Indirect Evaporative Cooling

Xiaoyun Xie
Building Energy Research Center, Tsinghua University

清華大學
Tsinghua University

Background

- Buildings account for nearly 1/3 of the total energy consumption, **20-30% of building energy is used for air conditioning and maintaining indoor thermal comfort in hot seasons.**
- As predicted, **many regions are going to change from non-air conditioning temperate zones to air conditioning zones, when there is a 2 °C lift** of the average global temperature due to climate change. Especially **for Europe, Southeast Asia, the Middle East, and South America**, as UNEP predicted.
- **Changing the mode of air conditioning is one of the important solutions** to meet the cooling demand without increasing electricity consumption and carbon emission.

Figure 15 • World CO_2 emissions associated with energy use for air conditioning in buildings by source

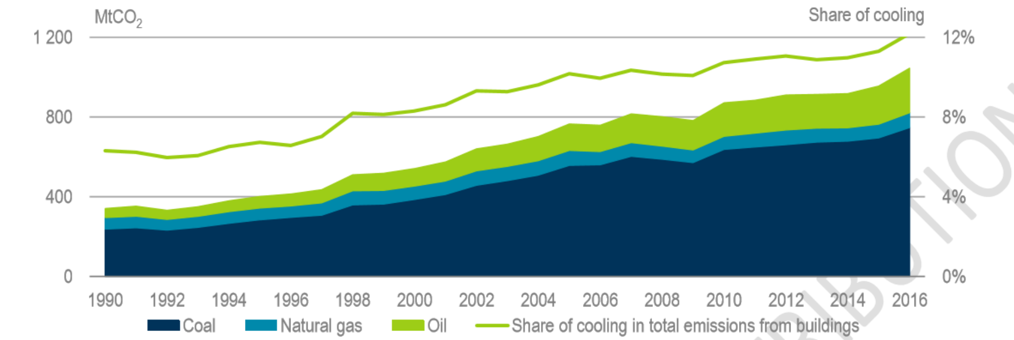


Figure 8 • World energy consumption for air conditioning in buildings by fuel type

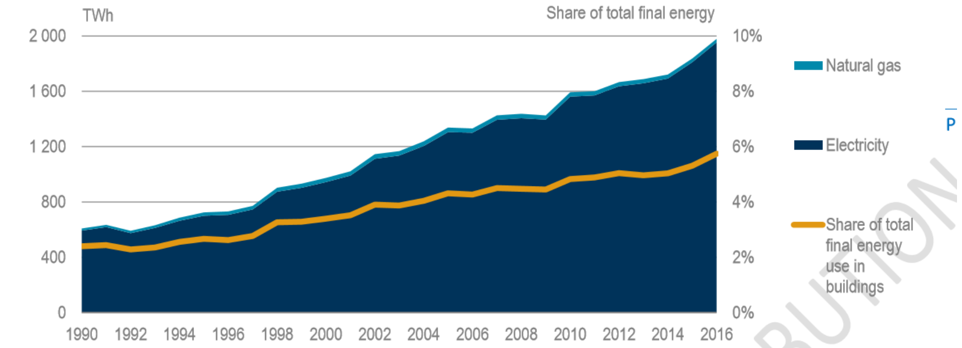


Figure 32 • Cooling capacity of air conditioning equipment in the commercial sector in the Reference Scenario by region

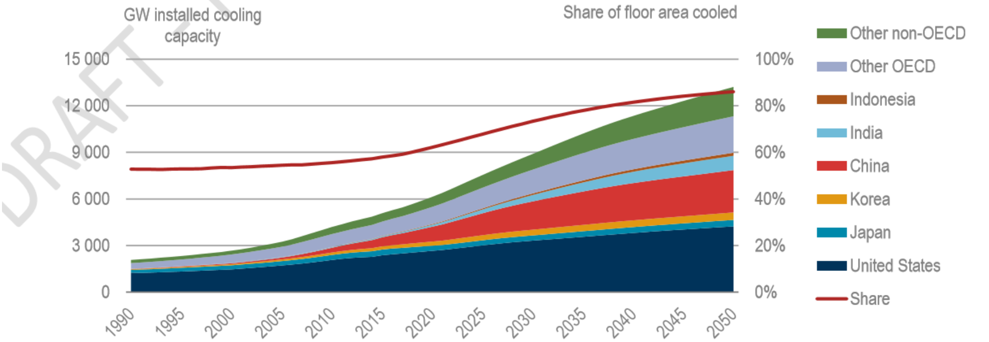
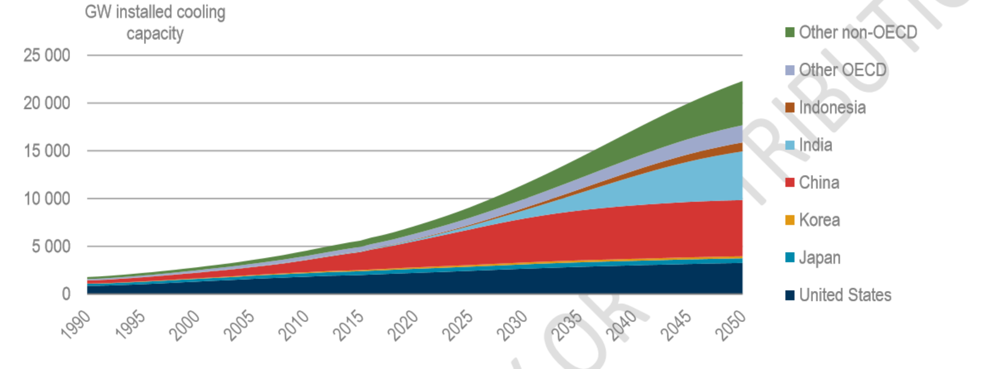


Figure 31 • Cooling capacity of residential air conditioning units in the Reference Scenario by region



Background

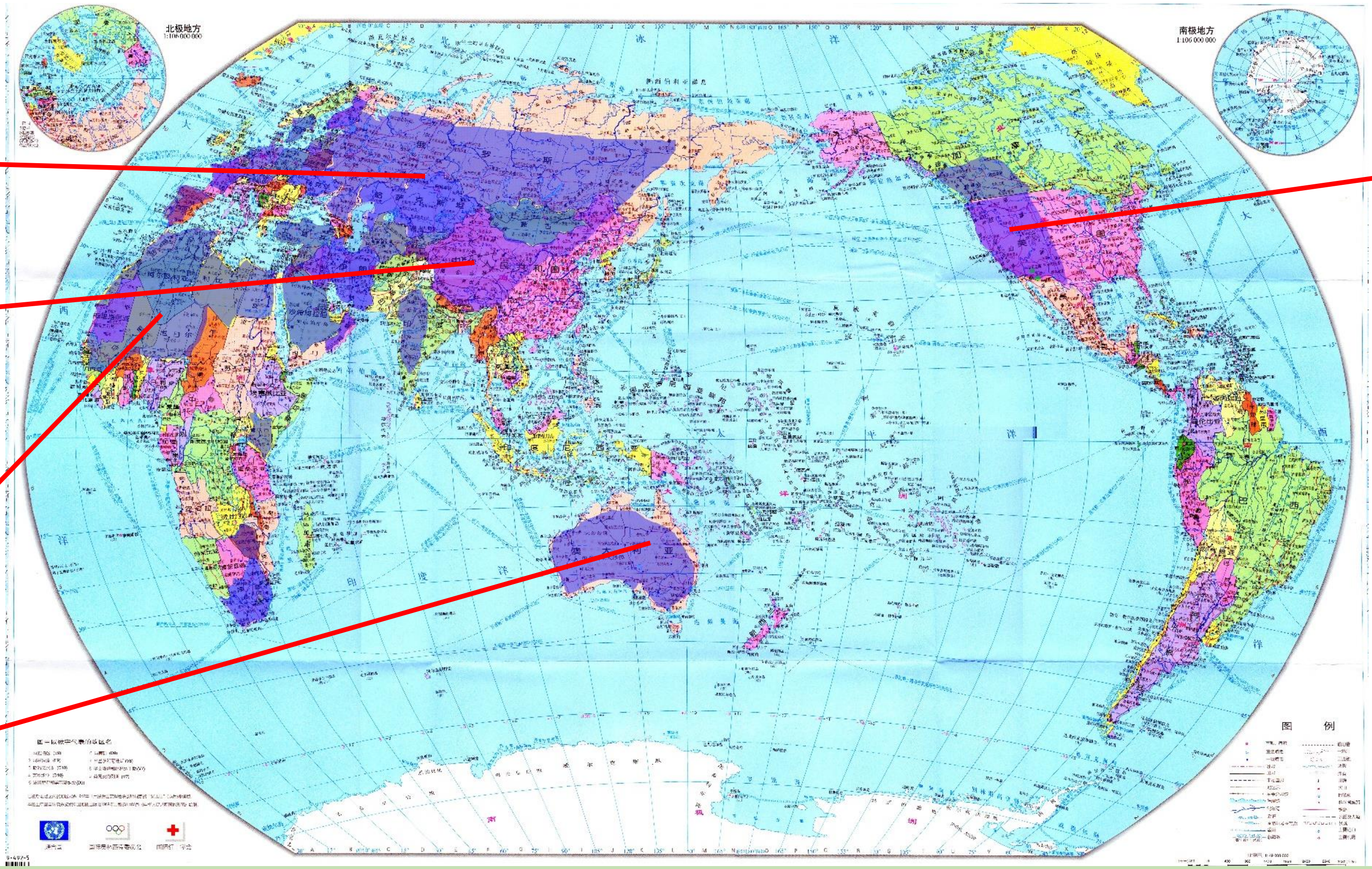
- Although over 85% of cooling around the world is achieved by mechanical refrigeration, more than 40% buildings of the regions where cooling is needed can be cooled by evaporative cooling instead mechanic, due to the dry climates.

