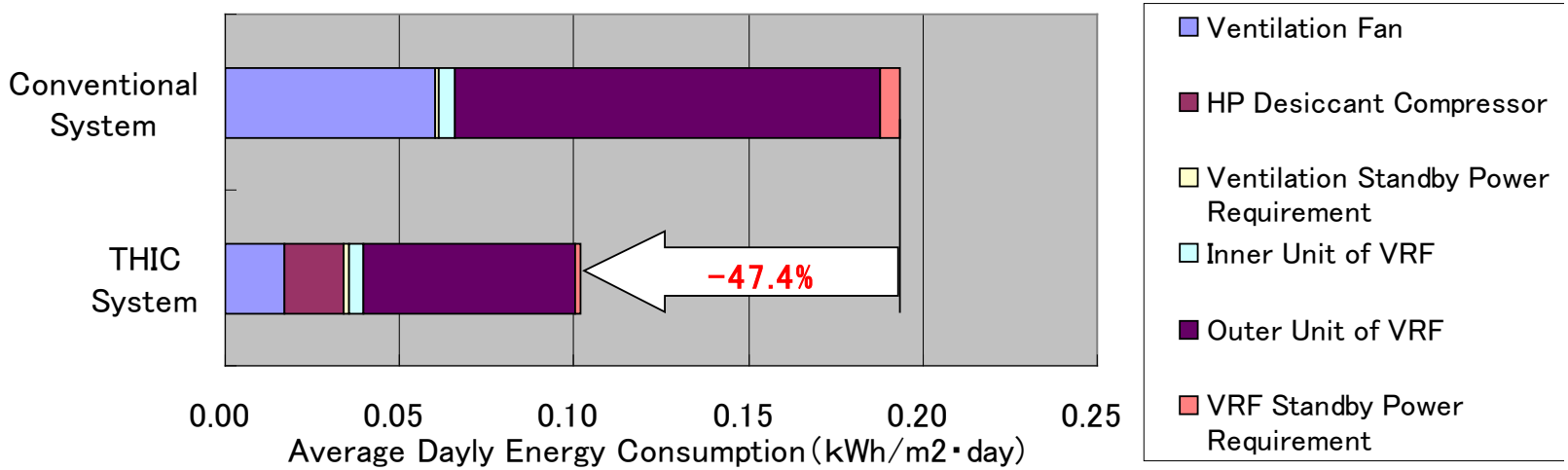
Conventional System



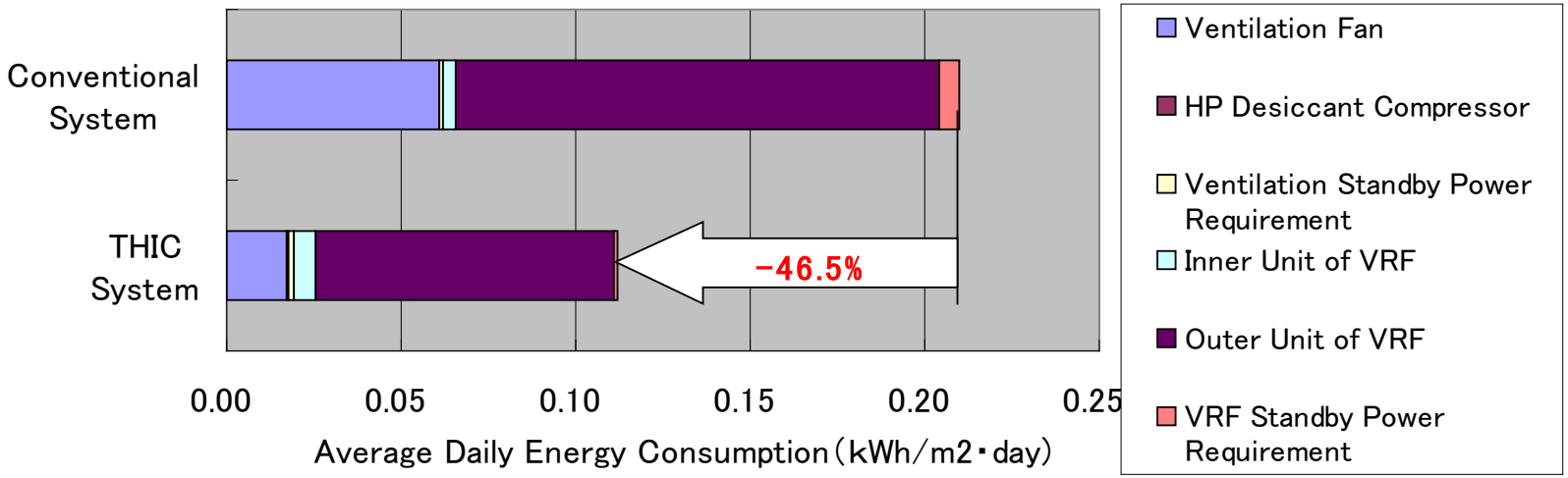
THIC System

Application——DESICA

DESICA for humidity control and VRF for temp. control

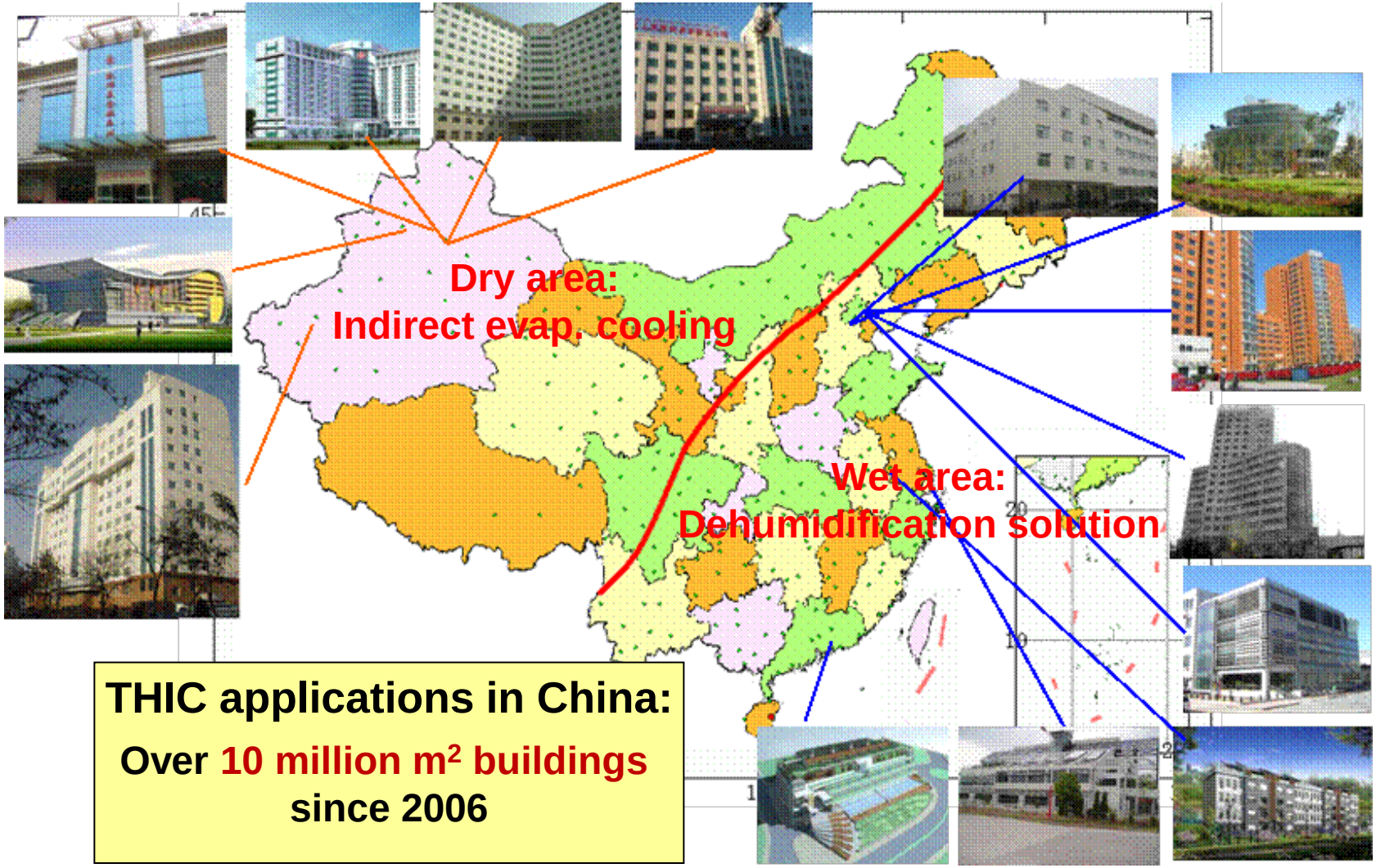


Set temperature is 28℃



Set temperature is 26℃

THIC applications in China



THIC applications in China:

Over 10 million m^2 buildings since 2006

