General Idea of the New Annex Project: Indirect Evaporative Cooling

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Outline

- Background
- Indirect evaporative cooling(IEC) technology
- Key problems needed to be studied for IEC technology
- Objectives of the new Annex
- Intended target audience
- Sub-tasks discussion



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.



- 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°C at ambient temperature of 35°C-38°C 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 threestream heat and mass transfer and external two-stream heat and mass transfer; countercurrent or crosscurrent;

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



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



Current situations of IEC technology: IEC water chiller

• 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 Technology: Applications of IEC water chiller

• Mainly applied in northwest of China, totally more than 2,000,000m², as the cooling source for large public buildings, instead of mechanical chillers.



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.



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

Key problems for wide applications of IEC technology

- The reasons why the IEC not be widely applied in dried regions in the world:
 - Lack of investigation of existing IEC systems in different regions of the world.
 - Lack of feasibility analysis of using IEC technologies for different types of buildings in different dry climates.
 - Lack of fundamental studies of heat and mass transfer processes with various IEC systems and components, and optimized process of IEC air coolers and IEC chillers.
 - Lack of analysis of water consumption and methods to consider both water and electricity consumption together.

Key problems 1. The cooling performance—Feasibility study

- How low the outlet cooling water/air temperature could be, for IEC air coolers and IEC water chillers? which determine the feasibility of the application of IEC technologies.
- How to identify the cooling capacity of each kind of IEC process?

For example, for IEC water chillers, two efficiencies could be used to express the outlet water temperature, the evaporative cooling efficiency and the sensible cooling efficiency

 $t_{w,o} = t_{wr} - \eta_{ev} [t_{wr} - (t_{sO} - \eta_c (t_{sO} - t_{dpO}))]]$

 $\boldsymbol{\eta_c} = (t_{sO} - t_{sA}) / (t_{sO} - t_{dpO}) \qquad \boldsymbol{\eta_{ev}} = (t_{wr} - t_w) / (t_{wr} - t_{sA})$

Total output cooling energy;

 $Q_w = G_w c_{pw}(t_{w,in} - t_{wo})$

Cooling capacity for unit inlet air flow rate;

 $q_w = G_w c_{pw} (t_{w,in} - t_{wo})/G_a$

A unified method is needed to identify and then compare the cooling performance of different IEC processes.

What are the main factors to influence the defined efficiencies? What about other IEC chiller with different processes?

Key problems 1. The cooling performance—Feasibility study

 What about the IEC air coolers? How to identify the outlet cooling air temperature and the cooling capacity?

The supply air temperature:

$$t_{sf} = t_0 - \eta_{dp} (t_0 - t_{dp,0}) - \varepsilon_{d-t} \eta_{dec} (1 - \eta_{dp}) (d_{wb,0} - d_0)$$

IEC efficiency

$$\eta_{dp} = (t_o - t_{sf,i}) / (t_o - t_{dp,o})$$

DEC efficiency for DEC stage

$$\eta_{dec} = (d_o - d_{sf}) / (d_o - d_{wb,sf,i})$$

Different processes, different efficiency;

What about other IEC air coolers with different processes, such as M-cycle process, multi-stage process? A Unified method is needed.

The process produced cooling energy:

$$Q_{cp} = G_a \left(h_{a,in} - h_{a,O} \right)$$

The indoor heat removed by the supply air:

$$Q_{indoor} = G_a (h_{indoor} - h_{a,0})$$
$$Q_{cp} \neq Q_{indoor}$$

The target cooling energy is Q_{indoor} , which is needed to be clarified.

Key problems 1. The cooling performance—Feasibility study

- A unified characterization method is needed for kinds of IEC processes, to identify the outlet water or outlet air temperature, and the output cooling capacity.
- Using the unified characterization method, to analyze the factors to influence the outlet cooling water/air temperature and the cooling capacity, to compare the cooling performance of different processes, and to obtain the performance of IEC processes under different working conditions at different regions of the world.
 - Theoretical analysis
 - Simulation analysis
 - Field testing of real projects

What we need to do

Finally, A unified characterization method is given, and the feasibility of different IEC technologies in different regions of the world is obtained.