Countries in Europe: North France, Germany, Holland, most part in Russia

Asia: North west of China, Mongolia, Saudi Arabia, Kazakhstan, middle of india

North of Africa

Australia

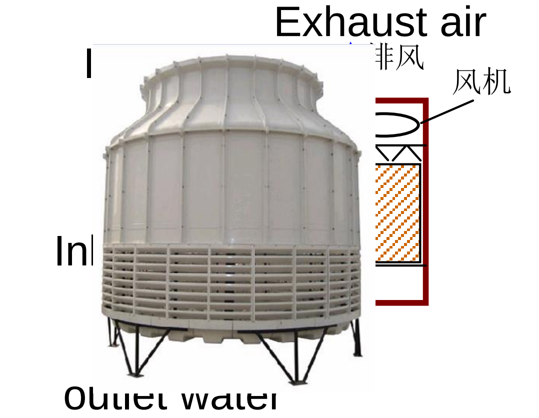
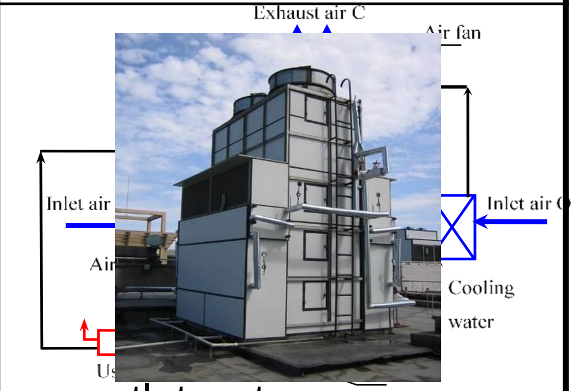


West of the U.S., South west of Canada

Using Indirect Evaporative cooling to substitute mechanical refrigeration in dry regions, with no refrigerants and no CFCs, to save energy significantly.

Evaporative cooling technologies

- Evaporative cooling is to make water directly or indirectly contact with air of low relative humidity, thus water evaporated to realize cooling effect.

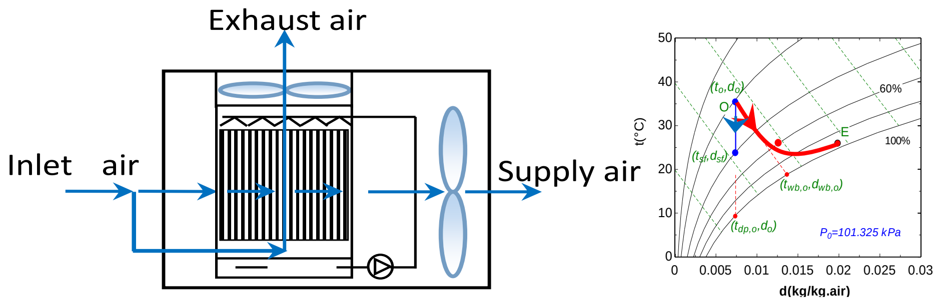
	Direct Evaporative Cooling (DEC) **Limit is inlet wet bulb temperature**	**Indirect Evaporative Cooling (IEC)** **Limit is inlet dew point temperature**
To produce cooling air		
To produce cooling water		

- Using IEC technology, the output temperature of water or air can be 6-10K lower than using DEC technology, and 3-5K lower than the inlet wet bulb temperature, reaching around 14-18℃ at ambient temperature of 35℃-38℃ and relative humidity of 20%-25%.
- Using IEC technology, electricity consumption can be reduced by 40%~70% compared with common mechanical chiller system, and no CFCs used.

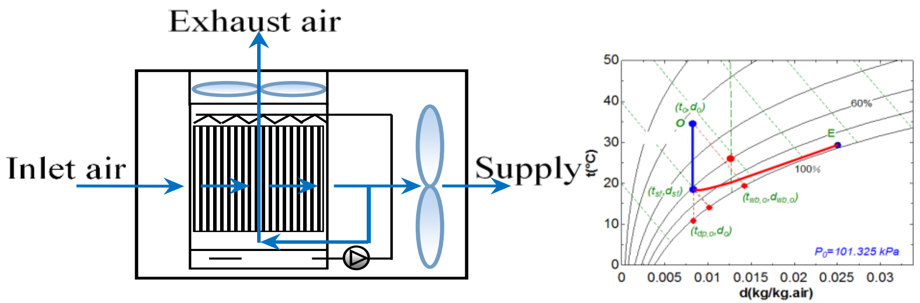
Current situations of IEC technology: IEC air coolers

- **Various kinds of processes:**
  - Different second air conditions
  - Different heat and mass transfer process: Internal three-stream heat and mass transfer and external two-stream heat and mass transfer; countercurrent or crosscurrent;
  - Different process structure: single stage or multi stage;

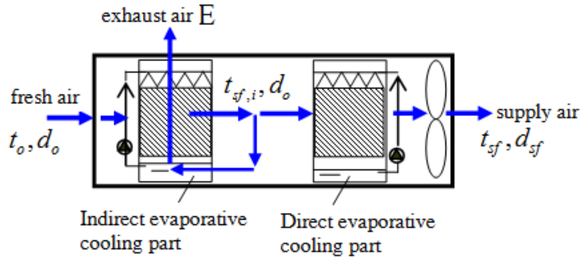
Different processes, with different cooling performance and different outlet cooling air temperature;



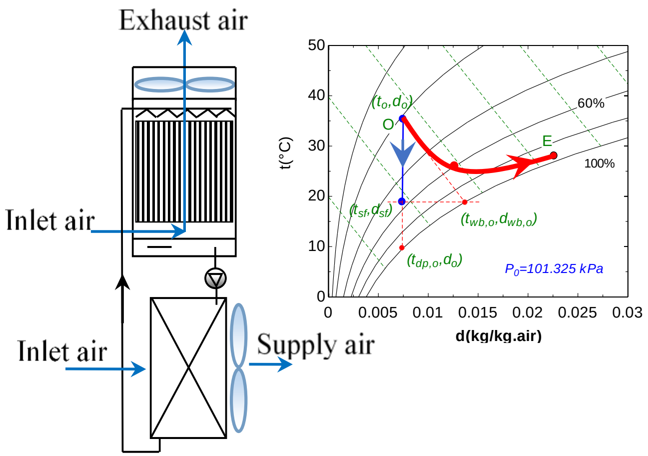
Internal IEC air coolers with inlet air as secondary air



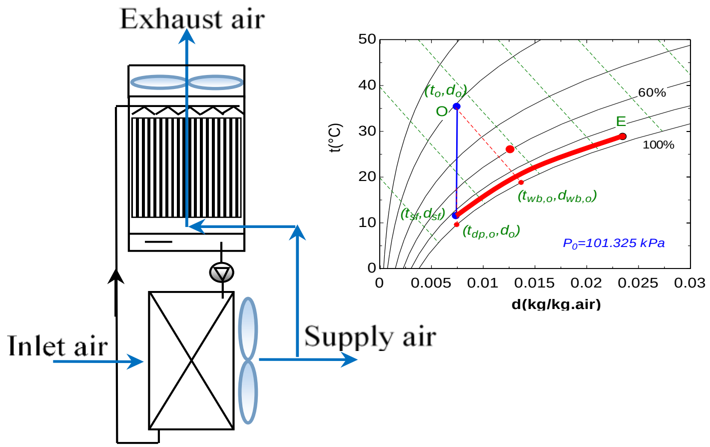
Internal IEC coolers with one part of outlet air as secondary air



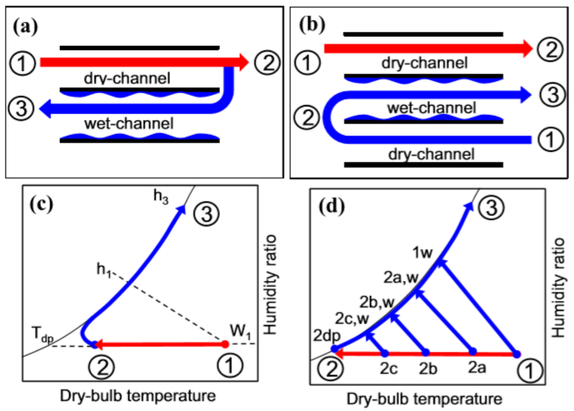
Multi-stage processes



External IEC coolers with inlet air as secondary air



External IEC coolers with one part of supply air as secondary air



M-Cycle IEC air coolers

Current situations of IEC technology: IEC air coolers

- Different technical structures with:
  - different heat and mass transfer forms
  - different heat and mass transfer coefficients
  - different cost of heat transfer area;
  - different size, including the volume and specific surface area

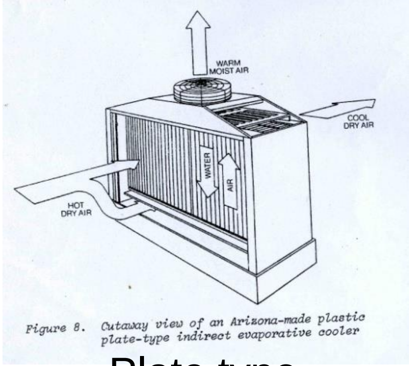
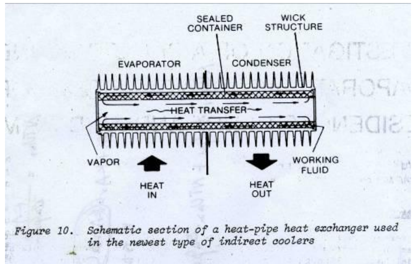
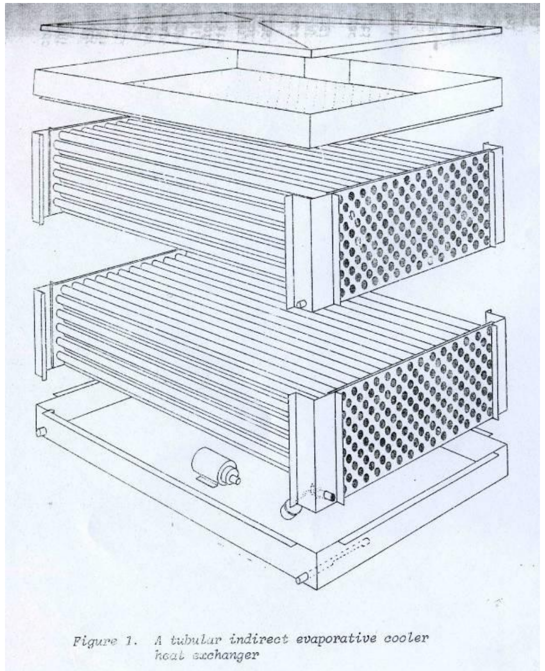


