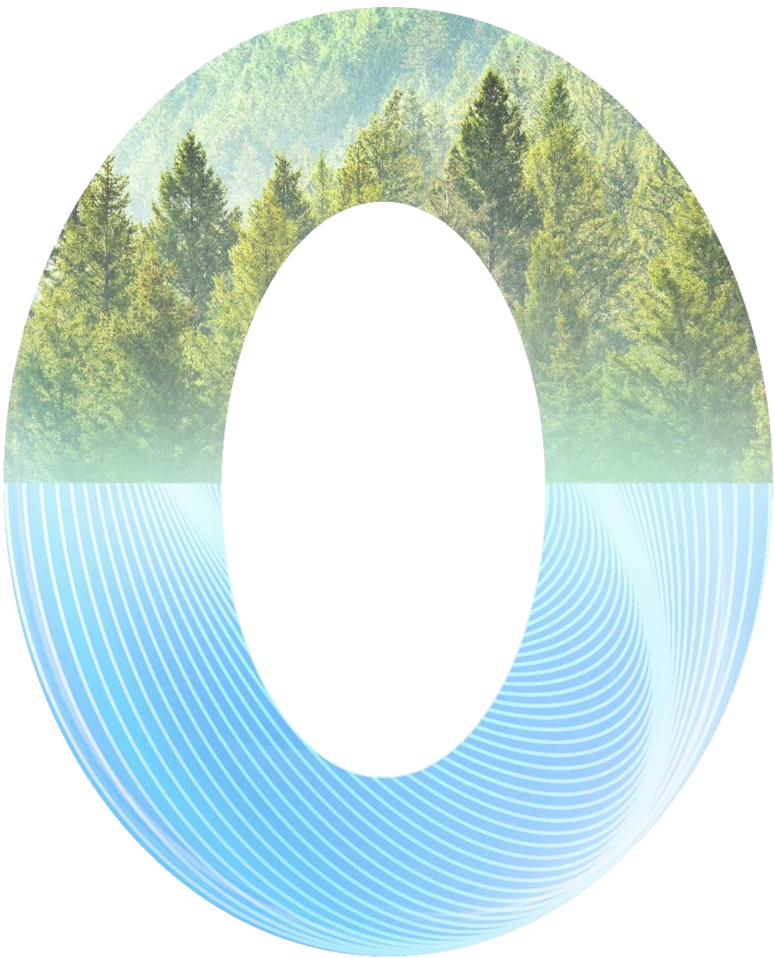
Data Center Facility
White Paper No. 401

◀ Leading Smart DC Program ▶

New-Generation
Intelligent Indirect Evaporative Cooling Solution
White Paper



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1. Preface

With the rapid development of 5G, cloud computing, and digital transformation, large data centers have become a focus of new infrastructure construction. As basic strategic resources, large data centers have been considered part of strategic commanding points. The construction scale and quantity of data centers are increasing rapidly.

Energy consumption of data center facilities, especially cooling systems, has become a shared concern across the industry. Improving the energy efficiency of cooling systems is not only in line with the national policy of energy conservation and emission reduction, but also an important objective to reduce the operating expense (OPEX) of data centers.

The traditional chilled water cooling systems of data centers face a number of challenges, such as high energy consumption, a long deployment period, complex systems, and high O&M costs. The indirect evaporative cooling technology is an effective approach to make full use of free cooling sources and reduce the energy consumption of data center cooling systems. An indirect evaporative cooling system is simple, easy to install and adapt, applicable to a wide range of areas with diverse climates. Compared with the traditional chilled water cooling system, the indirect evaporative cooling system saves more power and water, has advantages in phased deployment, deployment period, reliability, and total cost of ownership (TCO), and so it is widely recognized across the industry. With accelerated use of the indirect evaporative cooling technology, new development trends have emerged, such as normalization of air handling systems and energy efficiency improvement and fault prediction using AI technologies.

To better promote the indirect evaporative cooling technology, this white paper is written to provide reference for involved personnel in the industry.

2. Glossary

Data center

A building that provides an operating environment for electronic information devices that are placed centrally. It can be one or more buildings or part of a building, and consists of a computer room, auxiliary area, support area, and administrative area.

Indirect evaporative cooling (IEC)

Indirect evaporative cooling means that the production medium (air or water) comes in indirect contact with the working medium (air or water, for direct evaporative cooling) to obtain cold air or water by performing only sensible heat exchange instead of mass exchange.

Indirect evaporative air-conditioning system

An air handling unit that adopts the IEC technology, uses air or water as the working medium and air as the production medium, and provides air circulation, air filtering, cooling, humidity control, and auxiliary cooling sources. The indirect evaporative air-conditioning system is referred to as IEC system in the following text.

Mechanical auxiliary cooling

Mechanical auxiliary cooling is an auxiliary cooling approach in which vapor compression cooling is used to supplement the cooling capacity when the IEC system cannot fully use free cooling or IEC to achieve the rated cooling capacity.

Redundancy

Units or components of a system are redundantly configured. When some units or components are faulty, the redundant units or components take over the work of the faulty ones, which prolongs the mean time between failures (MTBF) for the system.

Power usage effectiveness (PUE)

A parameter that indicates the power utilization efficiency of a data center. The value is the ratio of the total power consumed by all devices in a data center to the total power consumed by all electronic information devices in the data center.

Water usage effectiveness (WUE)

A parameter that indicates the water utilization efficiency of a data center. The value is the ratio of the total water consumed by all devices in a data center to the total power consumed by all electronic information devices in the data center.

Artificial intelligence (AI)

Theories, methods, techniques, and application systems used for simulating, extending, and expanding human intelligence.

3. Status Quo and Challenges of the Data Center Cooling Industry

3.1. Interpretation of Industry Standards

With the technical progress of IT devices such as servers, the requirements for cooling are changing. One of the important indicators is the increasing air inlet temperature. According to the ASHRAE Technical Committee (TC) 9.9, the allowed air inlet temperature of servers increases from 20–25°C in 2004 to 18–27°C in 2015. Some data centers have attempted to further increase the air inlet temperature over recent years, allowing the supply air temperature to exceed 27°C or even approach 32°C during a certain proportion of time in a year.

The extension of the temperature environment standards in data centers is favorable to energy saving of cooling systems. Data centers can use more free cooling sources to reduce mechanical cooling. Mature free cooling solutions, such as IEC, have been adopted for data center cooling and are used in an increasing scope.

3.2. Status Quo and Challenges of Traditional Cooling Systems in Data Centers

3.2.1. High Power Consumption of Traditional Cooling Systems

As the data center scale and power density keep increasing, data centers have become typical big power consumers. Use a typical data center with a rated IT capacity of 1 MW and a designed PUE of 1.5 as an example. Its electricity expense accounts for more than 60% of the TCO over the 10-year period from construction to operation.

The energy consumption of the cooling system accounts for about 30% of the total energy consumption. Therefore, the cooling solution of a data center is decisive to the upper limit of its energy consumption. Energy saving of the cooling system has become the primary demand of data center construction.

3.2.2. Long Deployment Period of Traditional Cooling Systems

The deployment period of a data center affects the use of capital. A short deployment period accelerates service rollout and return on investment. The time from construction to operation is about 10 to 12 months for a medium-sized data center (with a rated IT capacity of 1 MW) that uses the chilled water cooling system. Considering the impact of weather during construction, the time may be longer. The deployment period of the cooling system may be five to six months as installation and joint commissioning are involved. Therefore, long deployment period is a big challenge to data centers.