The objectives

- The water consumption analysis for different kinds of IEC processes:
- How to calculate and identify the total quantity of consumed water?
- What are the main factors to influence the water consumption?
- What is the most principal factor to influence the water consumption, the process produced cooling energy, the cycled water flow rate or other parameters?
- How to evaluate the water consumption, when considering both water consumption and electricity consumption, to compare with common mechanical chiller?

Air: $O \rightarrow E$; Water: $t_{wr} \rightarrow t_w$

From energy balance, the out put cooling energy:

$$Q_{w} = G_{w}c_{pw}(t_{wr}-t_{w}) = G_{a}(h_{E}-h_{O}) = G_{a}\Delta h_{1}$$

The water consumption:

W= $G_a(d_E - d_O) = G_a \Delta h_2 / r_0$

r₀: latent heat of vaporization

An efficiency to describe the water consumption could be defined, to identify the effective water consumption:

 $\eta_w = Q_w/r_0 W = \Delta h_1/\Delta h_2$

The higher the η_w , the lower the water consumption by water vaporization.

What is the principal parameter to influence $\eta_w\,?$

- The higher the exhaust air enthalpy, the higher η_w
- The higher the return water temperature, the higher n_w
- The higher the evaporative cooling efficiency, the higher η_w
- The larger NTU of the tower, the higher η_w

What about different process structure?

The water consumption efficiency could also be used for water vaporization consumption analysis of IEC air coolers.

• Take the IEC water chiller for example.

When totally heat recovery between the inlet air and exhaust air, and the evaporative cooling efficiency equals to one,

$$\eta_w = Q_w/r_0 W = \Delta h_1 / \Delta h_2 = 1$$

Even the sensible cooling efficiency and the evaporative cooling efficiency equals to one,

$$\eta_w = Q_w/r_0 W = \Delta h_1/\Delta h_2 < 1$$

For the same return water temperature t_{wr} from the users, why the difference of η_w for different processes? For process I, the sensible cooling process of inlet air O also consume water;

While, for process II, the sensible cooling process is realized by temperature difference and don't need water vaporization

What about different IEC air coolers? The water consumption analysis is also needed to be studied.

- Water consumption performance for kinds of IEC processes, including IEC water chillers and IEC air coolers, is needed to be analyzed.
- To evaluate the water consumption and electricity consumption together, the electricity consumption to produce pure water, such as by seawater desalination, need to be studied.
- Real projects investigation, to get the real water consumption, including vaporization water, drifting water, and the regular drain off water to reduce the hardness of water.
 - Investigation of water resource in different regions of the world
 - Theoretical analysis of water consumption for IEC processes
 - Simulation analysis
 - Field testing of real projects for water consumption

What we need to do

- Give the equivalent method between water consumption and electricity consumption
- Compare the different IEC processes, and compare IEC process and mechanical chiller process

The objectives

Key problems 3. System design, cooling air and cooling water

• 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?

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.

When considering all kinds of IEC air coolers and IEC water chillers, what about the comparison result? When considering the various outdoor conditions? For buildings with different function, the better system?

Key problems 3. System design, cooling air and cooling water

- Investigation of the real projects using IEC technologies needs to be carried out, to get a overview of the using system;
- Comparison between different IEC processes, by simulation under all working conditions.
- Cases design for different type of buildings.
 - Investigation of real projects and comparison between real projects using different IEC processes
 - Theoretical analysis
 - Simulation analysis
 - Cases design
 - Comparison by real performance of projects

What we need to do

- Give system design guideline for different types of buildings.
- Give the suitable application conditions of different system structure.

The objectives

Key problems 4. IEC equipment, IEC air cooler and IEC chiller

- How to compare different IEC air coolers with different process structure?
- How to compare different IEC water chillers with different process structure?

