EBC

Energy in Buildings and
Communities Programme

Proposal for a new IEA EBC-ANNEX

Indirect Evaporative Cooling (Draft Annex Text)

June 2020

Prepared by
Associated Professor Xiaoyun Xie
Building Energy Research Center
Department of Building Science
Tsinghua University
100084
Beijing, China
Phone:+8613811611425
Fax:+86-10-62770544
Email: xiexiaoyun@tsinghua.edu.cn

Contents

1. Background

1.1. General Background

At present, buildings account for nearly 1/3 of the total energy consumption, over 10% of which is used for air conditioning and maintaining indoor thermal comfort in hot seasons. As predicted, most regions across the world 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. According to the United Nations Environment Program, this could double or triple the electricity consumption of air conditioning in Europe, Southeast Asia, the Middle East, and South America. Changing the mode of air conditioning is one of the solutions to meet the cooling demand without increasing electricity and carbon emission. Although over 85% of cooling around the world is achieved by mechanical refrigeration, buildings in about 40% of the air-conditioning in dry regions can be cooled by evaporative cooling instead, as shown in Fig. 1. To study the feasibility and provide the roadmap of using indirect evaporative cooling technology in different dry regions of the world is the main focus of the proposed project.

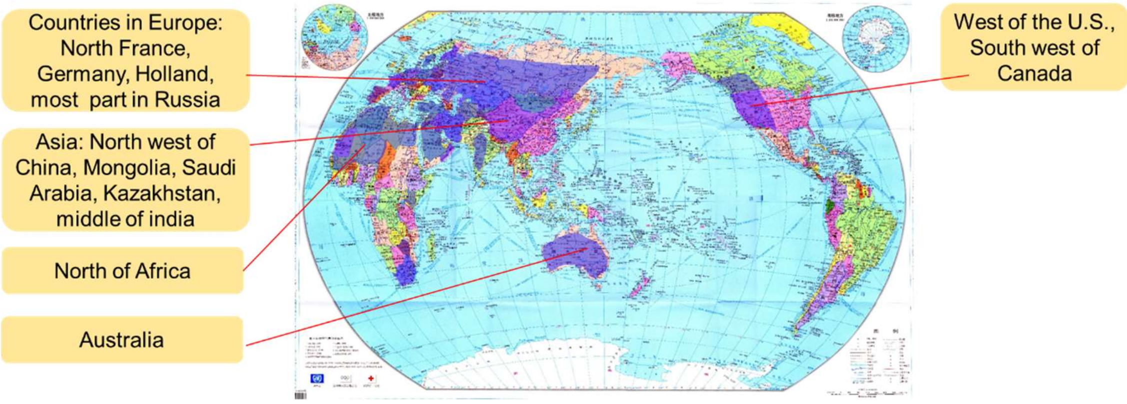


Fig. 1 The suitable application regions for indirect evaporative cooling technology

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

There are four main kinds of evaporative cooling technologies, direct evaporative cooling (DEC) to produce cooling air; DEC to produce cooling water, such as cooling tower; indirect evaporative cooling (IEC) to produce cooling air, IEC to produce cooling water. For DEC processes, which are easy to apply, the lowest output temperature is inlet wet bulb temperature, while for IEC processes, the lowest output temperature is inlet dew point temperature. Thus, 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%. For cooling water, the system transportation electricity consumption could be 1/10~1/3 of cooling air system for large scale systems. The electricity consumption of IEC water chiller systems could be reduced by 40%~70% compared with common mechanical chiller system, and no CFCs used.

1.2. Current Situations of IEC technologies

1.2.1 IEC air coolers

There is a long history for IEC air coolers study and development. First, for IEC air coolers, various kinds of IEC air cooler processes have been introduced and studied, including different processes with different second air conditions, different processes with different heat and mass transfer processes and different processes with different structure of single stage or multi-stage processes. Several typical IEC air cooler processes are shown in Fig 2. Fig. 2(a) and Fig. 2(b) show different IEC processes with different second air conditions, as well as for Fig. 2(d) and Fig. 2(e). Fig. 2(a) and Fig. 2(b) show internal IEC air coolers, with internal three-stream heat and mass transfer processes. Fig. 2(d) and Fig. 2(e) show external IEC air coolers, with two-stream heat and mass transfer processes. Fig. (f) shows the M-cycle IEC air coolers.