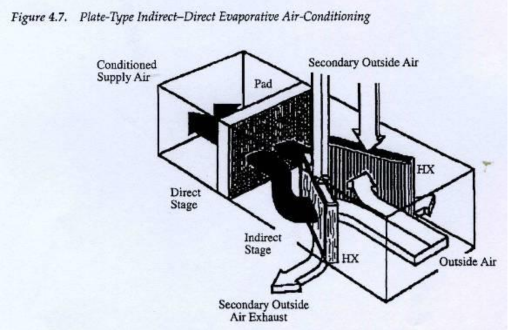
Plate type



Heat pipe type



Pipe type IEC air cooler



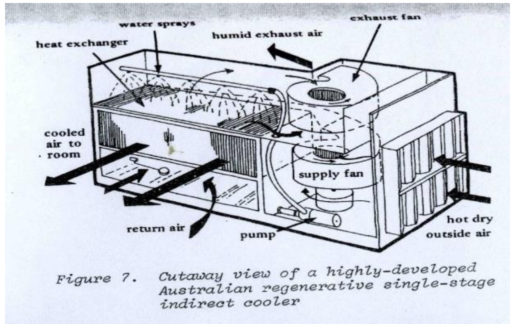
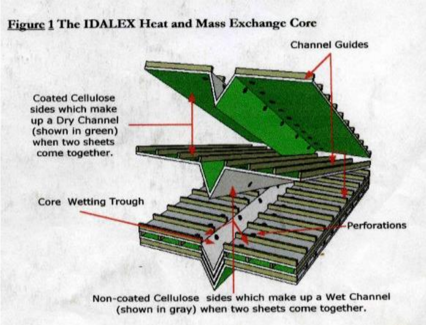
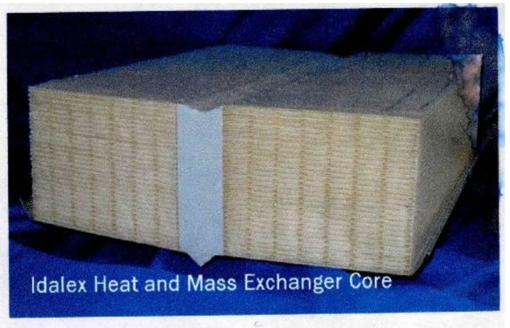
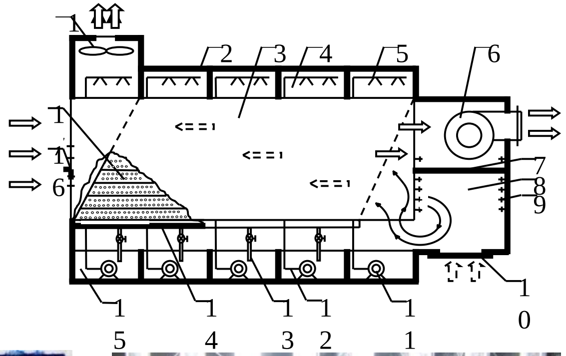


Plate type





M-Cycle core



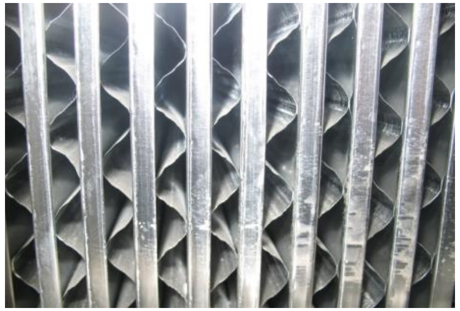


Plate type, internal IEC core

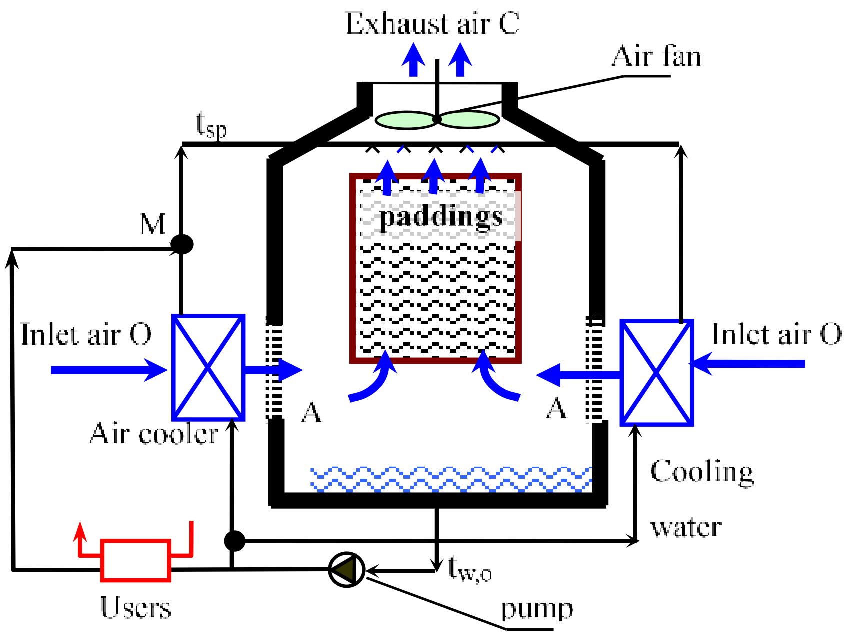
IEC Technology: Applications of IEC air coolers

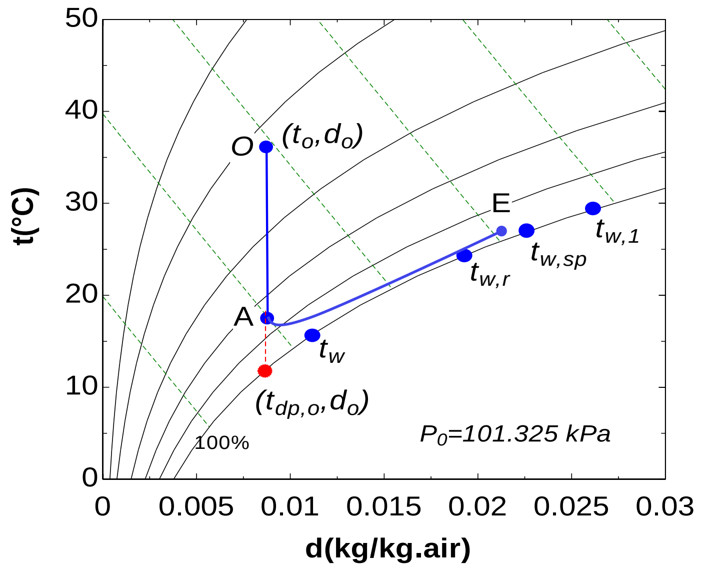
Country	City	type of IEC process	Size(m^2)	Application buildings	air flow rate(m3/h)	wetbulb temperature efficiency
India	Delhi	IEC＋DEC, 3 stages		public buildings	13600~68000, total 4730000(52 projects)	1.15
India	Maharashtra	IEC+DEC	650	exhibition hall	70560	
India		IEC+DEC	650300	plants	67200000	
India		IEC	371.6	plants	23520	
India	Nagpur	IEC+DEC		plants	53760	
India	Pimpri	IEC+DEC	65030	large public building		
Australia	Adelaide	M-cycle IEC		commercial building	19.7kW	1.06
Australia	Adelaide	IEC	4225			
Australia	Roxby, downs	M-cycle IEC	140	resential buildings	10.5kW	1.24
Australia	New South wales	M-cycle IEC				
China	Urumqi	Multi stage IEC	2,000,000	hospital building, high-speed railway station, office building, exhibition centers	20,000,000	1.0~1.2
China	Gansu	Multi stage IEC+DEC	1,700	office building		0.927
China	Xian	Multi stage IEC+DEC	300	plants	30,000	1.29

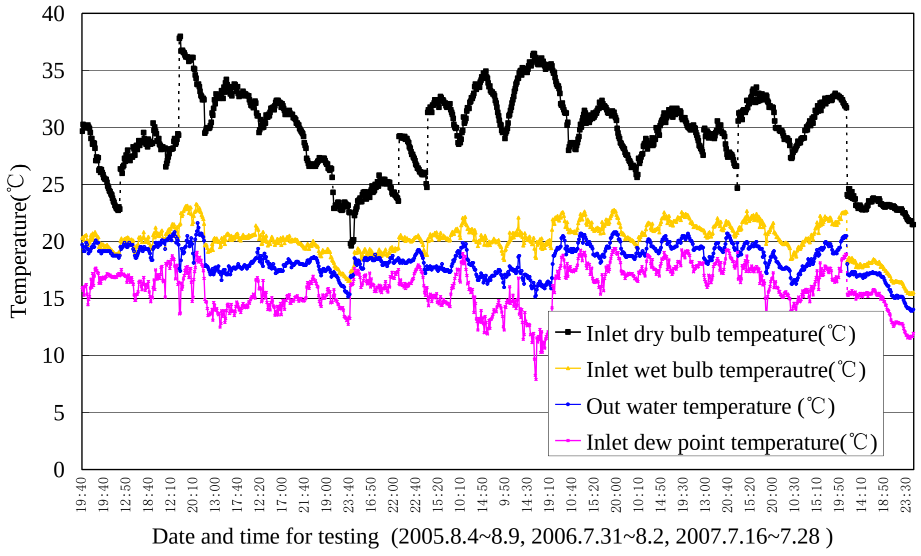
Country	City	type of IEC process	Application buildings	wetbulb temperature efficiency
The United States	Colorado	M-cycle IEC	single house	1.2
The United States	Arizona	M-cycle IEC	single house	1.2
The United States	California	M-cycle IEC	single house	1.2
The United States	Utah	M-cycle IEC	hosipital	1.2
The United States	California	M-cycle IEC	hosipital	1.2
The United States	Watchingt on	M-cycle IEC	hosipital	1.2
Mexico	Mexicali	M-cycle IEC	food plant	1.2
South Africa	Bloemfont ein	M-cycle IEC	restarant	1.2
Kuwait		IEC+DEC		0.9~1.2
Iran	Teheran	IEC+DEC		1.1

Current situations of IEC technology: IEC water chiller

- Introduced by Prof. Yi Jiang in 2002, China, to produce the cooling water by near reversible process, with limit out water temperature to be outdoor dew point temperature.