How much energy can be saved?

Office building in dry climate

- Conventional system for cooling: electricity used 50 kWh/m²,
  - Total cooling: 100 kWh/m², COP=2, fans: 17kWh/m², pumps: 11kWh/m², chiller:22kWh/m²
- Evaporate cooling with the innovative system: electricity used 23kWh/m², 54% saved
  - Total cooling 100 kWh/m², COP=5, fans:8kWh/m², pumps: 15kWh/m²

Office building in moist region

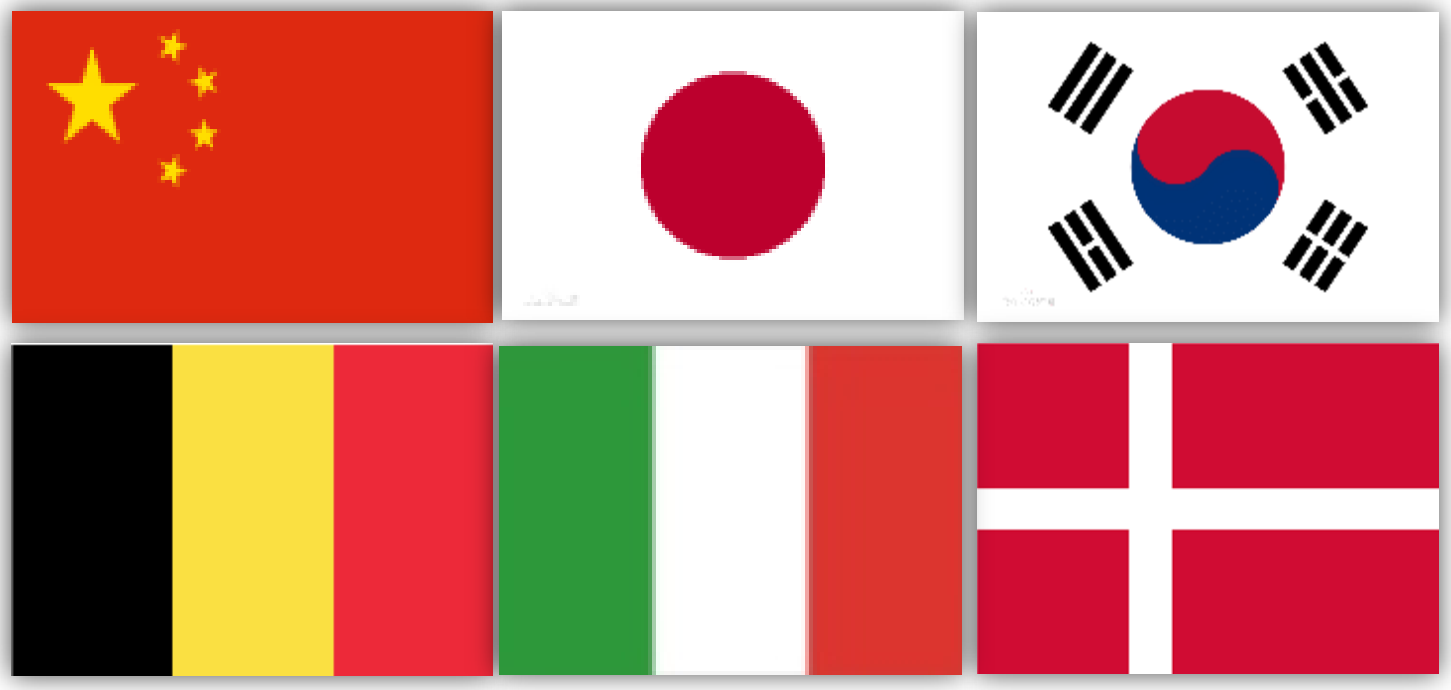
- Conventional HVAC system for cooling: electricity used 65kWh/m²
  - Total cooling:130 kWh/m², COP=2, fans:22kWh/m², pumps:14kWh/m², chiller:29kWh/m²
- THIC system: electricity used 44kWh/m², 32% saved
  - Total cooling:130kWh/m², dehumidifier with fan: 14kWh/m², pumps:15kWh/m², chiller:15kWh/m²
  - Latent heat:35kWh/m², COPL=2.5, sensible heat:95kWh/m², COPs=3.2