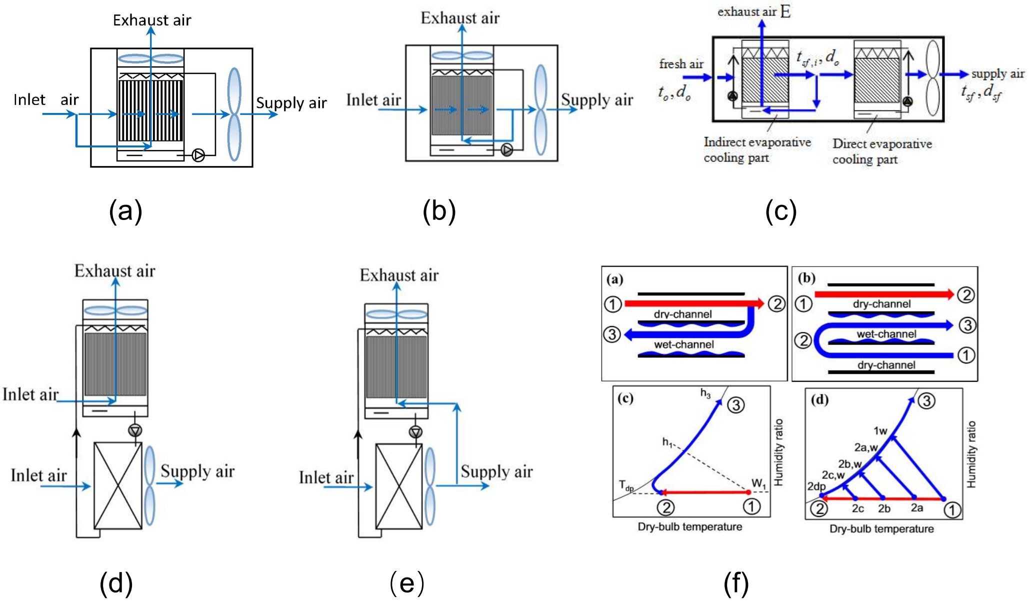
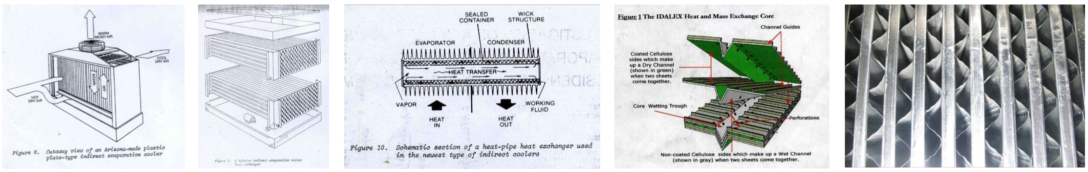


Fig. 2 Various kinds of IEC air coolers

(a) IEC air coolers with part of inlet air as second air
(b) IEC air coolers with part of outlet air as second air
(c) Multi-stage IEC air coolers combined IEC and DEC processes
(d) External IEC air coolers with part of inlet air as second air
(e) External IEC air coolers with part of supply air as second air
(f) M-cycle IEC air coolers

Different cooling performance of IEC air coolers could be obtained with different IEC air cooler processes. For IEC air coolers with part of the supply air as the second air, including the M-cycle processes, the limit cooling air temperature could be low to inlet dew point temperature.

Besides different IEC air cooler processes, different technical structures have been developed, as Fig. 3 shows, with different heat and mass transfer forms, different heat and mass transfer coefficients, different size, volume and specific surface area, and different heat transfer area cost.



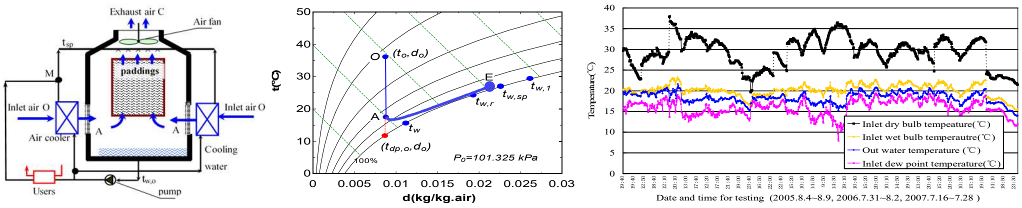
(a)Plate type (b) pipe type (c) heat pipe type (d) M-cycle (e) plate type

Fig. 3 IEC air coolers with different technics

IEC air coolers have been used in different type of buildings, in different dry regions all over the world. The processes of some typical applications reported in literatures are mainly multi-stage IEC air coolers, including IEC combined DEC air coolers, and M-cycle IEC air coolers. Multi-stage IEC air coolers have been applied in large public buildings, hospital building, high-speed railway station, office building, exhibition centers and plants, in India, China, Kuwait, Iran and so on. M-cycle IEC air coolers have been applied in commercial buildings, hospitals, residential buildings, single house and plants, in Australia, the United States and so on.