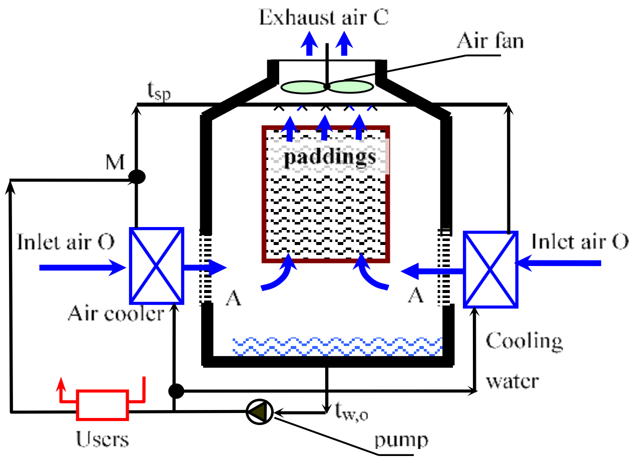




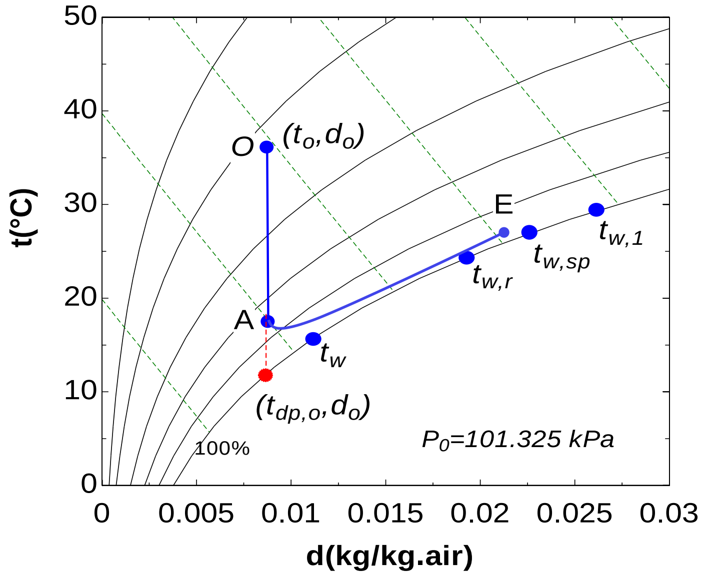
- **Key processes:**
  - to cool the inlet air to make it near the saturation line through a countercurrent air cooler by part of the produced cooling water;
  - to produce cold water by a counter current padding tower;
  - flow rate ratio matching design for each of the heat transfer or heat and mass transfer process.

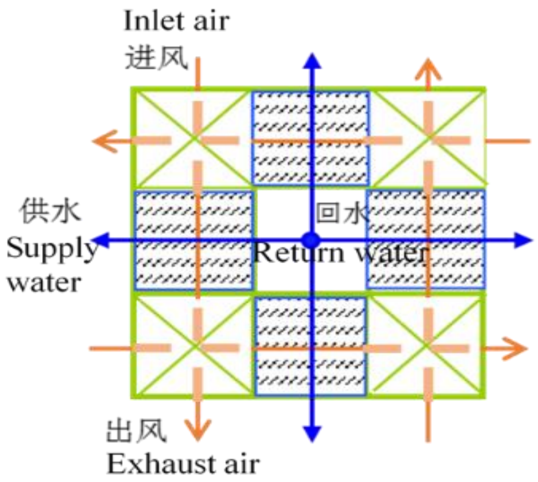
Current situations of IEC technology: IEC water chiller

- Different process structure of IEC chiller
- IEC chiller I:
  - The limit outlet water temperature is outdoor dew point temperature
  - The total cooling energy produced by the padding tower is higher than the output cooling energy;
- IEC chiller II:
  - The limit outlet water temperature is higher than outdoor dew point temperature
  - The total cooling energy produced by the padding tower is equal to the output cooling energy;

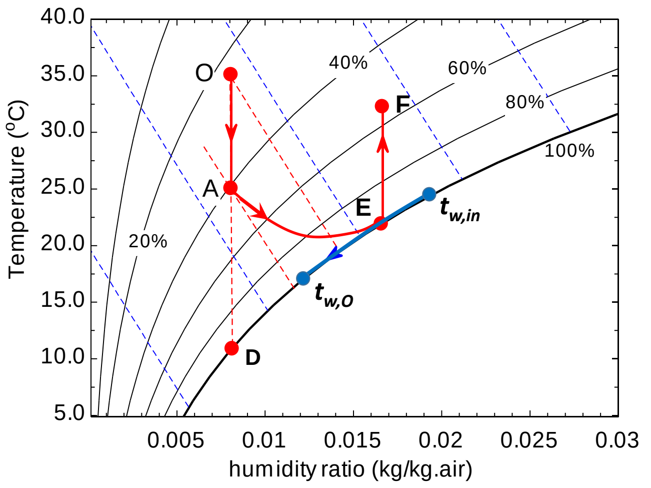


IEC chiller I





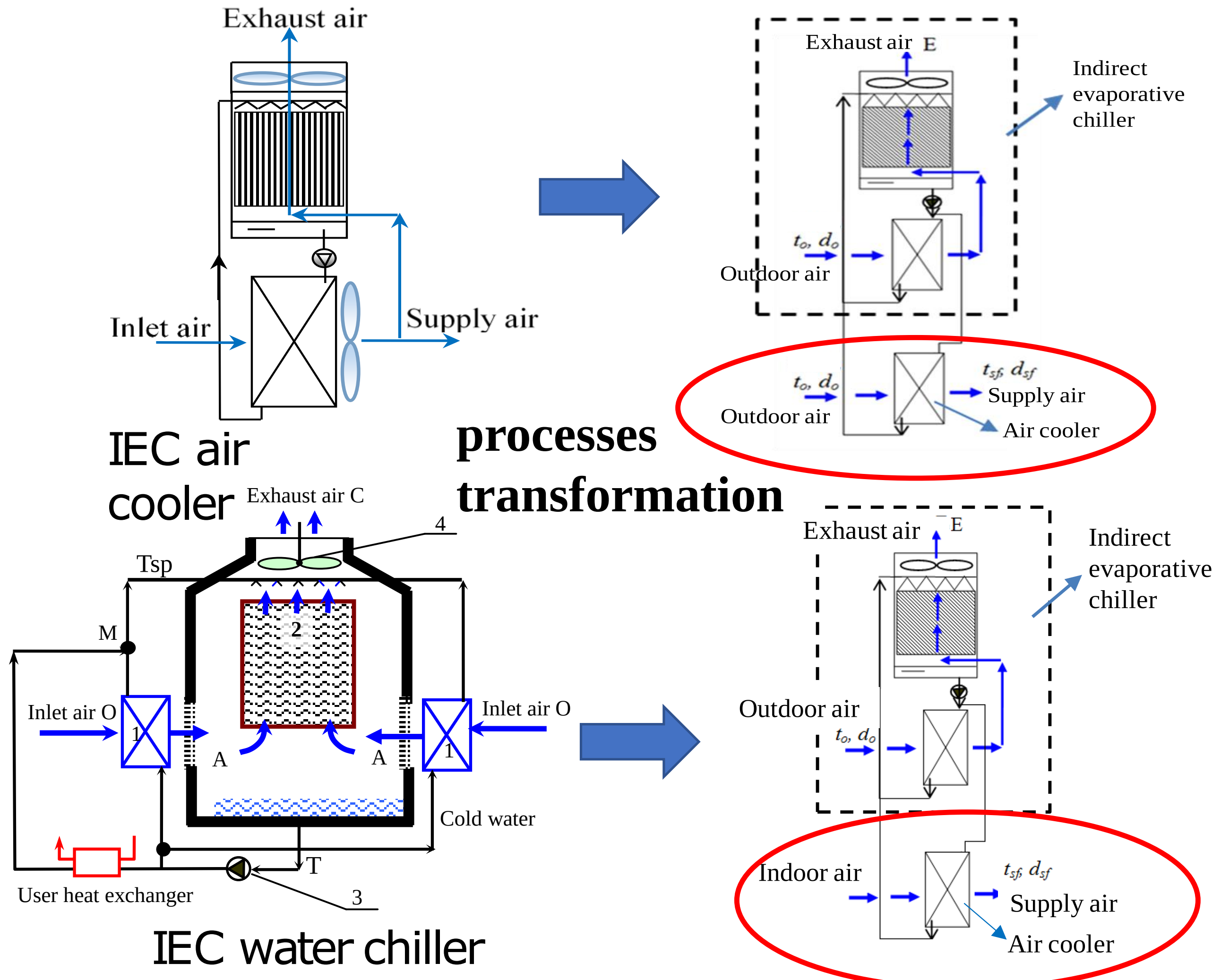
IEC chiller II



To remove indoor sensible heat: IEC water chiller OR IEC air cooler?

- For the IEC cooling system to remove indoor sensible heat, choose the IEC cooling air system or IEC water chiller system, which one is better?

Theoretical research of the process:

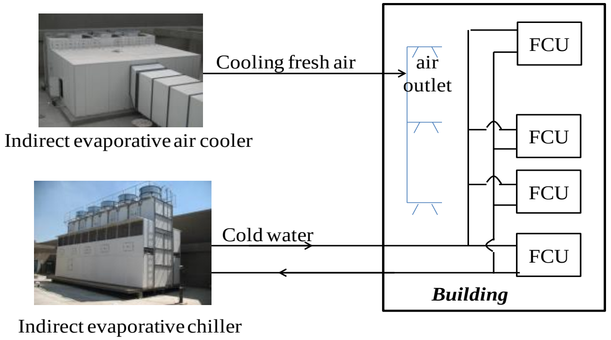


To remove the same quantity of indoor heat:

- The process produced cooling energy IEC air cooler is larger than IEC water chiller, when outdoor air is hotter than indoor air, the difference is the outdoor air heat load of IEC air cooler.
- Thus, larger heat transfer area and larger cost when using IEC air cooler to remove indoor sensible heat.

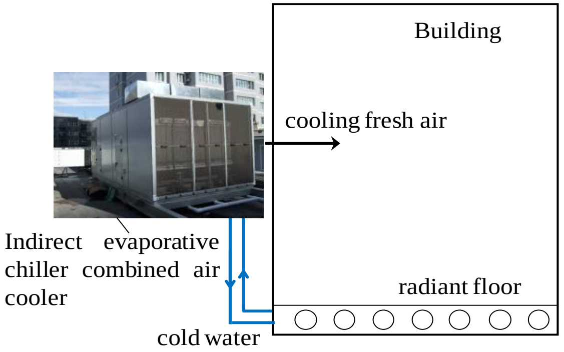
To remove indoor sensible heat: IEC water chiller OR IEC air cooler?