Conclusion

- **Huge potential saving in space cooling technology!**
- **Dry regions, ~40% of current cooling applications**
  - **Direct/indirect evaporative cooling instead of mechanical chillers**
  - **System should be well designed both for indoor terminal and heat delivering to adapt "high temperature cooling"**
  - **More than 50% energy can be saved!**
- **Moist regions: east China and US, Japan, south India**
  - **Humidity should be treated independently with temperature**
  - **Desiccant humidity control techniques should be applied for dehumidification**
  - **Sensible heat should be removed with high temperature cooling source**
  - **About 30% saving can be achieved!**

IEA EBC Annex 59

- **High Temperature Cooling & Low Temperature Heating In Buildings (2012-2016)**



This presentation is the summary of EBC Annex 59:

High temperature cooling & low temperature heating in buildings

THANKS

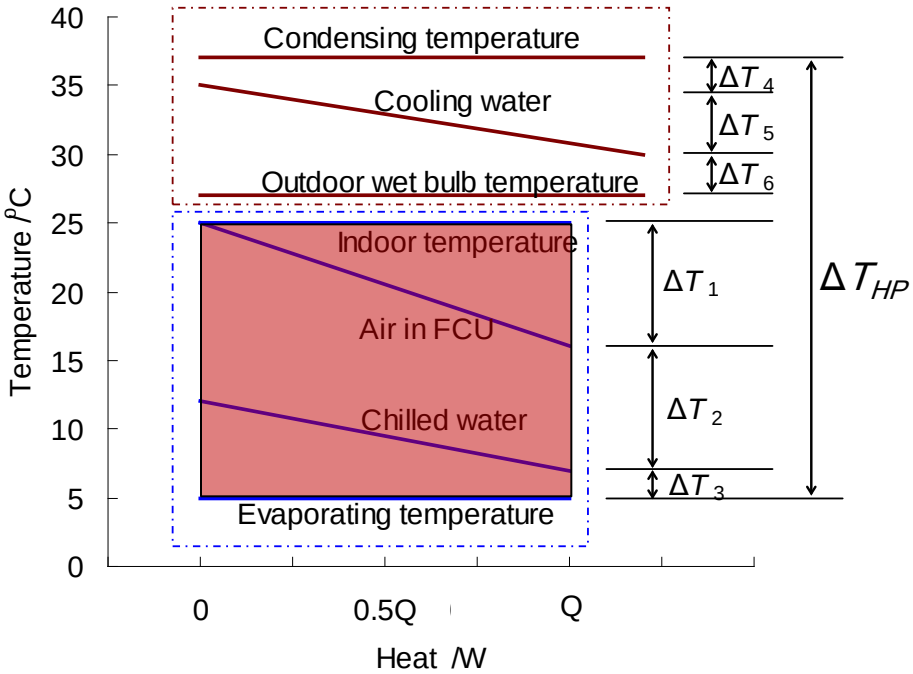
For more information:
jiangyi@mail.tsinghua.edu.cn