1.2.2 IEC water chillers

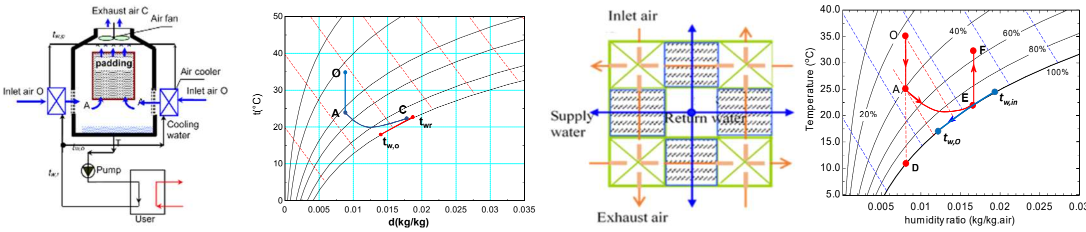
The IEC water chiller was introduced in 2002 in China, with the process shown in Fig. 4. Using the indirect evaporative chiller, the cold water could be produced with the limit temperature to reach the inlet dew point temperature. The key processes of the indirect evaporative water chiller are 1) to cool the inlet air to make it near the saturation line through a countercurrent air cooler by part of the produced cooling water; 2) to produce cold water by a countercurrent padding tower; 3) flow rate ration matching design for each of the heat transfer or heat and mass transfer process. These made the IEC water chiller process shown in Fig. 4(a) to be a near reversible process.



(a) Process structure I (b) process of air and water (c) testing performance

Fig. 4 Process and performance of indirect evaporative chiller

After the introduction of the process shown in Fig. 4, different IEC water chiller processes have been introduced after 2008, in China, the United States and so on, as shown in Fig. 5.



(a) Process structure II (b) Process structure III

Fig. 5 Different IEC water chiller processes

IEC water chillers were developed in 2005 and have been applied mainly in northwest of China, totally more than 2,000,000m^2, as the cooling source for large public buildings, instead of mechanical chillers.

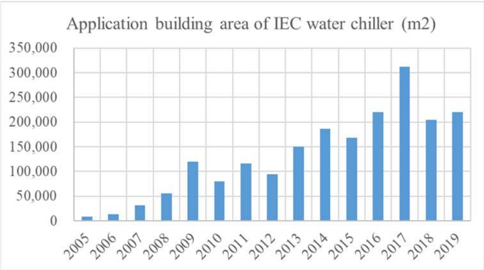


Fig. 6 Application building area of IEC water chillers

1.3. The preliminary performance analysis of IEC technology applied in the world

Take the IEC water chiller for example, the outlet water temperature in different dry regions is around 15~19℃, which shows large application potential of IEC water chillers as the cooling source in these dry regions, including most cities in west of the United States, southwest of Canada, Australia, northwest of China, some cities in India, a lot of countries in Europe, some countries in middle east, and north part of the Africa.

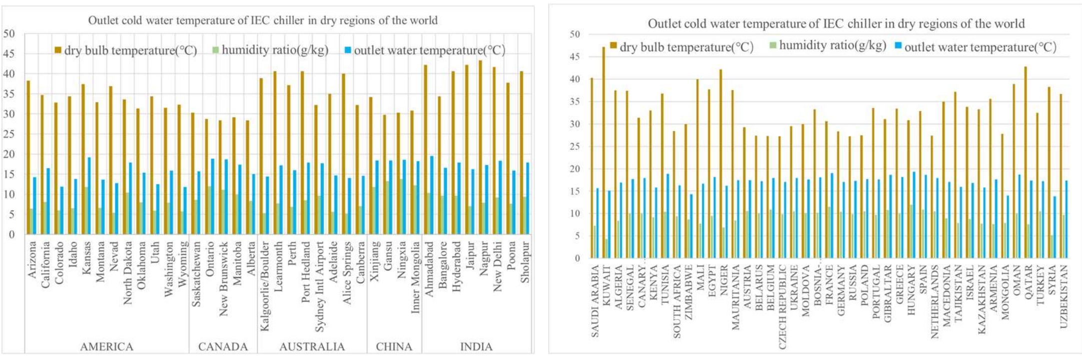


Fig. 7 The application potential of IEC technology in dry regions of the world.