- Comparison based on real applications of IEC water chillers and IEC air coolers



Sensible heat removed by cold water (kW)	Electricity consumption of Fan of IEC chiller (kW)	Electricity consumption of water pump (kW)	Electricity consumption of Fan-coils(kW)	Water system COP to remove indoor sensible heat
219	13.8	14.9	19.2	4.6

Fresh air supply (m3/h)	Sensible heat removed by cooling air (kW)	Electricity consumption of IEC air cooler(kW)	Electricity consumption of supply air fan (kW)	Air system COP to remove indoor sensible heat
88000	169	13.5	28.3	4.05

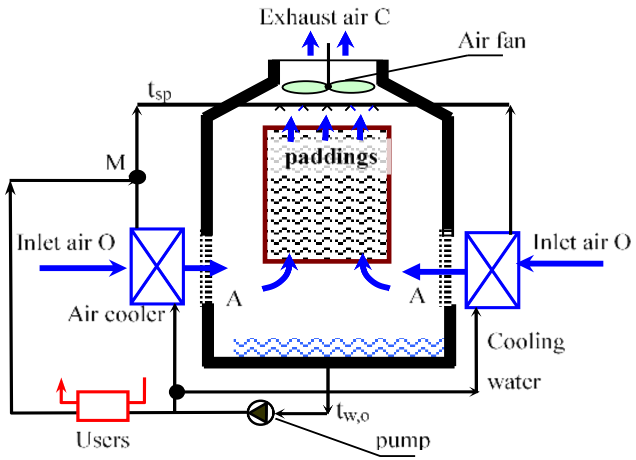


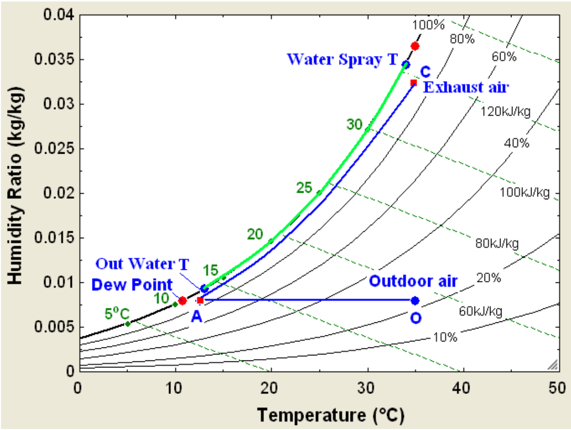
Sensible heat removed by cold water (kW)	Electricity consumption of Fan of IEC chiller (kW)	Electricity consumption of water pump (kW)	Electricity consumption of radiant floor (kW)	Water system COP to remove indoor sensible heat
20.3	1.4	2.16	0	8.23

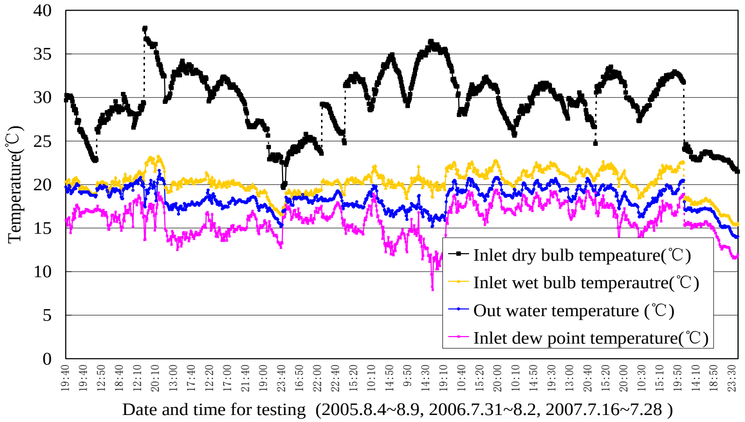
Fresh air supply (m3/h)	Sensible heat removed by cooling air (kW)	Electricity consumption of IEC air cooler(kW)	Electricity consumption of supply air fan (kW)	Air system COP to remove indoor sensible heat
8400	10.8	2.0	1.76	2.9

Development of IEC water chillers

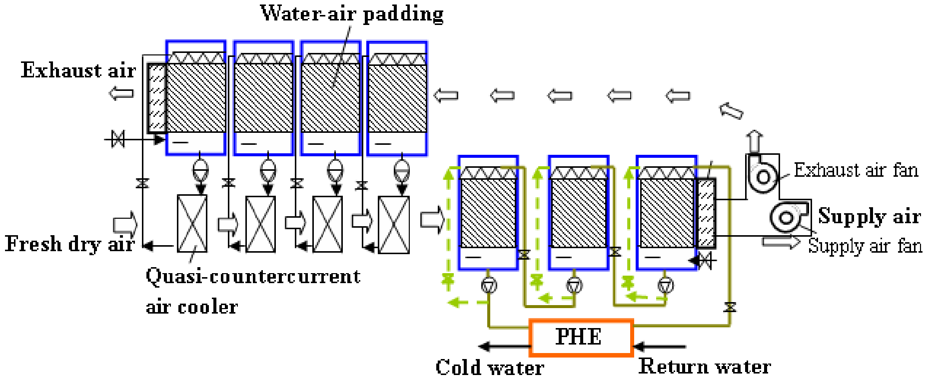
- Present the innovative indirect evaporative cooling concept and the technology to produce cold water, developed the first indirect evaporative chiller in 2005. Produces cold water with temperature lower than outdoor wet bulb temperature and limit to outdoor dew point temperature.

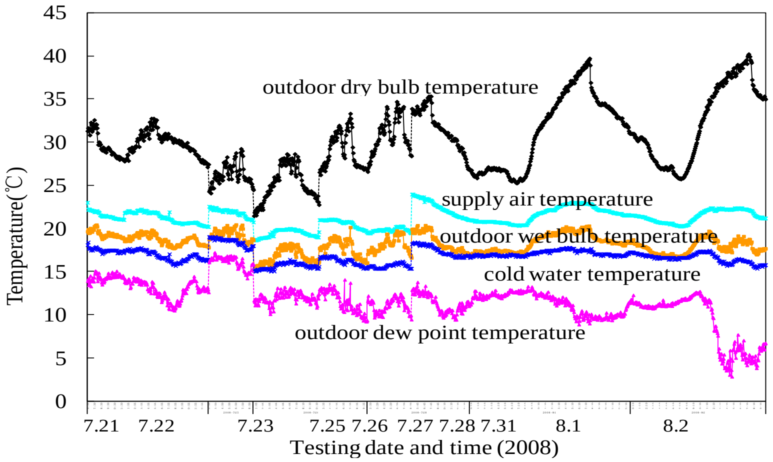






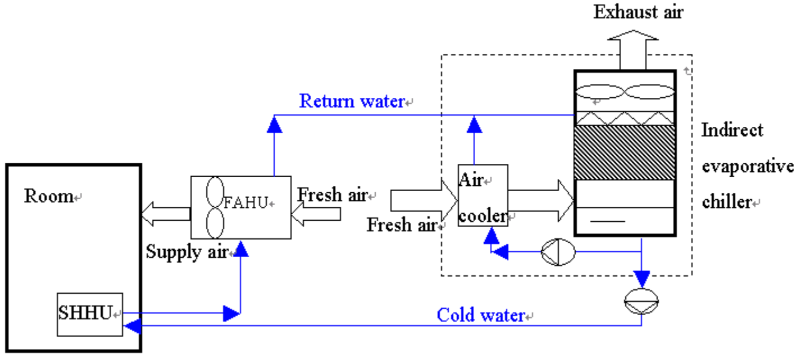
- Present the IEC water chiller combined air cooler processes, and developed the first device in 2008, produces cold water with temperature lower than outdoor wet bulb temperature and cooling air with temperature more or less at wet bulb temperature.

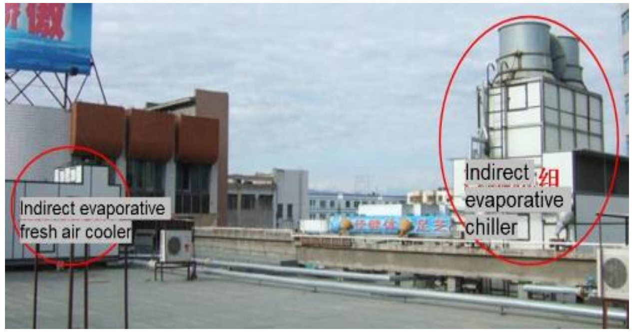


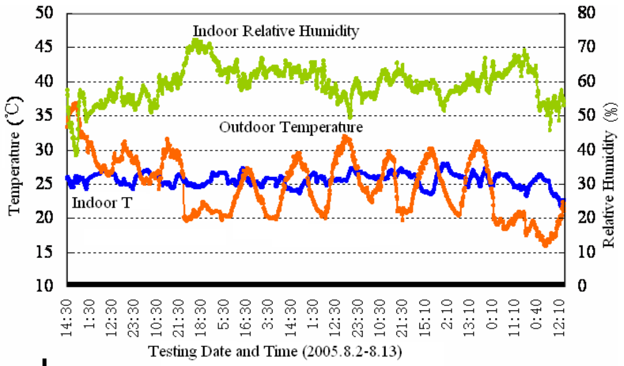


Applications of different IEC water chillers systems

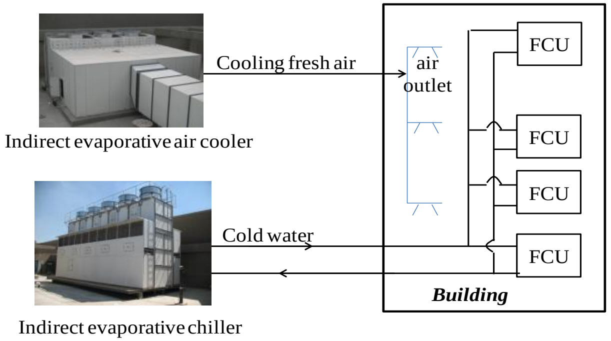
- Different kinds of IEC systems design and optimization and final realized in real applications.

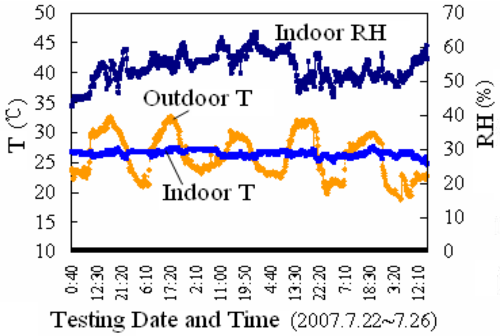




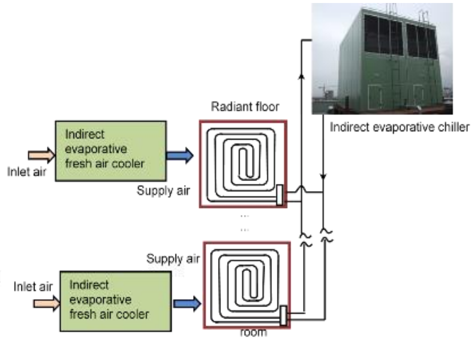


Serial water cycle system using IEC water chiller, with FCUs as terminals.