Phased construction of large data centers has become a common practice. The time span may reach two to three years or even longer. To support phased deployment of IT loads, the cooling solution needs to be rapidly deployed in phases. The solution of each phase needs to be quickly replicated and decoupled from each other.

3.2.3 High Complexity of Traditional Cooling Systems

According to the requirements of different Uptime tiers, the following is a feasible chilled water solution for a Tier IV data center:

The chilled water system usually uses a loop pipe network or dual water supply and return pipelines. Valves need to be installed for each pipe segment to ensure that each pipe segment can be maintained if leakage occurs. Chillers, water pumps, and indoor units are connected to the loop, and water pipes are interconnected. N+R (at least, N+1) configuration is required for chillers, water pumps, cooling towers, and computer room air handlers (CRAHs). There is no redundancy backup for valves and meters on the main pipelines. As a result, a single point of failure may occur if a valve or meter fails or a welding point leaks. Chilled water tanks are configured to implement continuous cooling. Therefore, simplifying the cooling system architecture is a challenge to data centers.

3.2.4 High O&M Cost of Traditional Cooling Systems

Operation and maintenance (O&M) is a key point for attention during the lifetime of a data center. Assume that a data center houses 1500 racks and uses the chilled water cooling solution, three or four O&M engineers are needed for each shift, and three shifts are required each day. A total of 9 to 12 O&M engineers are required. Routine maintenance of devices such as chillers, water pumps, and pipes is also necessary. The O&M manpower cost accounts for about 10% of the 10-year TCO of the data center. O&M should be simplified to reduce the O&M cost. Therefore, how to simplify O&M and realize O&M intelligence is also a challenge to the cooling systems of data centers.

3.3. Status Quo and Challenges of Traditional IEC Systems in Data Centers

The electricity expense of the cooling system accounts for about 35% of the total electricity expense. Fully using free cooling sources can further improve the energy efficiency of the cooling system and reduce its power consumption. For example, in northern hemisphere, long-time use of free cooling sources is available in northern areas and the energy saving effect is good there. In areas that are hot in summer (long-time hot whether) and cold or warm in winter, IEC systems can leverage water evaporation to absorb the heat in the air and cool the air supplied from the outdoor to meet the cooling requirements of data centers. In hot weather, an IEC system uses the compressor cooling system to dissipate heat for the data center, which reduces the water consumption of the chilled water cooling system. However, traditional IEC systems also face the following challenges:

3.3.1. IEC Systems Should Match Buildings

When an IEC system is used in a multi-story data center, it is necessary to properly design the building and deploy equipment rooms, air ducts, maintenance channels, and air exhaust shafts. Both the characteristics of IEC units and economical efficiency of buildings should be considered.

3.3.2. IEC Systems Should Be Applicable in Humid and Hot Areas

With the improvement of server temperature tolerance, the temperature in data centers will become increasingly high and free cooling will be used for a longer time to save energy. IEC units will be applicable in wider areas. As the supply air temperature in data centers rises, free cooling can be used for a longer period of time. Compared with a traditional chilled water cooling system, an IEC system consumes less water, has a smaller failure domain, and is more suitable for phased deployment and capacity expansion. IEC systems will gradually become a mainstream solution for data centers. However, as the difference between dry and wet bulb temperatures is small during certain periods in humid and hot areas, the spray cooling effect of the IEC units is limited. In addition, spraying generates extra air resistance, which reduces the energy efficiency of the units. How to prolong the application of IEC during humid and hot periods and how to achieve optimal operation are also the challenges faced by traditional IEC systems.

3.3.3. IEC Systems Should Support Simplified O&M

The IEC system solution integrates the free cooling system and direct expansion air cooling system into one device, so O&M consumables and maintenance are different from those of the traditional chilled water system. How to implement fault prediction, predictive maintenance, and intelligent O&M using AI technologies to reduce O&M costs should be considered in the application of IEC.

4. IEC System Overview

4.1. Working Principles and Components

4.1.1 Working Principles

The integrated IEC system can be put into use after air ducts, water pipes, and power distribution devices are installed in a data center. The IEC unit can work in three modes:

- Dry mode (only the fans work and free cooling is used).
- Wet mode: The fans and spray pump are working, and air is exchanged after spray cooling.
- Hybrid mode: The fans, spray pump, and compressor work at the same time. The three working modes can be combined with local meteorological parameters and the characteristic curve of the unit itself to work under the control system to meet temperature control requirements while saving energy.

Table 4-1 *Working modes of the IEC system*

Working Mode	Fan Status	Water Pump Status	Compressor Status
Dry mode (fan)	On	Off	Off
Wet mode (fan + spray)	On	On	Off
Hybrid mode (fan + spray + compressor cooling)	On	On	On

① Dry mode

When the outdoor ambient temperature is lower than a certain value, the unit can work in dry mode to meet the cooling requirements of the data center. In this mode, the indoor and outdoor fans are working.

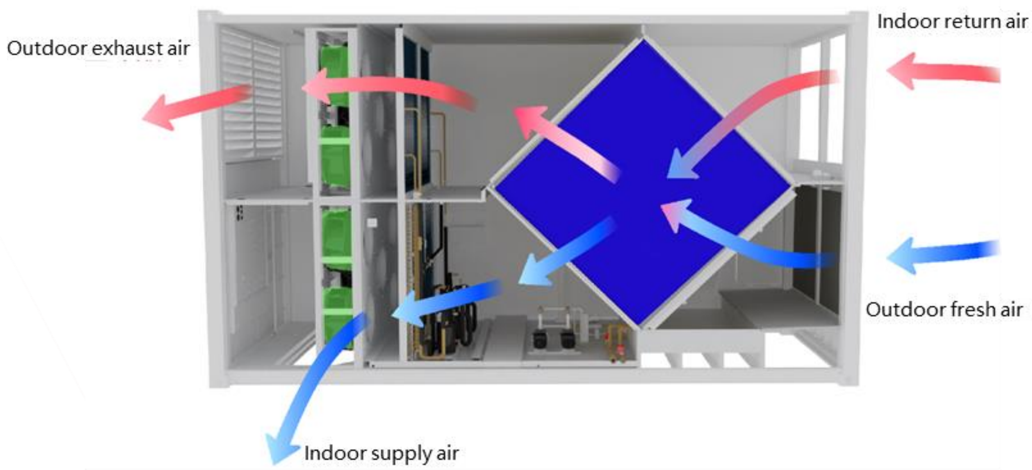


Figure 4-1 *Running status of the IEC system in dry mode*

② Wet mode

When the outdoor ambient temperature is higher than the temperature for startup in wet mode, the unit begins to work in wet mode, and the water pump starts.