1.4. Importance and Emergency

Even IEC air coolers and IEC water chillers have been developed and applied in a certain scale, they haven't been widely applied in dry region in the world, the reasons are shown as below:

(1) Lack of investigation of existing IEC systems in different regions of the world.

(2) Lack of feasibility analysis of using IEC technologies for different types of buildings in different dry climates.

(3) Lack of fundamental studies of heat and mass transfer processes with various IEC systems and components, and optimized structure design of IEC air coolers and IEC water chillers.

(4) Lack of analysis of water consumption and methods to consider both water and electricity consumption together.

Thus, seeing the huge potential to substitute mechanical cooling and significantly reduce the energy use for cooling, the following key problems are needed to be studied and finally solved to give a feasible roadmap to widely apply IEC technologies in suitable regions.

Key problems needed to be solved：

- **Investigation of real operation problems of IEC technologies, to answer why IEC technologies have not been widely used:** what problems have been encountered in real projects of IEC technologies, as well as for cooling towers, especially for cost, space, maintaining, and environment impacts? Why IEC or DEC technologies have not been accepted even in very dry climates? Deep and wide investigations are needed to be carried out to find the doubts and key problems, and to give the possible solutions for each problem, thus to give a feasible approach of widely application of IEC technologies.
- **The cooling performance of IEC air coolers and IEC water chillers:** 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? How to identify the outlet cooling air temperature and the cooling capacity? 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.
- **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? 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.
- **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? 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 is needed.
- **IEC equipment optimization, both for IEC air coolers and IEC chillers:** How to compare different IEC air coolers with different process structure? How to compare different IEC water chillers with different process structure? 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.
- **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.

2. Objectives

Thus, the proposed Annex project intends solve the above key problems, the objectives are:

(1) 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.

(2) 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.

(3) Develop the general theoretical analysis method of IEC processes, to guide the design of different IEC systems used in different dry climates.

(4) Evaluate the water and electricity consumption of IEC processes.

(5) 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.

(6) Develop a guideline for designing the IEC systems for different types of buildings under different dry climates and water resource conditions.

3. Means

3.1. The framework of this Annex

The whole framework of this Annex is shown in Fig. 8, to solve the key problems, the main tasks include investigation, theoretical analysis, simulation analysis, cases design and field testing. The corresponding results to solve each key problem are shown as well.

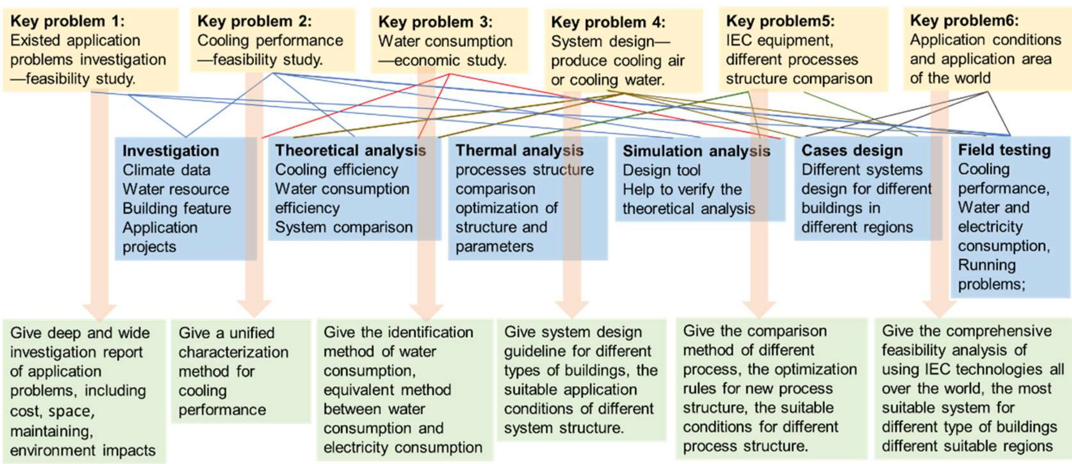


Fig. 8 The whole framework of this Annex

To finish the main tasks as to achieve the objectives of this Annex by the participants, the following subtasks are arranged:

3.2. Subtask A: Definition & Field study

For theoretical study as well as feasibility study of IEC technologies, investigation and field study are the basic task, to get the real running conditions and real running results of the existed projects of IEC air coolers and IEC water chillers in the world, and to find out the main constraints for the application of IEC technologies. As there are some similar features between evaporative cooling processes and cooling towers, the investigation and field-testing work also cover some typical cooling tower projects. The main objective Besides, not only thermal performance, but also life of the products, life cycle cost of the equipment are needed to be investigated, which are main considerations of real project. Moreover, the climate data of the suitable regions of the world, including extremely hot conditions are also needed to be investigated.

The scope of the subtask is as follows:

1. Investigation in the world, for the existed projects using IEC technologies;
2. Investigation of the main constraints for the application of IEC technologies, as well as for cooling towers, including cost, maintaining, space and environment impacts.
3. Field testing of some of the projects; (including some typical cooling tower projects)
4. Life of the equipment and products.
5. Projects cases collecting.
6. Investigation of climate data of the world, including extremely hot conditions, the building feature, the running mode of air conditioning, indoor design parameters and heat load.

3.3. Subtask B: Feasibility study of IEC technologies

To study the feasibility of IEC technologies is the premise of the deep research of application of IEC technologies. The basic performance includes cooling performance, water consumption performance, electricity consumption, environmental impact, and cost. The cooling performance, including both temperature and quantity of cooling energy is needed to be identified, both for IEC air coolers and IEC water chillers, to get a unified characterization method. The water consumption performance is very important, especially for dry regions where lack of water resource. Thus, it is needed to identify the water consumption performance, to define the corresponding water consumption efficiency as to give the effective water consumption contributed to the cooling energy. Then the transformation method of water consumption to electricity consumption is needed to be studied, by considering the electricity consumption of desalination process. Then, the total electricity consumption of IEC technologies including electricity consumption and water consumption could be calculated and analyzed, which could be used to be compared with common mechanical refrigeration systems. Besides, the environment impacts should be also considered, including the compactness, the risk associated to IEC water chiller system as well as for cooling towers(including aging, dirtiness, scale), noise, the possible legionella and so on. Based on above basic performance identification and analysis, the feasibility of IEC technologies in different type of buildings of different suitable regions in the world could be discussed.

The scope of the subtask is as follows:

1. Cooling performance identification and analysis.
2. Water consumption performance analysis. (including cooling towers)
3. Cost analysis: including initial cost, running cost(electricity consumption cost), maintenance cost, life-cycle cost.
4. Electricity consumption, and the equivalent method of water consumption to electricity consumption.
5. Environmental impacts (compactness, risk associated to water system (aging, dirtiness, scale), noise, legionella, and so on)
6. The application Feasibility of IEC systems for different type of buildings in suitable regions of the world.
7. The cooling tower application feasibility.

3.4. Subtask C: Fundamental Study

For the regions where IEC technologies are suitable to use, to design suitable system structure and then to optimize the device processes become the key point, for which fundamental study is needed to carry out through thermal analysis. For system design, both IEC air cooler system and IEC water chiller system could be used to remove indoor sensible heat, how to choose from air cooler and water chiller is the key problem. Theoretical analysis is needed to be carried out to point out the essential difference between IEC cooling air system and IEC chilled water system. Then, comparison of these two systems from real application could be used to see the real difference of these two kinds of system. Combined theoretical analysis and real projects analysis, the choosing principle could be obtained.

Then, for an IEC air cooler or an IEC water chiller, there are various kinds of process structure, how to compare the different processes then to choose the better one is the key problem for design of IEC equipment. Thermal analysis, especially the internal losses analysis for internal heat transfer, heat and mass transfer processes are needed to be carried out, to give the design principle of IEC process.

The scope of the subtask is as follows:

1. For system design, comparison of IEC cooling air system and IEC cooling water system.
2. Different process structures comparison, through thermal analysis.