EBC
Energy in Buildings and Communities Programme

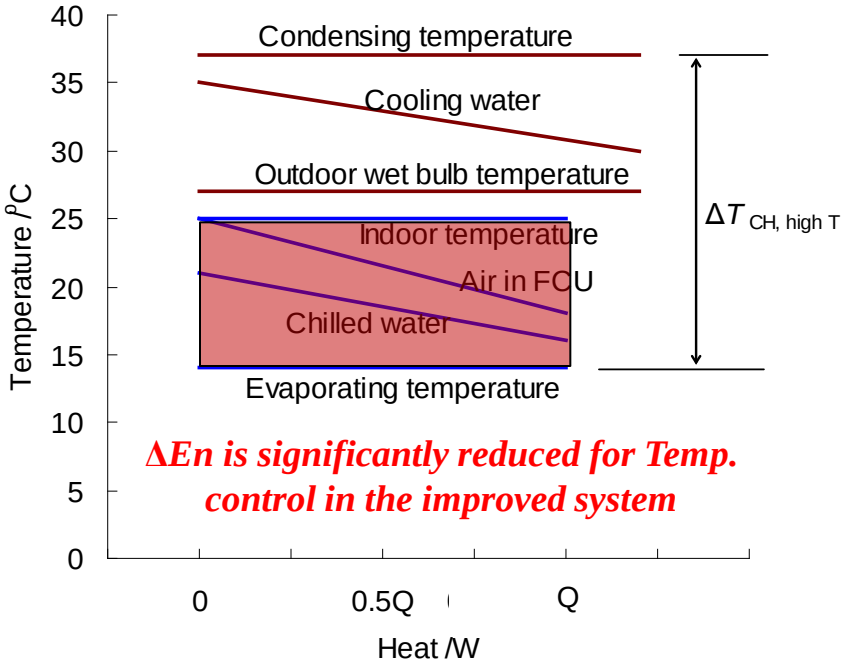
Reducing ΔEn in HV&AC system

2. Coupled Temp. & Humid. control

- Conventional system: coupled control of indoor Temp. & Humid.
- ~7ºC chilled water is required for cooling & dehumidification