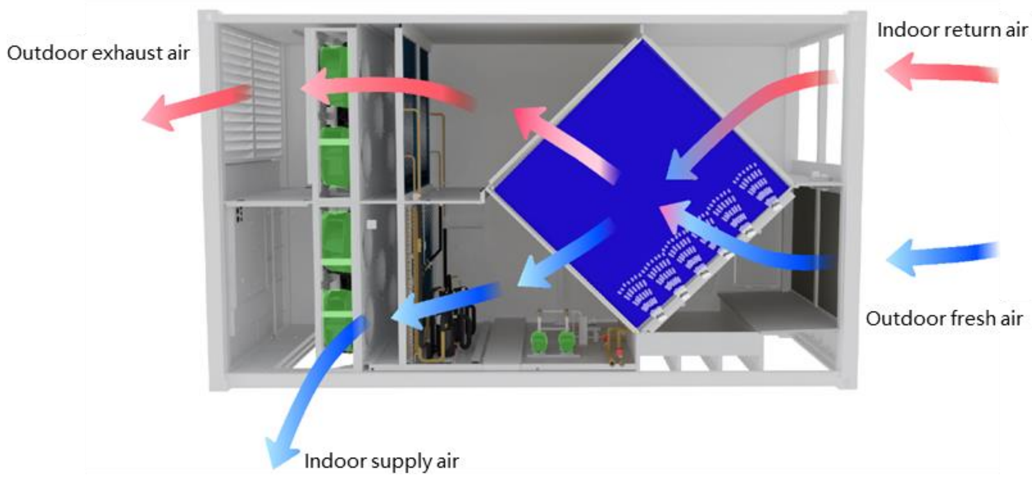


Figure 4-2 *Running status of the IEC system in wet mode*

③ Hybrid mode

When the outdoor ambient temperature is higher than the temperature for startup in wet mode + auxiliary cooling mode, the unit begins to work in hybrid mode, and both the compressor and water pump start.

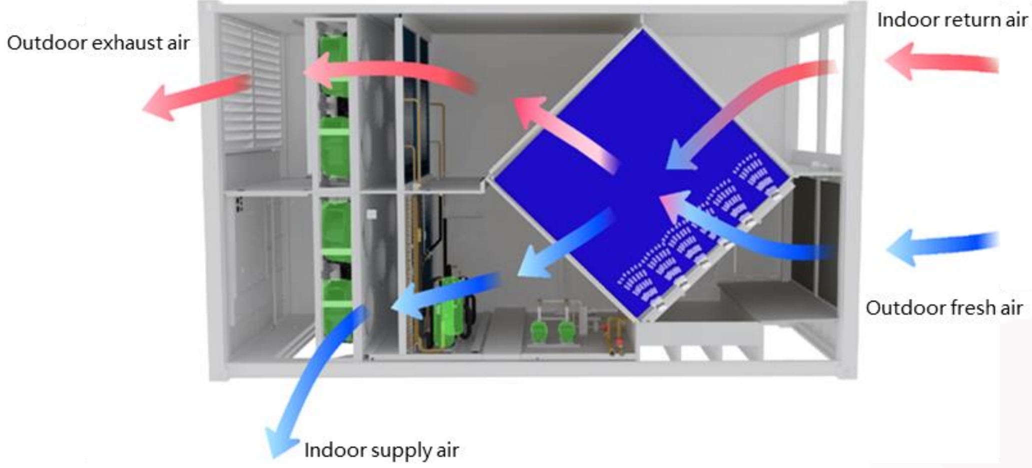


Figure 4-3 *Running status of the IEC system in hybrid mode*

4.1.2 Outdoor Air Handling System

The IEC unit is in direct contact with the outdoor air. Dust, impurities, and catkins in the air may attach to the surface of the core or deposit in the circulating water tank under the action of spray water, which affects the water quality and the reliability of the spray system.

With proper layout of the IEC unit and building, the outdoor air can be turned, slowed down, and settled before entering the unit. Large particles in the air are separated first and not directly sucked into the unit, preventing the air filter from being blocked. As shown in the following figure, this handling mode effectively prevents rain and snow from entering the unit.

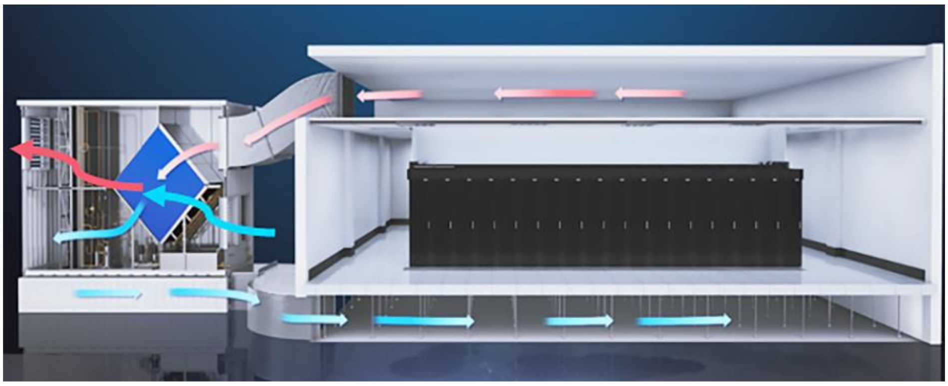


Figure 4-4 *Air handling based on airflow organization*

It is recommended that a G3 or better air filter be installed at the fresh air inlet to prevent the outdoor air quality from adversely affecting the unit. It is recommended that the designed air speed of the air intake surface be 3 m/s at most.

This ensures that the air filter provides a good filtering effect.

In the season with fluffy catkins, the air filter installed in a unit can be easily blocked. Manual cleaning requires heavy workload. It is recommended that an automatic catkin removal device be configured to reduce the O&M workload. In other seasons, the catkin removal device automatically folds up or is bypassed, reducing the operating air resistance and improving the energy efficiency ratio of the IEC system.

4.1.3. Water Treatment System

When the IEC unit works in wet mode or hybrid mode, the spray water directly contacts the heat exchanger core and evaporates on the core surface. In this case, impurities in the water form scale on the core surface, and the chloride in the water corrodes the metal core. It is necessary to control both the hardness of spray water and the content of chloride in water. Therefore, spray water must be pretreated by a water treatment system. The water quality requirements vary depending on the core material. Select a proper water treatment method based on the local water quality. Generally, metal cores have strict requirements on water hardness and chloride content. Therefore, reverse osmosis water needs to be used. Polymer cores provide good anticorrosion performance and have specific requirements only on water hardness. Therefore, softened water needs to be used.

Table 4-2 *Water quality requirements of metal cores and polymer cores*

Item	Water Quality Requirements of Metal Cores	Water Quality Requirements of Non-metal Cores
Filter class	≥ 89 μm	≥ 89 μm
PH value	5 < PH value < 8	5 < PH value < 8
Conductivity	< 1300 μS/cm	< 1300 μS/cm
Total hardness	< 100 mg/L	< 100 mg/L
Total alkalinity	< 50 mg/L $CaCO_3$	< 200 mg/L $CaCO_3$
Chloride	< 120 mg/L	< 250 mg/L
SiO_2	< 5 mg/L	< 10 mg/L
Organic matter	< 3 mg/L	< 3 mg/L

The basic working process of a common water treatment system is as follows:

Raw water supply → Rough filtration → Precision filtration → Water supply tank → IEC unit → Circulating water supply → Rough filtration → Precision filtration → Ultraviolet sterilization device → Water supply tank

4.2. Installation Scenarios and Airflow Organization

The IEC system is installed outside a data center. Cold air is supplied to the data center through the raised floor or diffused air supply. No additional CRAH is required in the data center, leaving more space for installing racks.