3.5. Subtask D: Simulation tool and Guideline

To analyze the basic performance of IEC processes, as well as assist theoretical study of different IEC process and then design of IEC equipment and IEC systems, simulation models are needed to set up of IEC air cooler device and systems, IEC water chiller and systems. The indoor terminals are also included in the simulation model, for example for IEC water chillers, to discuss the design of indoor sensible terminals with higher water temperature. On the basis of theoretical analysis and simulation analysis, a design guideline for IEC systems is needed to be developed to direct the design of IEC systems.

The scope of the subtask is as follows:

1. 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.

2. Develop a guideline for designing the IEC systems for different types of buildings under different dry climates and water resource conditions. (including the indoor design temperature set up, how to ensure the indoor conditions when using the IEC processes with cold water temperature higher than common chillers)

4. Results

This Annex aims to give the application feasibility of IEC technologies in the world, and to provide the technology roadmap of using IEC systems for different type of buildings in different dry regions of the world.

4.1. The overall outputs

The outputs include:

1. **Theoretical analysis results of general performance of IEC technologies:**
   - Give a unified characterization method for cooling performance of IEC air coolers and IEC water chillers.
   - Give the identification method of water consumption, and the equivalent method between water consumption and electricity consumption
2. **Fundamental analysis results through thermal analysis and optimization:**
   - Get the comparison results and choosing principle between IEC air cooler systems and IEC water chiller systems.
   - Put forward the comparison method of different process, and the optimization rules for new process structure, the suitable conditions for different process structure.
3. **Simulation tools of IEC technologies**
   - Develop the simulation tools for kinds of IEC air coolers and IEC water chillers, and the corresponding systems.
   - Give the overall performance analysis results of IEC air coolers and IEC water chillers, for different type of buildings in different dry regions.
4. **Design guideline of IEC technologies**
   - Provide system design guideline for different type of buildings, in different regions of the world.
   - Give the suitable application conditions of different system structure.
5. **Feasibility analysis of IEC technologies**
   - Give an investigation report of the existed applications of IEC systems and cooling towers, including the performance, the running problems, the lifetime of the devices and so on, as the basis for feasibility analysis.
   - Give a report for overall comparison between IEC systems and mechanical refrigeration systems, to show the climate conditions to use IEC technologies.
   - Give the comprehensive feasibility analysis of using IEC technologies all over the world, the most suitable system for different type of buildings in different suitable regions

The above outputs would be shown by reports, papers, simulation tools and publications on the IEA EBC platform, through the research work of all the subtasks.

4.2. The outputs of each subtask and the targeted audience

Table 1 Outcomes and targeted audience of the subtasks

<table>
<tr><th>Subtask</th><th>Outcomes</th><th>Targeted audience</th></tr>
<tr><td>A</td><td>• An investigation report of the existed applications of IEC systems and cooling towers.
• Real testing performance of the existed IEC systems.
• An investigation report of the climate data, water resource, building load features of different dry regions of the world.</td><td rowspan="2">• Design and planning practitioners who focus on cooling system design and selection of real projects.
• Scientific communities who focus on study of cooling or evaporative cooling processes;
• Government officials who are responsible for formulating energy saving policies in respond to the climate change</td></tr>
<tr><td>B</td><td>• A unified characterization method for cooling performance of IEC air coolers and IEC water chillers.
• An identification method of water consumption, and the equivalent method between water consumption and electricity consumption.
• An overall comparison report between IEC systems and mechanical refrigeration systems.
• A comprehensive feasibility analysis report of using IEC technologies all over the world</td></tr>
<tr><td>C</td><td>• The comparison and choosing principle between IEC air cooler systems and IEC water chiller systems..
• The comparison method of different device process, the optimization rules for new process structure and the suitable conditions for different process structure.
• A report for optimization of IEC systems and IEC device process structure, using thermal analysis and especially internal losses analysis method.</td><td>• Scientific communities who focus on study of cooling or evaporative cooling processes;
• Manufactures who make indirect evaporative cooling equipment or products;</td></tr>
<tr><td>D</td><td>• Simulation tools for kinds of IEC air coolers and IEC water chillers, and the corresponding systems.
• An overall performance analysis report of IEC air coolers and IEC water chillers, for different type of buildings in different dry regions.
• System design guideline for different type of buildings, in different regions of the world.</td><td>• Design and planning practitioners who focus on cooling system design and selection of real projects
• Scientific communities who focus on study of cooling or evaporative cooling processes;
• Manufactures who make indirect evaporative cooling equipment or products;</td></tr>
</table>

5. Time Schedule

This Annex shall remain in force until June 2025. An International expert meeting was organized On April 20, 2020 online with participants from Australia, Belgium, China, Denmark, France, the United States and Egypt. The proposed time schedule of the Annex is shown in the following table.