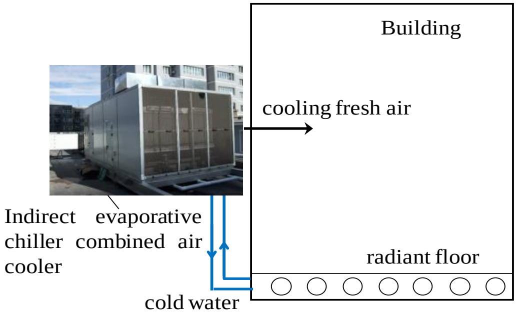


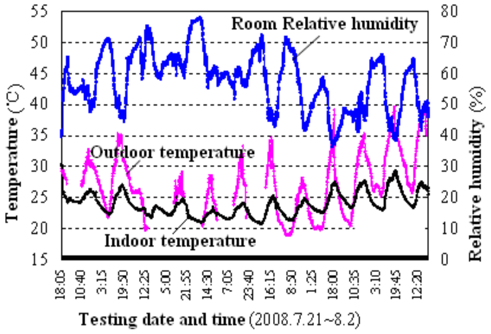


Parallel water cycle system using IEC water chiller, with FCUs as terminals.

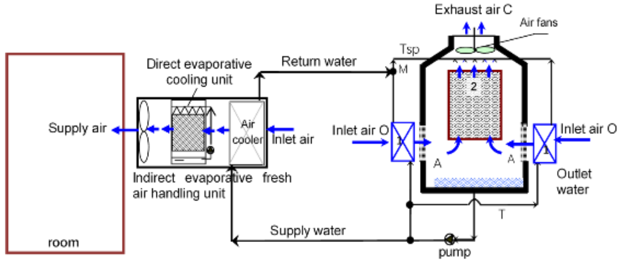


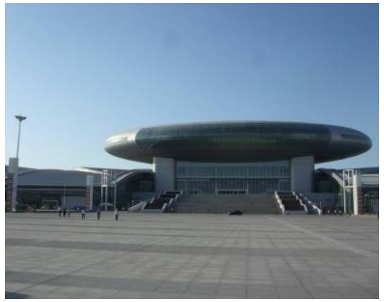
IEC water chiller system using radiant floor as terminals





IEC water chiller combined air cooler system





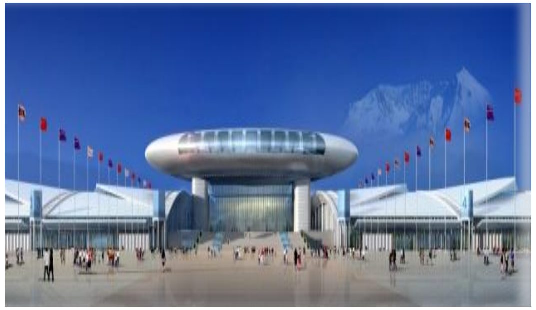
All fresh air system using IEC water chiller

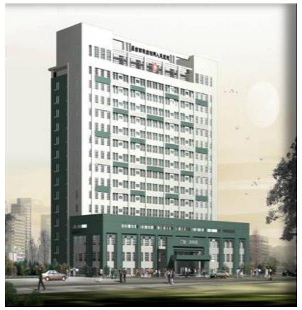
Applications of IEC water chillers

- IEC water chillers, mainly applied in northwest of China, totally more than 2,000,000m^2, as the cooling source for large public buildings, instead of mechanical chillers.


Shihezi Kairui Hotel, 2005, 3000m^2;

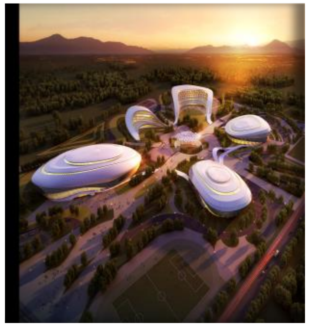

Hospital, 2007, 46093 ㎡


International exhibition center, 2008~2010, 110767㎡


Hospital , 2009, 25195.6 ㎡


Hospital , 2012, 49200 ㎡


Office building, 2014, 7668 ㎡

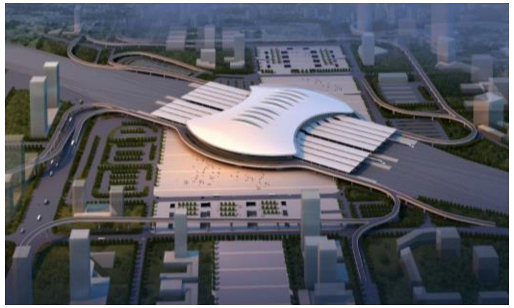

Sports field, 2014, 75146 ㎡


Theater, 2015, 28654㎡

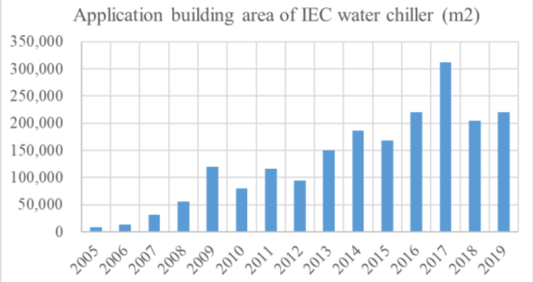

Art Center, 2017, 78219㎡


Office Building, 2015, 190000㎡


Detection Building, 2018, 452000㎡


High Speed railway station, 2015, 99982 ㎡

Industry cooling system



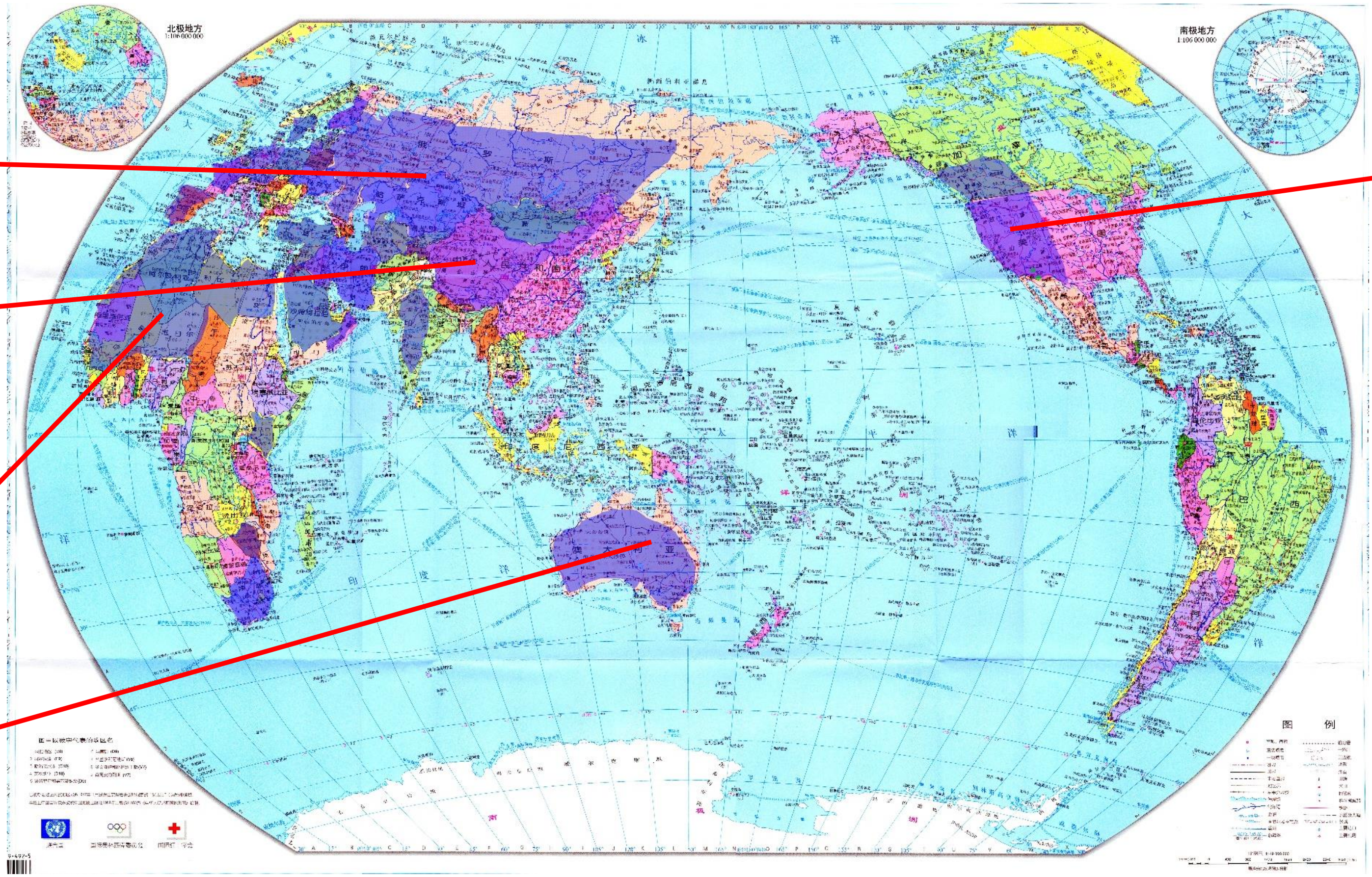
The preliminary performance analysis of IEC technology applied in the world