4.2.1. Installation Scenarios

IEC units were mainly installed on large flat floors or rooftops in the past. With increasing application of IEC, multi-story installation has become the mainstream and accounts for more than 60% of total installation scenarios.

Multi-story installation scenarios include prefabricated modular data centers as well as indoor and outdoor application of multi-story buildings. The indoor multi-story installation has strict requirements on the length, width, and height of the unit due to building restrictions.

Table 4-3 Installation scenarios of the IEC system

Installation Scenario	Single-Story Application		Multi-Story Application		
	Large flat floor	Rooftop	Prefabricated modular data center	Multi-story building–indoor	Multi-story building–outdoor
Picture					
Feature	Air is supplied and returned on the same side of the data center. Air can be directly exhausted upward outdoors.	Air is supplied and returned on different sides of the data center. Air can be directly exhausted upward outdoors.	Full container stacking and prefabrication	■ The units are installed on the outer edge of each floor. ■ The air exhaust shaft is shared for outdoor air exhaust.	■ The units are installed on a steel support outside the building. ■ The air exhaust shaft is shared for outdoor air exhaust.

4.2.2. Airflow Organization

IEC units were mainly installed on large flat floors or rooftops in the past. With increasing application of IEC, multi-story installation has become the mainstream and accounts for more than 60% of total installation scenarios.

Multi-story installation scenarios include prefabricated modular data centers as well as indoor and outdoor application of multi-story buildings. The indoor multi-story installation has strict requirements on the length, width, and height of the unit due to building restrictions.

① Rooftop application of a single-story data center

Secondary side (outdoor): Air flows in from one end of the unit, exchanges heat inside the unit, and is exhausted from the other end (or directly from the top). The yellow line in the figure shows the airflow direction.

Primary side (data center): Air returns through the shared hot aisle on the top of the data center through the air duct, exchanges heat inside the unit, and is supplied into the data center through the air duct on the other side. The blue line in the figure shows the airflow direction.

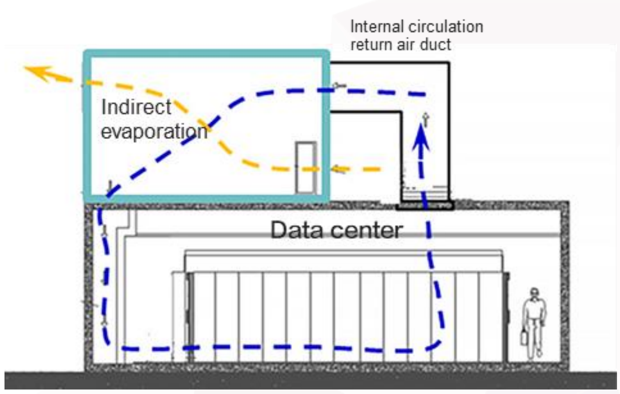


Figure 4-5 IEC system installed on a rooftop

② Side application of a single-story data center

Secondary side (outdoor): Air flows in from one end of the unit, exchanges heat inside the unit, and is exhausted from the other end (or directly from the top). The yellow line in the figure shows the airflow direction.

Primary side (data center): Air returns from the shared hot aisle on the top of the data center through the air duct, exchanges heat inside the unit, and flows into the data center from the other side through the air duct in a 180° direction. The blue line in the figure shows the airflow direction.

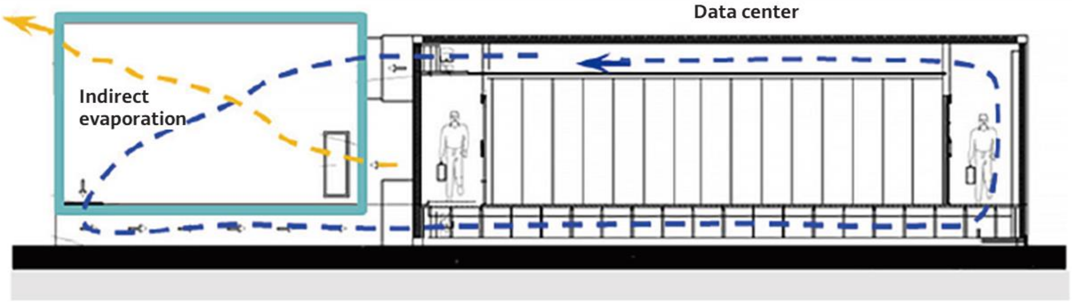


Figure 4-6 IEC system installed on an outdoor side

③ Side application of a multi-story data center

Secondary side (outdoor): Air flows in from one end of the unit, exchanges heat inside the unit, and is exhausted to the outdoor through the air exhaust shaft on the other end. (The air exhaust shaft can be shared by multiple floors or separately deployed for each floor.) The yellow lines in the figure show the airflow direction.

Primary side (data center): Air returns from the shared hot aisle on the top of the data center through the air duct, exchanges heat inside the unit, and flows into the data center from the other side through the air duct in a 180° direction. The blue lines in the figure show the airflow direction.

Note: Ask a professional design institute to design the construction or reconstruction solution for specific installation. In addition, ensure that the installation solution meets the government regulations on planning and fire protection.

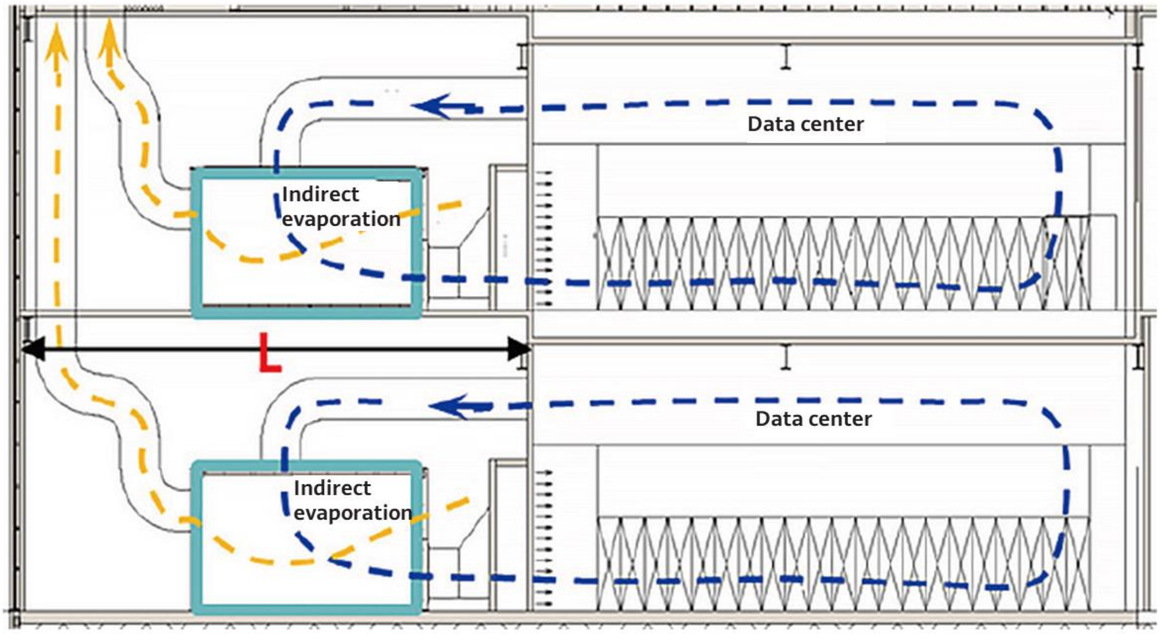


Figure 4-7 IEC system installed on a side of a multi-story data center

4.3. Climate Adaptability

The key of the IEC solution design is to use more free cooling sources. The application effect varies according to local meteorological parameters and air quality. Generally, the direct evaporative cooling solution can be used in areas with good air quality and suitable temperatures, such as China's Guizhou, Europe, and North America. IEC units are suitable in Asia, Europe, South America, and Africa where the temperatures are suitable.