Conventional system

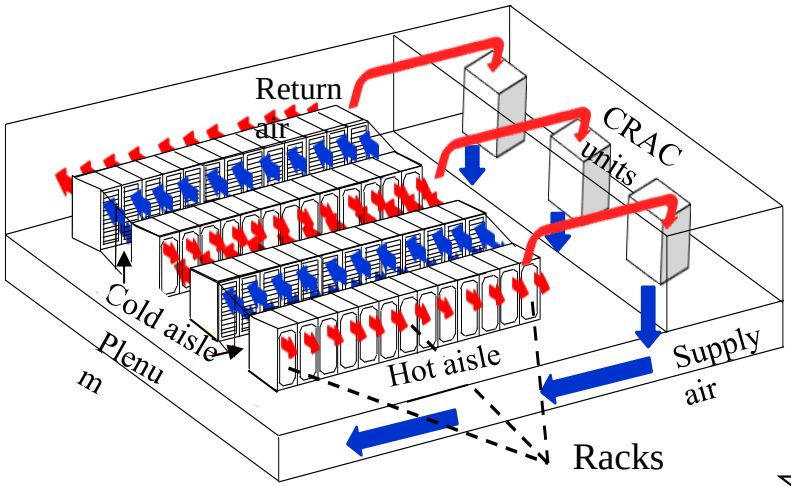


ΔEn is significantly reduced for Temp. control in the improved system

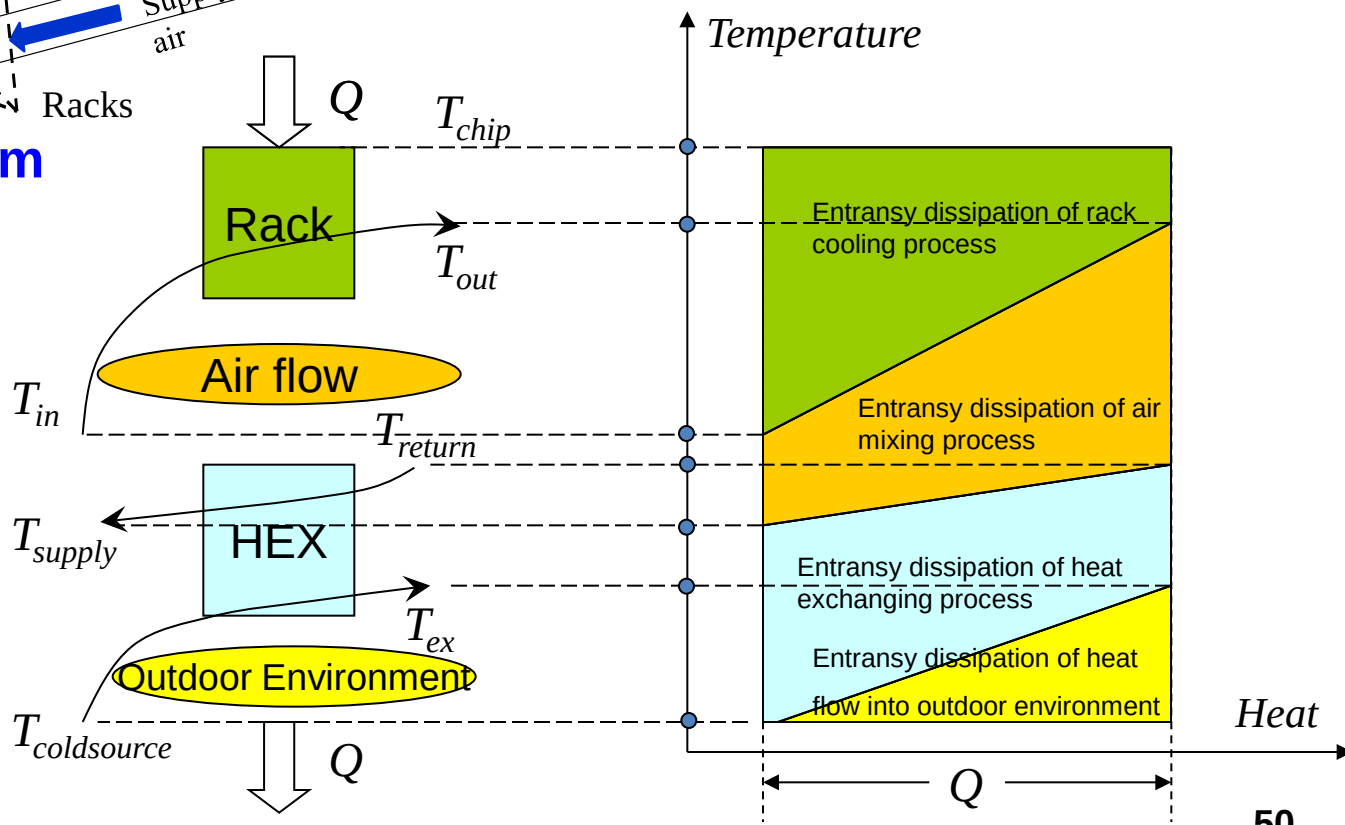
THIC system (for Temp. control)