Years	2020	2021		2022		2023		2024		2025
Months	6~12	1~6	7~12	1~6	7~12	1~6	7~12	1~6	7~12	1~6
preparation phase										
working phase										
Reporting phase										

6. Funding

Semi-annual meetings: The working meetings shall be hosted in turn by one of the participants. The working meetings shall be carried out online or on-site meeting. The costs of organizing the meeting shall be borne by the host participant.

Task sharing activities: Each participating country shall commit a minimum of 3 person-months of labor for each year of the Annex term. In addition, the Operating Agent shall commit a further 3 person-months per year.

Individual financial obligations: Each participating country or, in case the country is not a member of the Executive Committee, the participant, shall bear all costs it incurs in carrying out the Annex activities. Funding is expected to cover labor costs, consumables, investments, reporting (included eventual overhead costs) and travelling for participation in two expert meetings per year during the three years working phase of the Annex. For the Operating Agent funding shall allow for an extra four person-months per year and the attendance at the semi-annual Executive Committee meetings.

Publications: The costs of publishing the final reports shall be met by the Operating Agent.

7. Operating Agent and Subtask Leaders

This Annex is managed by the Operating Agent and Subtask leaders. The Operating Agent is responsible for managing the Annex and the overall progression of an Annex and the delivery of Annex products. The Subtask leaders are responsible for managing each subtask and preparing the corresponding subtask reports and assisting the Operating Agent for organization of this Annex.

The Operating Agent for the Annex is: Associate Professor Xiaoyun Xie (Tsinghua University)

The possible subtask leaders are:

Subtask A:	Sylvano Tusset, Belgium ATIC organization
	Frank Bruno, Professor, University of South Australia, Australia
	Stephen White, Energy for Buildings Manager, CSIRO Energy Center, Australia
Subtask B:	Michal Pomianowski, Associate professor, Aalborg University, Denmark
	Lu Aye, Professor, University of Melbourne, Australia
	Omar Abdelaziz, Assistant Professor, Zewail City of Science and Technology
Subtask C:	Xiaoyun Xie, Associate professor, Tsinghua University
	Xiaobing Liu, Oak Ridge National Lab, Oak Ridge National Lab
Subtask D:	Jean Lebrun, Professor, University of Liège;
	Chadi Maalouf, Associate professor, University of Reims Champagne Ardenne

8. Commitments

8.1 Specific Obligations and Responsibilities of the Participants

Each participant shall work in at least one of the subtasks of the Annex.

Each Participant shall provide the Operating Agent with detailed reports on the results of the work carried out for each Subtask.

Each Participant shall participate in the editing and reviewing of draft reports of the Annex and Subtasks.

Each participant shall attend the semi-annual Annex working meetings. If several people from the same country participate, that country should designate at least one expert to act as a technical contact regarding the national contribution.

8.2 Specific Obligations and Responsibilities of the subtask leaders

Subtask leaders who are responsible for a subtask have the duty to:

Coordinate and supervise work of the subtask;

Assist the Operating Agent to prepare detailed work plans.

Report to the Operating Agent with the results.

Coordinate the final reporting resulting from subtasks.

Assist the Operating Agent in editing the final reports of the Annex.

8.3 Specific Obligations and Responsibilities of the Operating Agent

The additional duties of the Operating Agent are to:

Prepare joint assessments of research, development and demonstration priorities;

At the request of the Executive Committee, organize workshops, seminars, conferences and other meetings;

Prepare the detailed Program of Work for the Annex in consultation with the Subtask Leaders and the Participants and submit the Program of Work for approval to the Executive Committee;

Propose and maintain a methodology and a format for the submission of information;

Provide, at least semi-annually, periodic reports to the Executive Committee on the progress and the results of the work performed under the Program of Work;

Provide to the Executive Committee, within six months after completion of all work under the Annex, a final report for its approval and transmittal to the Agency;

In co-ordination with the Participants, use its best efforts to avoid duplication with activities of other related programs and projects implemented by or under the auspices of the Agency or by other competent bodies;

Provide the Participants with the necessary guidelines for the work they carry out with minimum duplication;

Perform such additional services and actions as may be decided by the Executive Committee, acting by unanimity.