Table 4-4 *Climate adaptability of IEC technology*

Tropical Climate	Temperate Climate	Arid Climate	Nival Climate	Polar Climate
Hot/humid	Warm/humid	Hot/dry	Cold/dry	Extremely cold/dry
Southern East Asia, Middle East, and Northern Latin America	US East, Central/Southern China Japan and West Europe	US West, Northwest China, Middle East, and Western Australia	Northern America, Canada, Northeast Europe, and Russia	Iceland and Sweden
Chilled water, IEC	Chilled water, IEC	Chilled water, IEC	IEC	IEC

5. Comparison Between IEC Systems and Traditional Chilled Water Systems

5.1. PUE and WUE Comparison

IEC systems make full use of free cooling sources. Compared with traditional chilled water systems, IEC systems have obvious advantages in saving power and water and do not require mechanical auxiliary cooling for most of the time when the load is low. The following tables compare the IEC systems and traditional chilled water systems in typical cities with hot summer and cold winter and with hot summer and warm winter. The results show that the PUE and WUE of the IEC systems are much lower than those of the chilled water systems.

Use a model of data centers in London (UK), Santiago (Chile) and Johannesburg (South Africa) The data center has 1500 racks, and a power density of 8 kW/rack. The IT load rate is 50%. IEC solution: N+1 configuration, 50% mechanical auxiliary cooling. Chilled water solution: variable-frequency centrifuge chiller, with free cooling, supply/return water temperature: 15/21°C. The following tables list the detailed data.

Table 5-1 *PUE and WUE comparison between an IEC system and a traditional chilled water system in London (UK)*

Data Center in London (UK)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
PUE	/	1.27	1.16
WUE	(L/kWh)	2.40	0.85

Table 5-2 *PUE and WUE comparison between an IEC system and a traditional chilled water system in Santiago (Chile)*

Data Center in Santiago (Chile)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
PUE	/	1.29	1.16
WUE	(L/kWh)	2.41	1.01

Table 5-3 *PUE and WUE comparison between an IEC system and a traditional chilled water system in Johannesburg (South Africa)*

Data Center in Johannesburg (South Africa)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
PUE	/	1.29	1.16
WUE	(L/kWh)	2.41	1.03

5.2. Phased Deployment Capability Comparison

The cost of water pumps, water valves, meters, pipes, chilled water tanks, and expansion tanks in the chilled water system accounts for about 50% of the overall system investment, and the onsite deployment period accounts for more than 60% of the cooling system. The pipe system construction is complex and involves onsite works such as wall penetration, welding, thermal insulation, and hoisting. For a data center that is constructed by phase, pipes of the entire cooling system are laid out one-off during construction. Only chillers, cooling towers, and CRAHs can be deployed by phase. Therefore, the chilled water system is usually constructed by phase at the system level, which cannot meet the requirements for reducing the initial investment and quickly rolling out services.

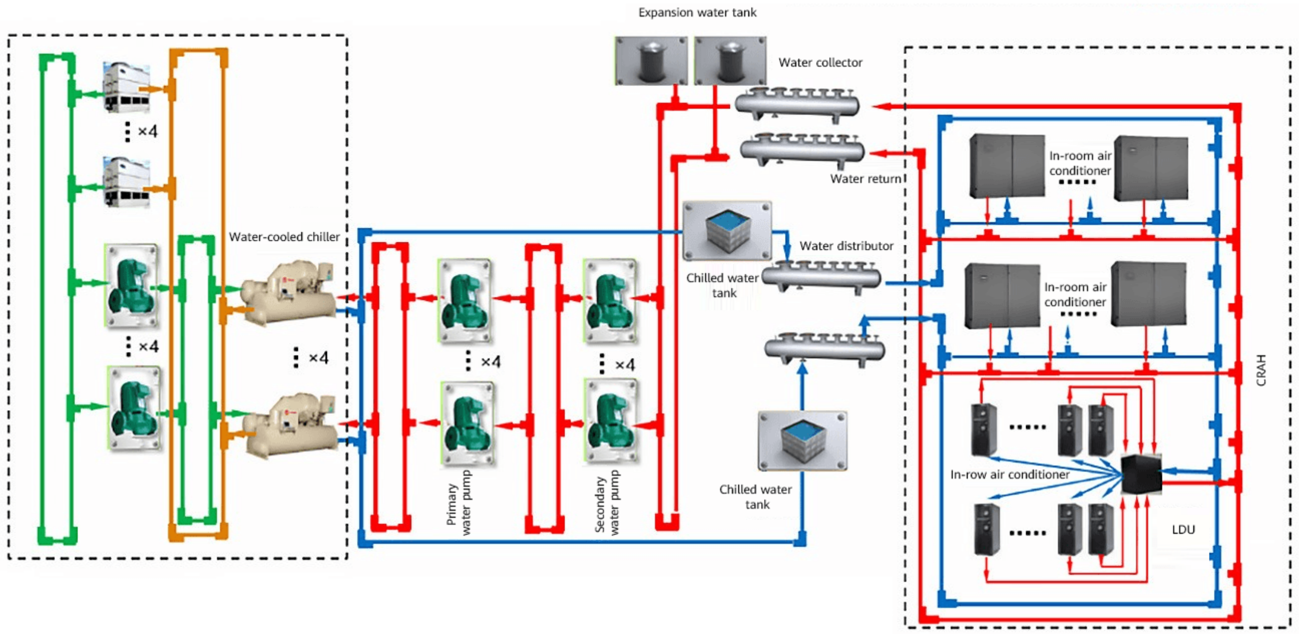


Figure 5-1 Composition of a water-cooled chilled water system

The integrated IEC system integrates mechanical auxiliary cooling, and the hardware of each unit is independent of each other. This design facilitates phased capacity expansion, greatly reduces customers' initial investment, meets the requirements for fast service rollout, and supports phased deployment.

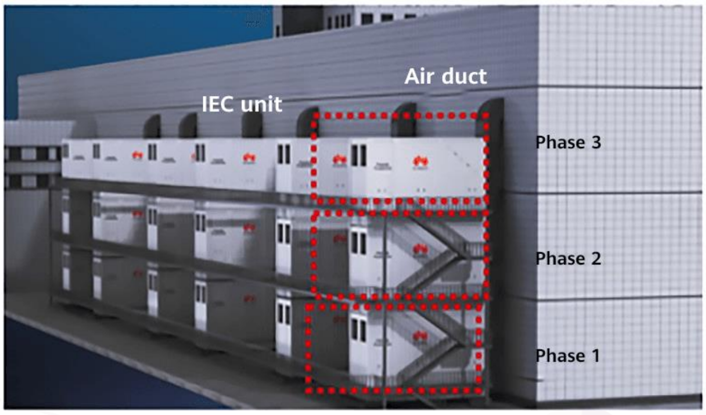


Figure 5-2 Phased deployment of an IEC system

5.3. Deployment Period Comparison

It is a long journey from initial solution design, detailed drawing design, component procurement and production, onsite installation, and commissioning, to the final acceptance and delivery of a data center.