Adopting other approaches for Humid. control

Application in buildings——Data center

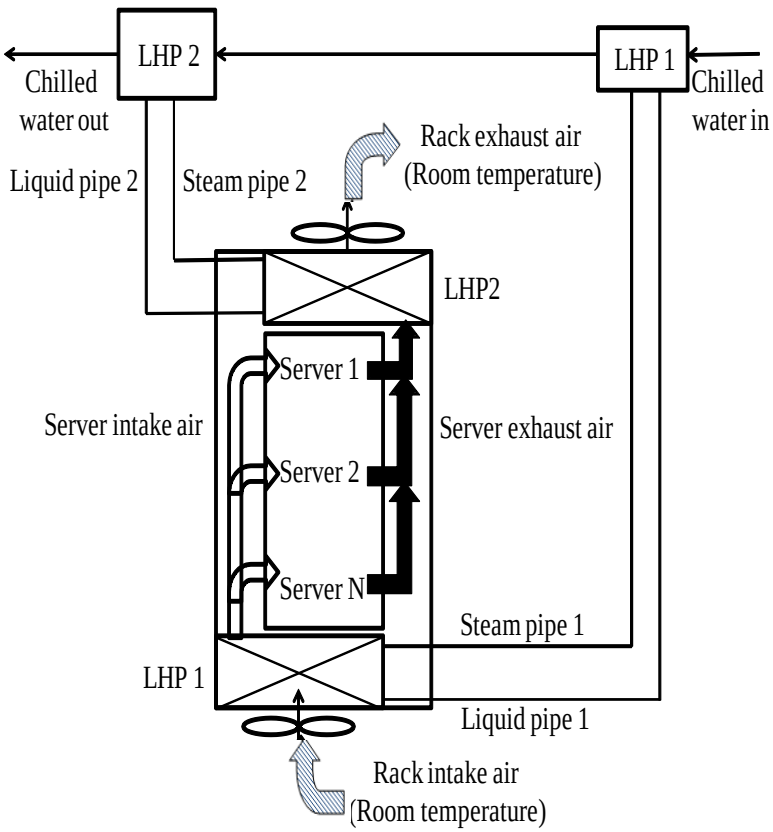


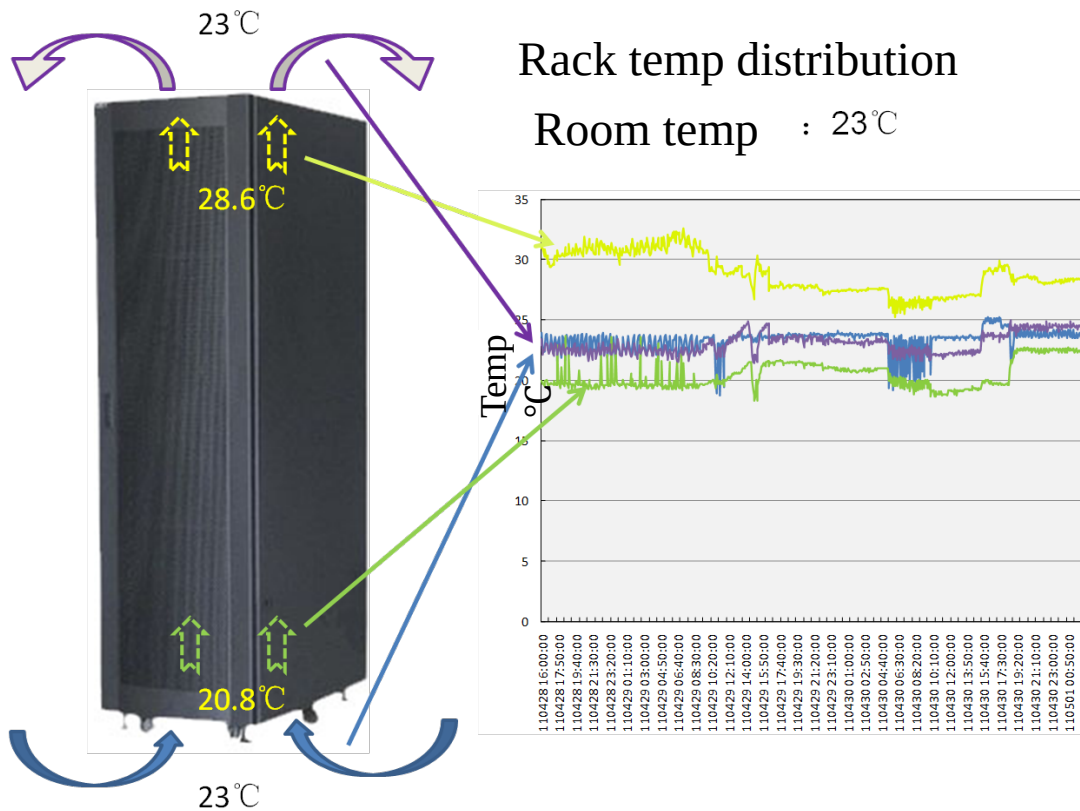
Conventional system



Application in buildings——Data center

Internal cooled new system





Former CRAC

	Compressor power kW	Fan power kW	Server power kW	EER	Indoor air temp ℃	Evaporative temp℃	Supply/ Return air temp℃	Rack inlet/exhaust air temp ℃	Outdoor air dry/wet bulb temp ℃
January 2nd	16.8	4.5	58	2.7	23.5	8.7	14/24	24/33	6 / 0.2℃
May 7th	18.0	4.2	56	2.5	24.6	8.5	15/25	24/33	22 /13℃
August 10th	21.0	4.6	58	2.3	25.0	8.2	14/25	25/34	29 /19℃

Current distributed cooling

Former：rack exhaust T=indoor T +9℃
Current：rack exhaust T≈indoor T

	Cooling tower kW	Chiller 1 power kW	Chiller 2 power kW	Pump power kW	Rack fan kW	Serv pow kW				
January 2nd	2.2	0	0	2	2.9	58	8.2	23.5	9.5/18	23.8/24.2
