Indirect Evaporative Cooling

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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.
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 mechanical, 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.

<table>
<thead>
<tr>
<th>Direct Evaporative Cooling (DEC)</th>
<th>Indirect Evaporative Cooling (IEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit is inlet wet bulb temperature</td>
<td>Limit is inlet dew point temperature</td>
</tr>
</tbody>
</table>

- 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 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
- External IEC coolers with one part of supply air as secondary air
- Multi-stage processes

E - Exhaust air
P
101.325 kPa
O
60%
0
10
20
30
40
50

Inlet air
Supply air
Exhaust air

Internal IEC air coolers with inlet air as secondary air

Inlet air
Supply air
Exhaust air

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

Inlet air
Supply air
Exhaust air

External IEC air coolers with inlet air as secondary air

Inlet air
Supply air
Exhaust air

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

Multi-stage processes

M-Cycle IEC air coolers

0 0.005 0.01 0.015 0.02 0.025 0.03
0
10
20
30
40
50

Inlet air
Supply air
Exhaust air

M-Cycle IEC air coolers

0 0.005 0.01 0.015 0.02 0.025 0.03
0
10
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40
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Inlet air
Supply air
Exhaust 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
## IEC Technology: Applications of IEC air coolers

<table>
<thead>
<tr>
<th>Country</th>
<th>City</th>
<th>type of IEC process</th>
<th>Size(m²)</th>
<th>Application buildings</th>
<th>air flow rate(m³/h)</th>
<th>wet bulb temperature</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>Delhi</td>
<td>IEC+DEC, 3 stages</td>
<td></td>
<td>public buildings</td>
<td>13600~68000, total 4730000(52 projects)</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Maharashtra</td>
<td>IEC+DEC</td>
<td>650</td>
<td>exhibition hall</td>
<td>70560</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td>IEC+DEC</td>
<td>650300</td>
<td>plants</td>
<td>67200000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td>IEC</td>
<td>371.6</td>
<td>plants</td>
<td>23520</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Nagpur</td>
<td>IEC+DEC</td>
<td></td>
<td>plants</td>
<td>53760</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Pimpri</td>
<td>IEC+DEC</td>
<td>65030</td>
<td>large public building</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Adelaide</td>
<td>M-cycle IEC</td>
<td></td>
<td>commercial building</td>
<td>19.7kW</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Adelaide</td>
<td>IEC</td>
<td>4225</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Roxby, downs</td>
<td>M-cycle IEC</td>
<td>140</td>
<td>residential buildings</td>
<td>10.5kW</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>New South Wales</td>
<td>M-cycle IEC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Urumqi</td>
<td>Multi stage IEC</td>
<td>2,000,000</td>
<td>hospital building, high-speed railway station, office building, exhibition centers</td>
<td>20,000,000</td>
<td>1.0~1.2</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Gansu</td>
<td>Multi stage IEC+DEC</td>
<td>1,700</td>
<td>office building</td>
<td>0.927</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Xian</td>
<td>Multi stage IEC+DEC</td>
<td>300</td>
<td>plants</td>
<td>30,000</td>
<td>1.29</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Country</th>
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<th>Application buildings</th>
<th>wet bulb temperature</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>The United States</td>
<td>Colorado</td>
<td>M-cycle IEC</td>
<td>single house</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>The United States</td>
<td>Arizona</td>
<td>M-cycle IEC</td>
<td>single house</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>The United States</td>
<td>California</td>
<td>M-cycle IEC</td>
<td>single house</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>The United States</td>
<td>Utah</td>
<td>M-cycle IEC</td>
<td>hospital</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>The United States</td>
<td>California</td>
<td>M-cycle IEC</td>
<td>hospital</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>Mexicali</td>
<td>M-cycle IEC</td>
<td>food plant</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>Bloemfontein</td>
<td>M-cycle IEC</td>
<td>restaurant</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Kuwait</td>
<td></td>
<td>IEC+DEC</td>
<td></td>
<td>0.9~1.2</td>
<td></td>
</tr>
<tr>
<td>Iran</td>
<td>Teheran</td>
<td>IEC+DEC</td>
<td></td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>
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;
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

<table>
<thead>
<tr>
<th>Sensible heat removed by cold water (kW)</th>
<th>Electricity consumption of Fan of IEC chiller (kW)</th>
<th>Electricity consumption of water pump (kW)</th>
<th>Electricity consumption of Fan-coils (kW)</th>
<th>Water system COP to remove indoor sensible heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>219</td>
<td>13.8</td>
<td>14.9</td>
<td>19.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

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

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<th>Water system COP to remove indoor sensible heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>84000</td>
<td>10.8</td>
<td>2.0</td>
<td>1.76</td>
<td>2.9</td>
<td>8.33</td>
</tr>
</tbody>
</table>
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 combined air cooler system

IEC water chiller system using radiant floor as terminals

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 2,000,000m², as the cooling source for large public buildings, instead of mechanical chillers.
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.
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

- **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.

### Subtasks

- **Subtask A:**
  - 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.

- **Subtask B:**
  - 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.

- **Subtask C:**
  - Develop the general theoretical analysis method of IEC processes, to guide the design of different IEC systems used in different dry climates.

- **Subtask D:**
  - 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.
IEA-EBC Exco meeting
Approved as Annex 85

EBC project Concept
Determine to develop a full proposal

13th Nov 2019

11th June 2020

Full Annex proposal
Preparation (draft Annex text)

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

20th April 2020

11th September 2020

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

26th June 2020

Technology Readiness Preliminary Assessment

One-year preparation phase starting in July 2020

IEA-EBC Annex 85 Online Workshop: Indirect Evaporative Cooling

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

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