The deployment usually takes 6 to 12 months. The construction and commissioning of the cooling solution account for the largest proportion.

Use a data center with 1500 racks as an example. If the traditional chilled water solution is used, it takes four months to place orders, deliver, and install components such as chillers, cooling towers, CRAHs, water pumps, pipes, and chilled water tanks.

Plus 1.5 months spent in joint commissioning of the components, the total deployment period is 5.5 months.

If the IEC solution is used, only the air ducts, water pipes, and power cables need to be installed onsite as the IEC unit is integrated. They are not strongly coupled with other devices. It takes about three months to complete the process from order placement and production to installation. The unit can be easily commissioned within one month. The total duration is four months, which is 1.5 months shorter than the deployment period of the traditional chilled water solution.

The IEC solution for large data centers greatly shortens the data center deployment period, reduces the CAPEX, and accelerates the service rollout.

5.4. Granularity and Reliability Comparison

The IEC system mainly uses air cooling and evaporative cooling. Multiple units can be deployed separately to meet the heat dissipation requirements of the data center. The IEC system is a distributed cooling source with small granularity and low correlation between devices. Faults cause little impact and can be easily troubleshot so the system is more reliable. The traditional chilled water system is a centralized cooling source. The system is large, complex, and involves a large number of devices that are highly associated with each other. Faults could cause considerable impact and are difficult to troubleshoot so the system is less reliable.

5.5. TCO Comparison

5.5.1. CAPEX Comparison

The CAPEX of a data center includes the costs of construction, devices, installation, and commissioning. The building construction cost is affected by the footprint of the cooling system. In the traditional chilled water solution, chillers have high cooling density but a small footprint. However, the overall solution consists of multiple independent and distributed devices such as cooling towers and CRAHs, resulting in low space utilization. In the IEC solution, devices have low cooling density but a large footprint due to the restriction of the reasonable air speed of the air-to-air heat exchanger. However, the integrated units can be deployed centrally. This feature facilitates the overall layout optimization of the building, improves the space utilization, and eliminates the need to deploy CRAHs in the data center. The IEC solution leaves more space for racks than the chilled water solution. For the same number of racks, the footprint of the IEC solution is 5% to 10% smaller than that of the traditional chilled water solution. However, the air vents of evaporative cooling equipment need to match the data center, which needs to be considered in the early solution design.

The installation and commissioning costs are closely related to the complexity of system composition. IEC equipment is an integrated unit. Compared with the traditional chilled water solution that consists of multiple devices, the IEC solution has natural advantages in installation and commissioning. For the same number of racks, the installation and commissioning costs are reduced by more than 50%.

The IEC unit is an innovative device with high integration and strict requirements on design and production, leading to higher device costs than the chilled water solution. Use a data center with 1500 racks and the power density of 8 kW/rack as an example. The CAPEX of the IEC solution is 10% to 15% higher than that of the traditional chilled water solution.

5.5.2. OPEX Comparison

The OPEX of a data center includes the costs of electricity, water, consumables, and routine maintenance. The electricity cost depends on the PUE of the data center.

The routine maintenance cost depends on the system complexity.

IEC units can use free cooling sources for most of the year, and the cooled air is directly supplied to the data center. In the traditional chilled water system, compressors are used for cooling for most of the year, free cooling is implemented for a small amount of time, and water is used as the secondary refrigerant. The cold water exchanges heat in the CRAHs, causing extra loss due to one more heat transfer. For the same area and load conditions are the same, the IEC solution reduces the annual PUE by more than 0.1 compared with the traditional chilled water solution. The chilled water solution consists of multiple independent devices of different brands, subject to poor collaboration between the devices. IEC equipment is an integrated unit, which is easier to implement collaborative optimization and reduce energy consumption.

The traditional chilled water solution is complex. The devices and parameters to be inspected are several times those of the IEC solution. During the lifetime of the data center, the traditional chilled water solution requires higher O&M costs than the IEC solution. As estimated, the 10-year OPEX of the IEC solution is over 25% lower than the traditional chilled water solution

Use a model of data centers in London (UK), Santiago (Chile) and Johannesburg (South Africa) The data center has 1500 racks, and a power density of 8 kW/rack. The IT load rate is 50%. The 10-year OPEX is estimated. IEC solution: N+1 configuration, 50% mechanical auxiliary cooling. Chilled water solution: variable-frequency centrifuge chiller, with free cooling, supply/return water temperature: 15/21°C. The following tables list the detailed data.

Table 5-4 *TCO comparison between an IEC system and a chilled water system in London (UK)*

Data Center in London (UK)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
CAPEX	M$	4.70	4.85
TCO (10 years)	M$	16.52	8.66
TCO (10 years) saving	M$		7.86

Table 5-5 *TCO comparison between an IEC system and a chilled water system in Santiago (Chile)*

Data Center in Santiago (Chile)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
CAPEX	M$	4.70	4.85
TCO (10 years)	M$	20.37	11.04
TCO (10 years) saving	M$		9.33

Table 5-6 *TCO comparison between an IEC system and a chilled water system in Johannesburg (South Africa)*

Data Center in Johannesburg (South Africa)	Unit	Chilled Water Solution	IEC Solution
Rated IT capacity	MW	12	12
IT load rate	/	50%	50%
CAPEX	M$	4.70	4.85
TCO (10 years)	M$	19.92	10.45
TCO (10 years) saving	M$	/	9.47

6. Applications and Development Directions of IEC Technology

6.1. Enhanced Building Adaptability

IEC units were mainly installed on large flat floors or rooftops in the past. With the exponential growth of data centers, the footprint disadvantage of single-story or two-story data centers increases, and multi-story data centers are developing into the mainstream. However, the outdoor layout of IEC units hinders routine O&M. For IEC units, multi-story indoor application will become the mainstream option.

If an IEC unit needs to be used in a multi-story data center, the building design should be tailored and an independent equipment room should be deployed. The room is used to deploy the IEC unit, air duct, maintenance channel, and air exhaust shaft. Considering the characteristics of the IEC unit and the economical efficiency of the building, it is recommended that the length of the equipment room be 7–9 m (difference in floor quantity affects the size of the exhaust shaft). The net height under the beams should be at least 4.5 m. The units on different floors exhaust air outdoors to the top of the building through the air exhaust shaft to avoid hot air backflow. One or two hoisting holes are reserved on each floor. The dimensions of the holes match the dimensions of the units. After a unit is hoisted to the corresponding floor using the hoisting holes, the unit is moved horizontally to the specified installation position in the equipment room. The exhaust shaft needs to be set at an end of the unit. If the shaft is set between two units, the units cannot be moved horizontally, which will hinder subsequent maintenance or capacity expansion.

In general, a single-story building needs to include the computer room, power distribution room, and pipe and cable shafts to deploy one data center on one floor, facilitating phased construction and on-demand capacity expansion in the future.