May 7th	2.2	7.6	0	2	3.1	58	4.0	24.6	12.5/21	24.9/25.3
August 10th	0	6.4	6.8	2	3.1	59	3.2	23.0	9.2/19	23.2/23.8

Former CRAC

	Compressor power kW	Fan power kW	Server power kW	EER	Indoor air temp ℃	Evaporative temp℃	Supply/ Return air temp℃	Rack inlet/exhaust air temp ℃	Outdoor air dry/wet bulb temp ℃
January 2nd	16.8	4.5	58	2.7	23.5	8.7	14/24	24/33	6 / 0.2℃
May 7th	18.0	4.2	56	2.5	24.6	8.5	15/25	24/33	22 /13℃
August 10th	21.0	4.6	58	2.3	25.0				

EER: Increased from 2.6 to 5.7
PUE: Decreased from 1.6 to 1.35

Current distributed cooling

	Cooling tower kW	Chiller 1 power kW	Chiller 2 power kW	Pump power kW	Rack fan kW	Server power kW	EER	Indoor air temp ℃	Supply/Return water temp ℃	Rack inlet/exhaust air temp℃
January 2nd	2.2	0	0	2	2.9	58	8.2	23.5	9.5/18	23.8/24.2
May 7th	2.2	7.6	0	2	3.1	58	4.0	24.6	12.5/21	24.9/25.3
August 10th	0	6.4	6.8	2	3.1	59	3.2	23.0	9.2/19	23.2/23.8