8.4 Information and Intellectual Property

All Annex related information will be stored on a website. Each participating country and each participant has access to a password protected part of that website through a password. The site will be managed by the Operating Agent. For the duration of the Annex, all specific Annex documents, except published reports and general Annex information, are considered not to be public domain.

All Annex participants have the right to publish congress and journal papers that report on Annex related work. When doing so, the Annex shall be acknowledged as one of the vehicles that assisted in carrying out the work. All final reports will be public domain

9. Participants

Name	Institute	Nation	Subtasks			
			A	B	C	D
Jean Lebrun	Professor, University of Liège	Belgium	√	√		√
Sylvano Tusset	Consulting Engineer and "ATIC" member, ATIC	Belgium	√			√
Per Kvols Heiselberg	IEA EBC exco member ,Professor, the advisor of this Annex, Aalborg University	Denmark	-	-	-	-
Alireza Afshari	Professor, Aalborg University	Denmark		√		
Michal Pomianowski	Associate professor, Aalborg University	Denmark	√	√	√	√
Omar Abdelaziz	Assistant professor, Zewail City of Science and Technology	Egypt		√	√	√
Yi Jiang	IEA EBC exco member ,Professor, Tsinghua University	China	√	√	√	√
Xudong Yang	IEA EBC exco member ,Professor, Tsinghua University	China	-	-	-	-

Xiaoyun Xie	Associate professor, Tsinghua University	China	√	√	√	√
Chaoyi Zhu	Post doctor, Tsinghua University	China	√	√	√	√
Yijie Liu	Ph.D. student, Tsinghua Unversity	China	√	√	√	√
Xiaobing Liu	R&D staff, Oak Ridge National Lab	the United States		√		
Marjorie Musy	Cerema	France			√	√
Constance Lancelle	Cerema	France			√	√
Chadi Maalouf	Associate professor, University of Reims Champagne Ardenne	France				√
Stanford Harrison	IEA EBC exco member, Department of Industry, Science, Energy and Resources, Australia	Australia	-	-	-	-
Stephen White	Energy for Buildings Manager, CSIRO Energy Center	Australia		√		
Frank Bruno	Professor, University of South Australia	Australia	√	√	√	√
Lu Aye	Professor, University of Melbourne	Australia		√		√
Rob Gilbert	Seeley International	Australia	√	√	√	√
Jon	Seeley International	Australia	√	√	√	√
Gilbert, Robert	Seeley International	Australia	√	√	√	√
Dean Brown		Australia	√	√	√	√
Seeley International	Seeley International	Australia	√	√	√	√

10. References

- Watt, J. R., Nationwide Evaporative Cooling Is Here. ASHRAE Transactions.1987, 93(1):1237-1251.
- D.R.Crum, J.W.Mitchell, W.A.Beckman. Indirect evaporative cooler performance. ASHRAE Transactions 1987, 93(1):1261-1275.
- Wicker, Ken. Life below the wet bulb: The Maisotsenko cycle. Power, 2003, 147(9):29.
- Muhammad H. Mahmood, Muhammad Sultan, Takahiko Miyazaki, Shigeru Koyama, Valeriy S. Maisotsenko. Overview of the Maisotsenko cycle – A way towards dew point

evaporative cooling. Renewable and Sustainable Energy Reviews, 2016,66: 537~555.
- Yi Jiang, Xiaoyun Xie, Theoretical and Testing Performance of an Innovative Indirect Evaporative Chiller, Solar Energy, 2010, 84: 2041-2055.
- Xiaoyun Xie, Yi Jiang, Comparison of Two Kinds of Indirect Evaporative Cooling System: To Produce Cold Water and To Produce Cooling Air, Procedia Engineering, 2015, 121: 881-890.
- Yi Jiang, Xiaoyun Xie. *Comparison of two indirect cooling processes to produce cold water,* Proceedings of 25th IIR International Congress of Refrigeration, Montreal, Canada, August 24-30, 2019, p4153-4160.
- Xiaoyun Xie, Yi Jiang, An indirect evaporative chiller, Frontiers of Energy and Power Engineering in China, 2010, (4):66-76.
- Xiaoyun Xie, Yi Jiang*, Some views on design and thermal performance calculation methods of evaporative cooling air conditioning systems,* China, HVAC, 2010,40 (11): 1–12.