6.2. Prolonged Free Cooling Duration in Hot and Humid Areas

With the improvement of server temperature tolerance, the temperature in data centers will become increasingly high and free cooling will be used for a longer time to save energy. IEC units will be applicable in wider areas. For example, in London, Santiago, and Johannesburg, the air temperature is lower than 25°C for more than 7500 hours throughout the year. When air is supplied at 25°C in a data center, free cooling can be used for more than 85% of the time in a year. As the supply air temperature in data centers rises, free cooling can be used for a longer period of time. Compared with the traditional chilled water cooling solution, the IEC solution consumes less water, has a smaller failure domain, and is more suitable for phased deployment and capacity expansion. IEC systems will gradually become a mainstream solution for data centers.

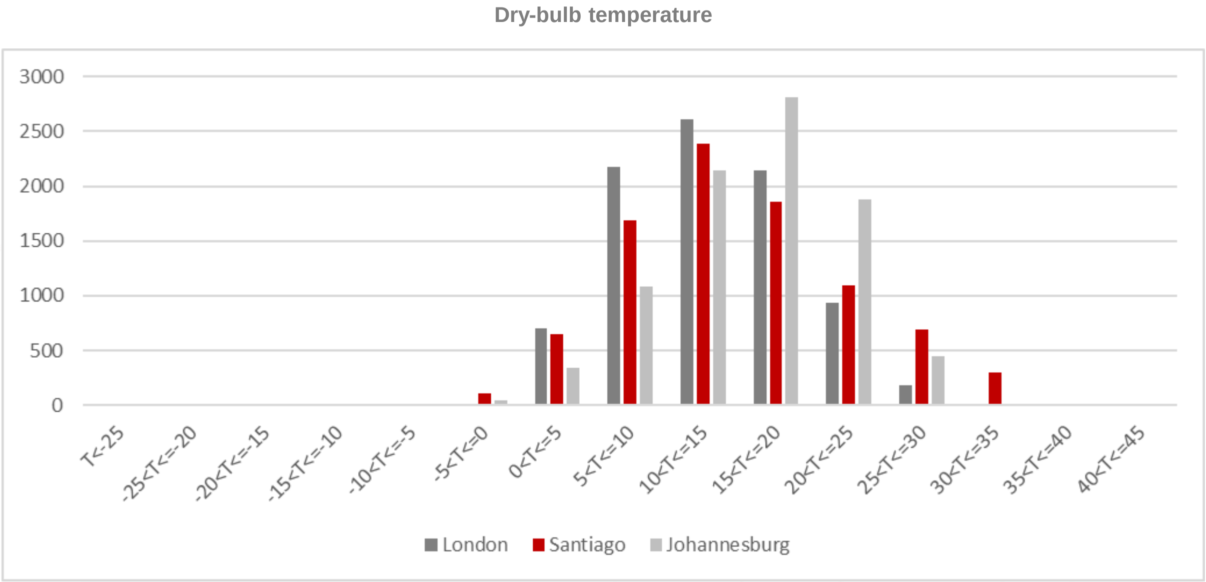


Figure 6-1 Annual dry-bulb temperature distribution in London, Santiago, and Johannesburg

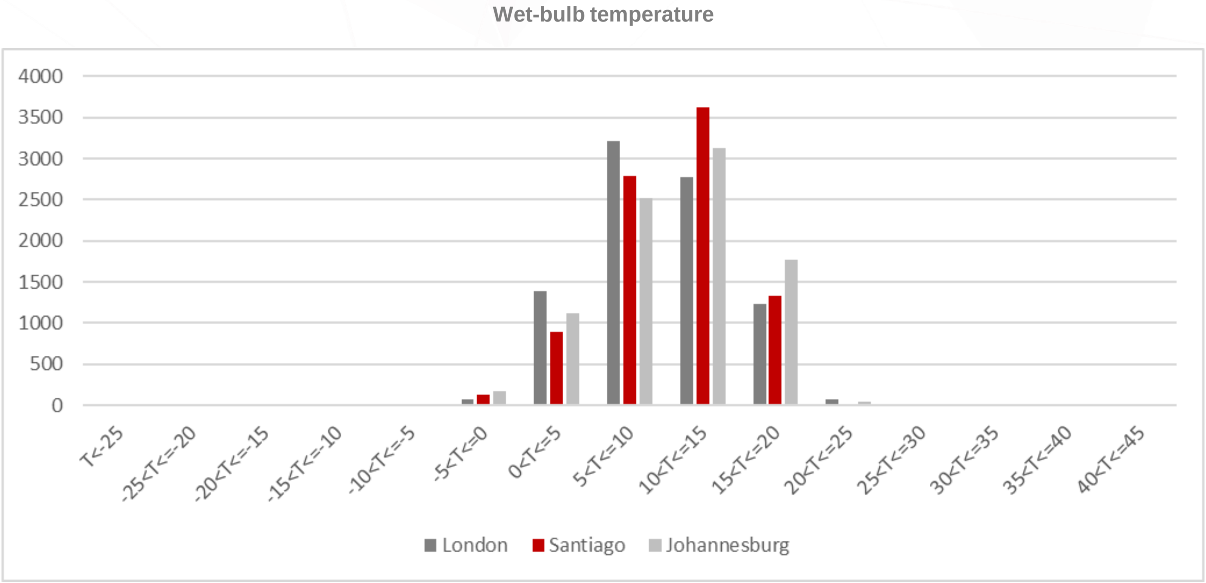


Figure 6-2 *Annual wet-bulb temperature distribution in London, Santiago, and Johannesburg*

However, as the difference between dry and wet bulb temperatures is small during certain periods in humid and hot areas, the spray cooling effect of the IEC units is limited. In addition, spraying generates extra air resistance, which reduces the energy efficiency of the units. During the high-humidity period, the IEC unit can automatically determine the benefit of spraying according to the meteorological parameters and adjust the running status of the spray system in real time to achieve optimal performance.

6.3. Enhanced Application Reliability in Cold Areas

If the IEC solution is used in cold areas, device anti-freezing protection must be considered to ensure continuous and stable running of the cooling system. When the outdoor temperature is low in winter and the surface temperature of the heat exchanger core is lower than 0°C, the condensate water from the primary side will freeze on the surface of the core. In severe cases, the heat exchanger core will be frozen and blocked, and the cooling function of the unit will fail. Effectively monitoring the surface temperature of the heat exchanger core, adjusting the air volume on the primary and secondary sides in real time, and controlling the air humidity on the primary side are necessary measures to avoid freezing.

6.4. Simplified O&M

To accelerate deployment, data centers may gradually evolve from traditional civil construction to prefabricated modular data center solution in the future. Complex onsite working procedures will be left to the factory for prefabrication, accelerating the onsite delivery and meeting the requirements of constructing a large number of data centers.

Traditional cooling systems, especially cooling solutions for large-scale data centers, cannot be integrated into prefabricated modules because a large number and variety of cooling devices and complex pipes are involved. The IEC system solution integrates the free cooling system and direct expansion air cooling system in a modular architecture. It can be quickly deployed with the prefabricated modular data center solution, nearly halving the delivery period compared with the traditional solution. The IEC solution with simplified O&M will gain popularity. In the future, devices will be inspected using a combination of running parameters, sound, light, and image sensors, and Big Data technology to implement intelligent and automatic O&M.