- Single stage or Multi-stage?
- Internal structure or External Structure? Three-stream heat and mass transfer or two-stream heat and mass transfer?

Key problems 4. IEC equipment, IEC air cooler and IEC chiller

Key problems 4. IEC equipment, IEC air cooler and IEC chiller

- Different processes need to be compared, to give deep understanding of different structures by thermal analysis, and to choose the suitable structure under different outdoor conditions, NTU conditions.
- Research on the process construction principle, to direct design of new structures.
 - Thermal analysis: internal losses analysis, matching analysis, heat exchangers loops, the optimization rules
 - Simulation analysis, to verify the theoretical analysis.
 - Comparison of lots of different IEC air coolers and different IEC water chillers.

What we need to do

- Give the optimization rules for design of new process structure.
- Give the suitable conditions for different process structure.

The objectives

Key problems 5. Application conditions and application area of the world

- From the climate conditions all over the world, where are the regions suitable for using evaporative cooling technology, and separately for DEC and different IEC technologies?
- In different suitable regions, the most suitable IEC system for different type of buildings?
- To give the feasibility analysis of application of IEC technologies all over the world, then to give the design guideline of IEC systems.
 - Investigation of climate data all over the world, the building types, running mode of building air conditioners, building indoor conditions, building cooling load and so on.
 - Theoretical analysis
 - Simulation analysis
 - Cases design

What we need to do

- Give the comprehensive feasibility analysis of using IEC technologies all over the world: the suitable application regions.
- Give the most suitable system design for different type of buildings, in different suitable regions.

The objectives

Main tasks

Key problem 1: Cooling performa —feasibility stud	Key problem 1: Cooling performance feasibility study. Key problem 2: Water consumpting economic study		tion dy.	n System design— produce cooling air or cooling water.		Key problem4: IEC equipment, different processes structure comparison			Key problem5: Application conditions and application area of the world			
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Investigation Climate data Water resource Building feature Application projects	Theo Cooli Wate efficie Syste	eretical analysis ng efficiency r consumption ency em comparison	The pro- com opti stru para	ermal analysi cesses structu nparison mization of acture and ameters	is ure	Simula Design Help to theoret	tool verify the ical analysis	is	Cases d Different design fo buildings different	esign systems or different in regions	Field testing Cooling performance Water and electricity consumption Running problems;)
Give a unified characterization method for cooling performance Give the identification method of water consumption, the equivalent method between water consumption and electricity consumption		on tion	Give system design guideline for different types of buildings, the suitable application conditions of different system structure.			Give the comparison method of different process, the optimization rules for new process structure, the suitable conditions for different process structure.			Give the comprehensive feasibility analysis of using IEC technologies all over the world, the most suitable system for different type of buildings different suitable regions			

Objectives of the new Annex

Field study	(1) 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.
Fundamental Study	 (2) Develop the general theoretical analysis method of IEC processes, to guide the design of different IEC systems used in different dry climates. (3) Evaluate the water and electricity consumption of IEC processes.
Simulation tool	(4) 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.
Guideline	(5) Develop a guideline for designing the IEC systems for different types of buildings under different dry climates and water resource conditions.

The 'step change' target of the proposed Annex

Include not only fundamental understanding of the IEC processes from thermodynamics viewpoint, but also simulation models, optimizing tools, and design guide for better utilization of this technology.

Provide a feasible approach to realize near-free cooling in dry climates

To respond to the sharp increase of cooling demand; Real-world operation data collected Providing a feasible and economical approach to obtain nearly-free cooling in dry climates to realize low energy consumption and low greenhouse gas emission.

1. Aimed at responding to the sharp increase of cooling demand in the world.

2. Real-world operating data will be collected and compared with counterpart technologies

Intended target audience

- The design and planning practitioners who focus on cooling system design and selection of real projects
- The scientific communities who focus on study of cooling or evaporative cooling processes
- The government officials who are responsible for formulating energy saving policies in respond to the climate change
- The manufactures who make indirect evaporative cooling equipment or products.