Countries in Europe: North France, Germany, Holland, most part in Russia

Asia: North west of China, Mongolia, Saudi Arabia, Kazakhstan, middle of india

North of Africa

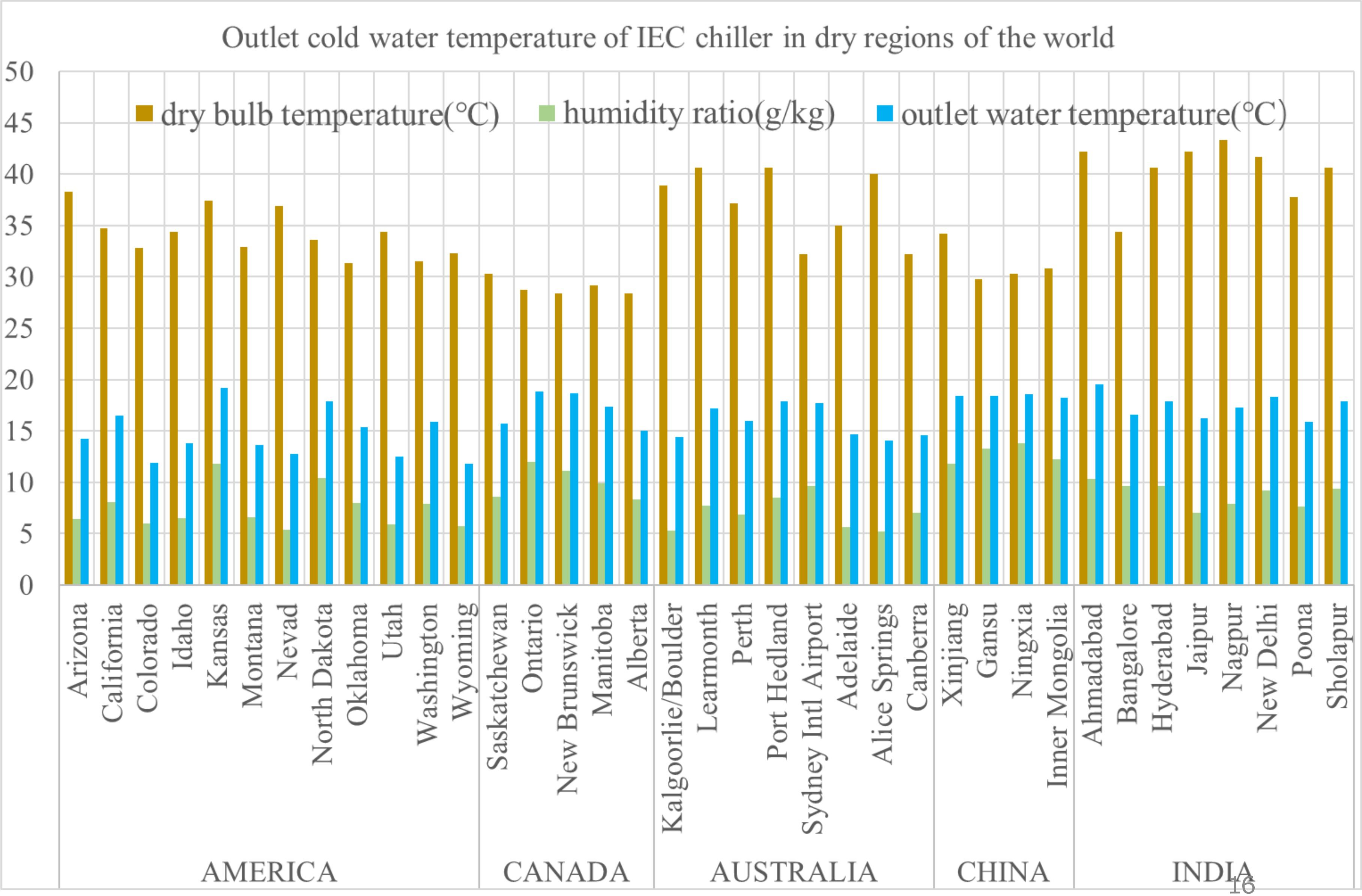
Australia



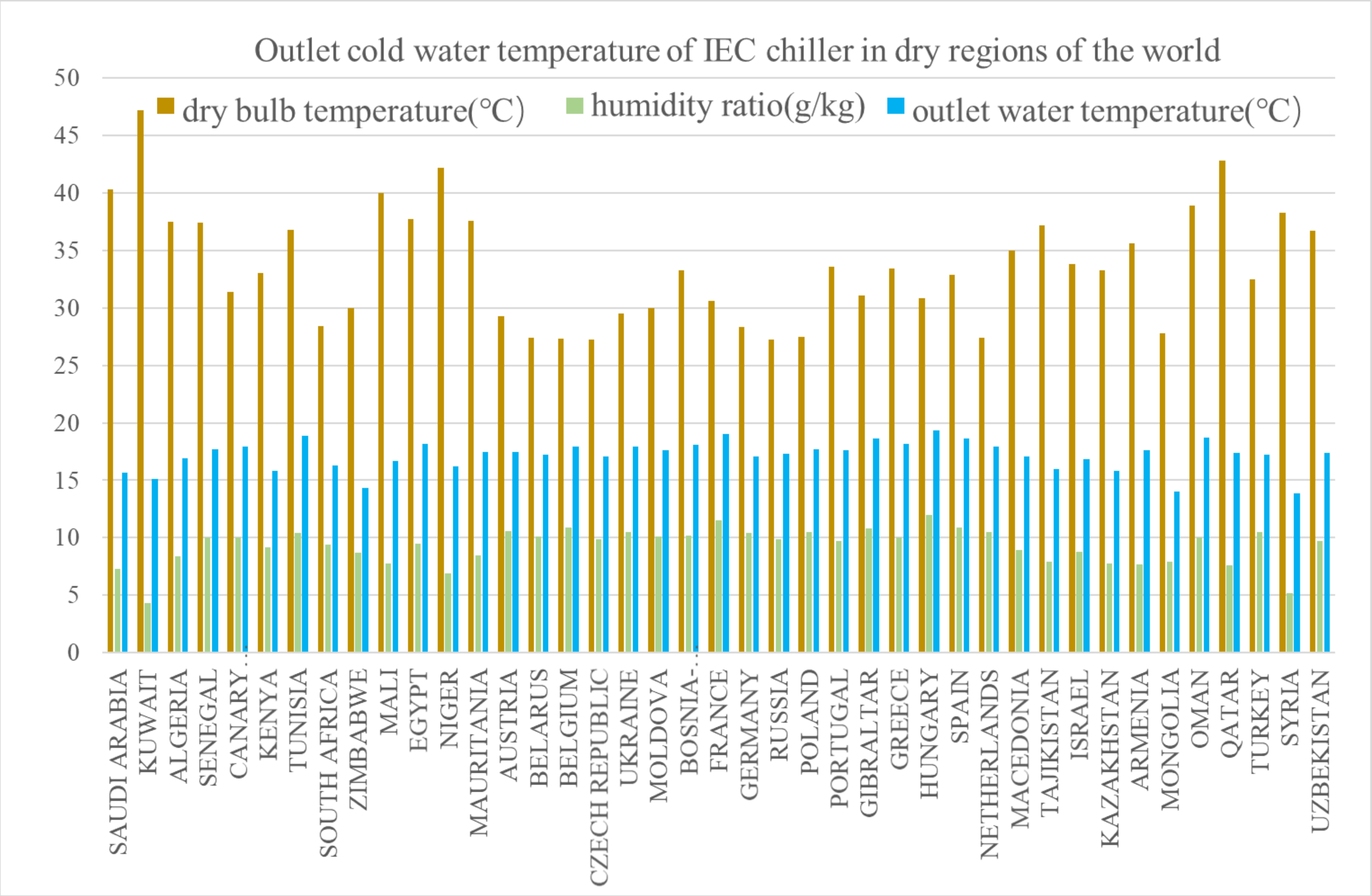
West of the U.S., South west of Canada

The preliminary performance analysis of IEC technology applied in the world

- Take the IEC technology to produce cooling water, called IEC chiller for example, the outlet water temperature is shown as the right figure.



IEC Technology



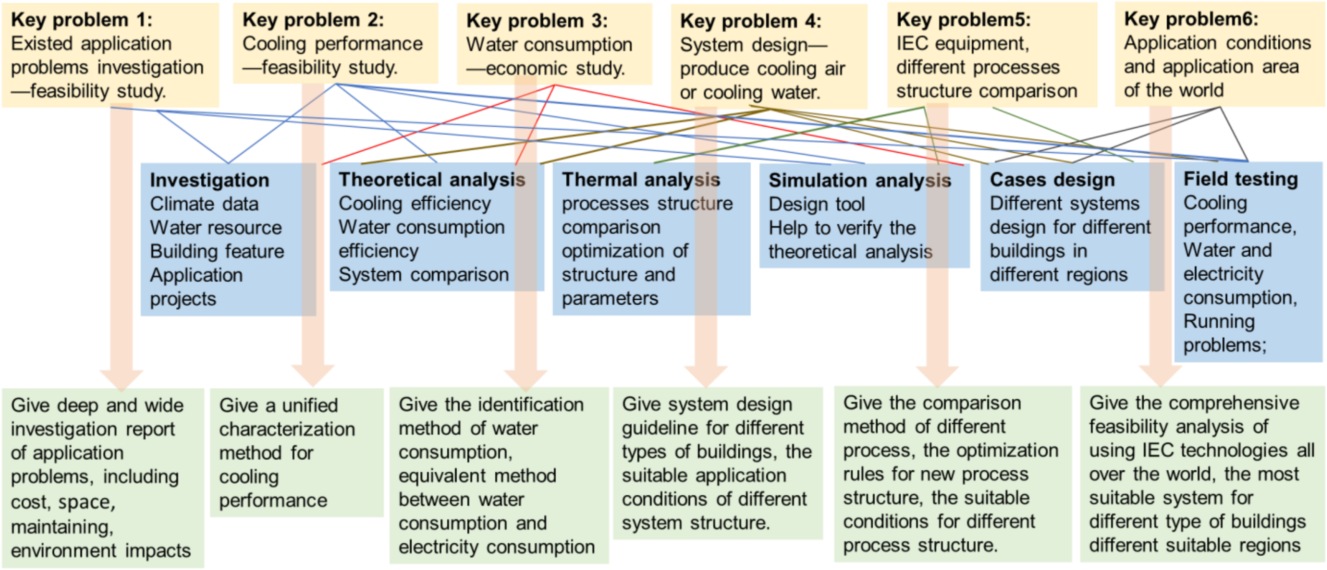
Huge potential to use IEC technology to substitute mechanical cooling and significantly reduce the energy use for cooling.

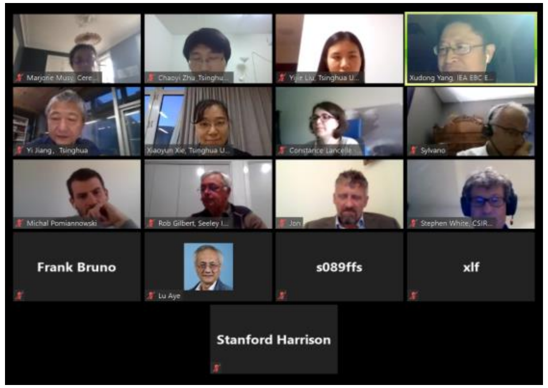
IEA-EBC Annex 85 : **Indirect Evaporative Cooling**

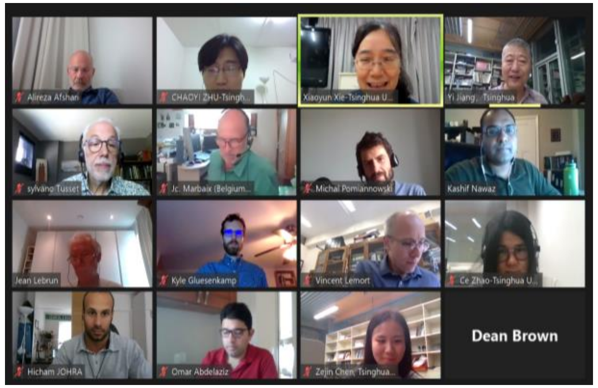
ANNEX 85

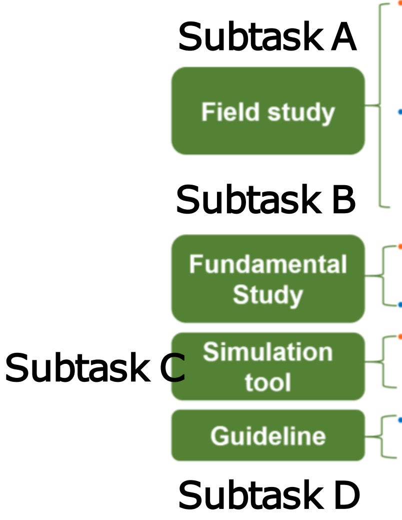
iea EBC Energy in Buildings and Communities Programme

- IEA EBC Annex 85: Indirect Evaporative Cooling
  - **Operating Agent:** Xiaoyun Xie, Tsinghua University
  - **Participating countries:** **Australia, Belgium, China, Denmark, Egypt, France, USA.**
  - **Project period:** 2020-2025
  - **Main objective:** study the feasibility and provide the roadmap of using indirect evaporative cooling technology in different dry regions of the world.









- **Carry out deep and wide investigation of IEC systems as well as for cooling towers,** including cost, space, maintaining, and environment impacts(noise, legionella and so on), **to find out the main reasons for why the IEC technologies have not been widely used.**
- **Carry out field testing of existing IEC systems applied in different climates to obtain real-world running data.** Existing projects can be found in northwest of China, western U.S., Europe, Australia, and other dry regions. Analyze the data and provide guidance for system improvement or optimization.
- **Develop the general theoretical analysis method of IEC processes, to guide the design of different IEC systems used in different dry climates.**
- **Evaluate the water and electricity consumption of IEC processes.**
- **Set up the system simulation model and tool for different kinds of IEC processes and systems** used in different kinds of buildings under different dry climates.
- **Develop a guideline for designing the IEC systems for different types of buildings** under different dry climates and water resource conditions.

清华大学 Tsinghua University

Full Annex proposal
Preparation (draft Annex text)

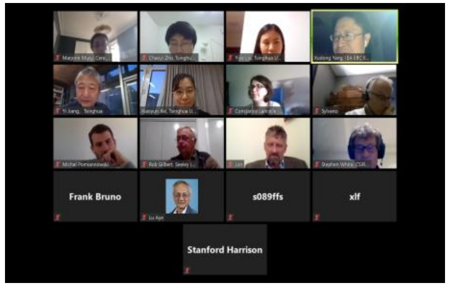
11th June 2020

EBC project Concept
Determine to develop a full proposal

13th Nov 2019

The first workshop
Determine the subtasks and the participants of each subtask

20th April 2020



Australia, Belgium, China, Denmark, France, United States

IEA-EBC Exco meeting
Approved as **Annex 85**

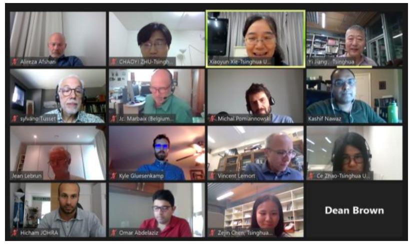
26th June 2020

Technology Readiness Preliminary Assessment

One-year preparation phase starting in **July 2020**

Online workshop
- Exchange current study related to IEC
- Activate preparation phase

11th September 2020

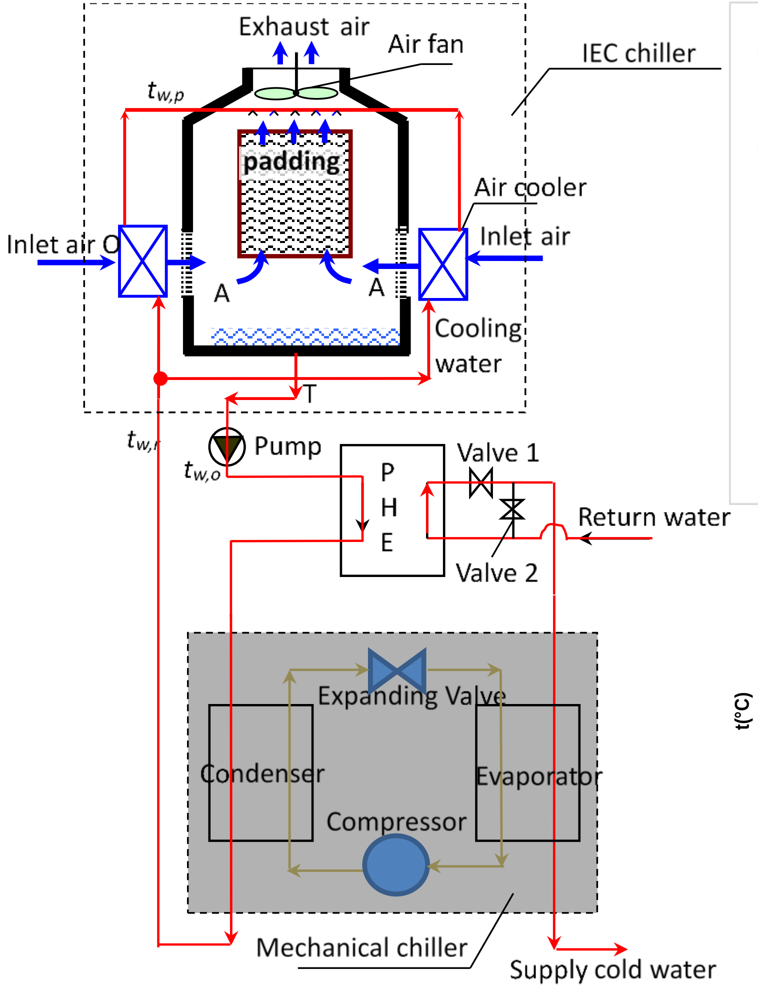


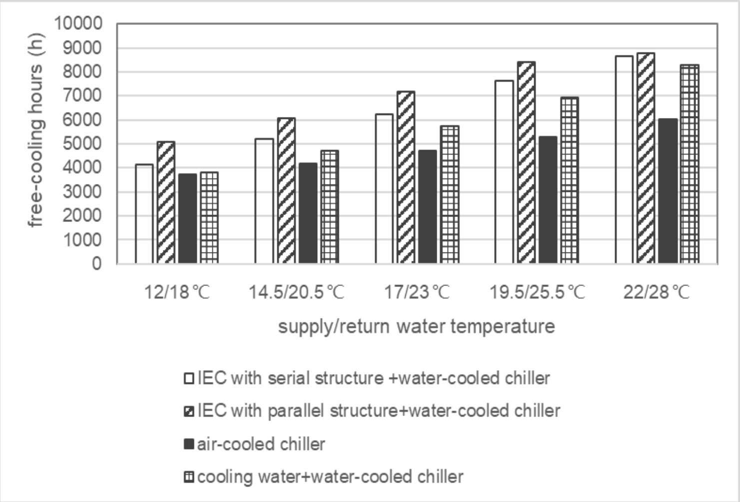
Tsinghua University

Indirect Evaporative Cooling used in Data center cooling

For all year industry cooling, such as data center cooling, to increase free cooling hours:

- Indirect Evaporative chillers for all year free cooling, with design of high temperature cold water;
- Indirect Evaporative Chillers combined with mechanical chillers, with design of low temperature cold water;
- In very cold winters, using Indirect Evaporative Chillers to realize zero freezing.

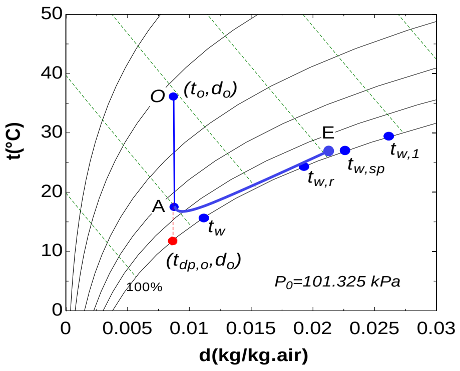




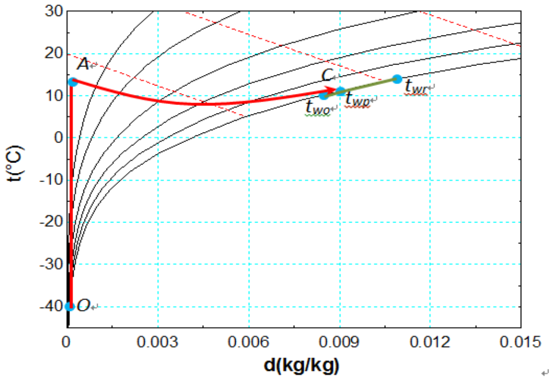
Freezing of common cooling towers

Indirect Evaporative cooling towers

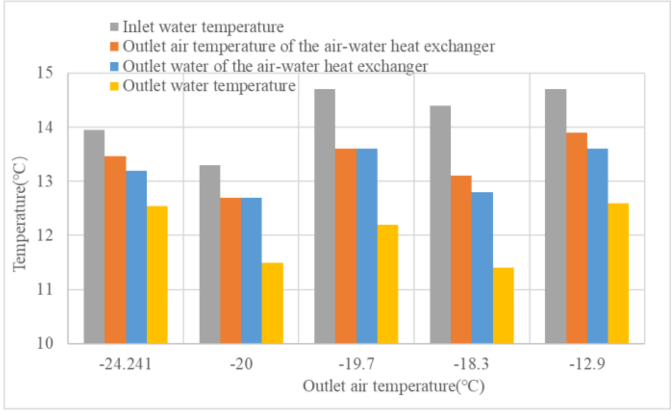
Free cooling hours of different systems



Summer condition



winter anti freezing process



Real testing of no freezing process

Conclusions

- Indirect Evaporative Cooling technologies would be one of promising technologies to substitute common mechanical chillers, with no CFCs, to meet the cooling demand without increasing electricity consumption and carbon emission;
- IEC technologies have been researched, developed and applied in some of the dry regions of the world, however not very widely, which need to be pay more attention and finally to give solutions to promote the applications.
- IEC water chillers could be also used in industry cooling, such as data centers, to save electricity consumption, as well as to avoid ice for common cooling towers in cold seasons.

Thank you very much for your attention.

xiexiaoyun@tsinghua.edu.cn

2020.9.28

清華大學
Tsinghua University