6.5. Normalization of Air Handling Systems

In addition to cooling devices, the heating, ventilation, and air conditioning (HVAC) solution for traditional large-sized data centers also needs to incorporate the humidification and dehumidification functions. The additional devices occupy space in data centers and affect the airflow organization. Most importantly, these devices are independently controlled based on the detected parameters and are not coordinated centrally. Due to differences of parameters detected in different areas of a data center, certain humidifiers and dehumidifiers may run at the same time, which affects the overall PUE of the data center.

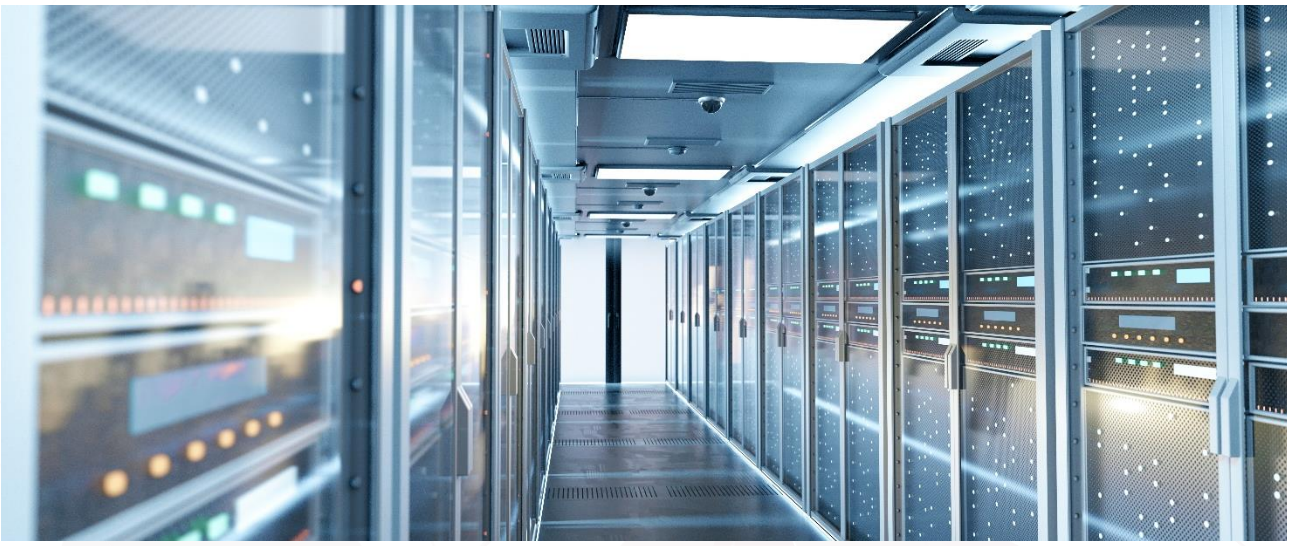
Based on the air distribution characteristics of the IEC system, the outdoor fresh air can be filtered and then supplied to the data center. The fresh air function is integrated to meet the air exchange requirements and maintain micro positive pressure in the data center. The IEC unit is equipped with a compressor-based supplementary cooling system, which implements the dehumidification function based on precise control over the running status of the compressor system. During warm periods in spring, summer, and autumn, the spray system of the unit works and water from the spray water tank can be used for humidification. In winter, the spray system does not work; then, condensate water generated by the heat exchanger core can be collected and reused for humidification in the data center. Wet film humidifiers are recommended because they save more than 95% energy compared with traditional electrode humidifiers and infrared humidifiers.

Fireproof dampers are installed at the return and supply air ducts between the data center and IEC units based on fire compartment design. The isolation damper in the system is closed when a unit is shut down or under maintenance to avoid impact on other running units.

The waste heat utilization of large-scale data centers will be a future development direction. Waste heat is mainly used to heat the domestic water for a campus currently, and it will be distributed remotely for further use in the future. Integrating the heat recovery function into IEC units will be a future development direction. To expand the recovery, it is recommended that waste heat at the air exhaust position on the secondary side be recovered.

Table 6-1 *Comparison between two IEC solutions that use heat recovery*

		Solution 1	Solution 2 (Recommended)
Heat recovery position		Air return position on the primary side (data center)	Air exhaust position on the secondary side (outdoor)
Heat source temperature	Winter (outdoor: –20°C)	38°C	30°C
	Summer (outdoor: 30°C)	38°C	45°C
Heat source	Winter	Data center IT devices	Data center IT devices
	Summer	Data center IT devices	Data center IT devices + compressor for mechanical auxiliary cooling
Heat recovery for exchange	Winter	A	A
	Summer	B	1.15B



7. AI-based New-Generation Intelligent IEC Solution

As data centers require efficient, simple, and intelligent cooling systems, the new-generation IEC technology, with AI as its core, will use IoT, cloud training, and local inference to implement intelligent control over data centers, such as pPUE optimization, fault convergence, root cause locating, and unattended inspection.

As the temperature that the servers can bear becomes higher, data centers will use more free cooling sources. The free cooling solution will be the first choice for future data center cooling. The gap between device hardware is narrowing, and the space for hardware energy-saving is limited. Therefore, software intelligent algorithms are used to achieve optimal energy-saving in terms of collaboration between devices, optimization between running modes, and coordination between internal components.

The IEC system is mainly based on free cooling, supplemented by mechanical auxiliary cooling. The intelligent control dynamically adjusts the operating status of the IEC system and associates with loads in real time to minimize the total energy consumption of the data center and achieve optimal PUE.

7.1. AI-based Energy Efficiency Improvement

The intelligent control of the IEC system includes the following aspects:

The optimal efficiency point of the IEC system is real-time and dynamic, which is closely related to the configuration and environmental disturbance. Through the linkage with the upper-layer servers, the intelligent control automatically optimizes the operating status of the IEC system in real time based on information about the server chip temperature and fans. This greatly improves the overall energy-saving effect of the data center.

The server chips, fans, indoor and outdoor temperature and humidity, and number and distribution of the IEC systems constitute a large amount of information. Therefore, it is difficult to adapt to all application scenarios based on limited test data or inference models. Automatic optimization and control in all scenarios can be achieved through the large amount of data collected by AI tools and processed by machine learning.

The linkage control policy of the IEC system and upper-layer servers is to break the traditional mainstream supply air temperature control mode, adjust the cooling capacity for each area based on the server inlet temperature, and directly provide the precisely matched cooling capacity.

Information about the server chip temperature, fans, indoor and outdoor temperature and humidity, and number and distribution of the IEC systems is used for self-learning from big data using AI.

The AI training platform optimizes the energy consumption model of "smart module servers and IEC system" in real time, produces the inference model for the lowest total energy consumption of the data center, and achieves optimal PUE.

As shown in the following figure, the left example indicates the traditional supply air temperature control mode. Each IEC unit has the same supply air temperature and automatically adjusts the temperature based on the return air. There is no coordination or cooperation between units. As a result, some units may be running at a high temperature and others may be running at a low temperature, which is neither healthy nor energy efficient. The right example indicates the linkage control mode. In this mode, IT loads and IEC units are combined to achieve intelligent IT partitioning. The IT equipment and IEC units in each area are linked. The air outlet temperature in each area can be set differently. In this way, the optimal and most energy-saving operation of the entire data center can be achieved.

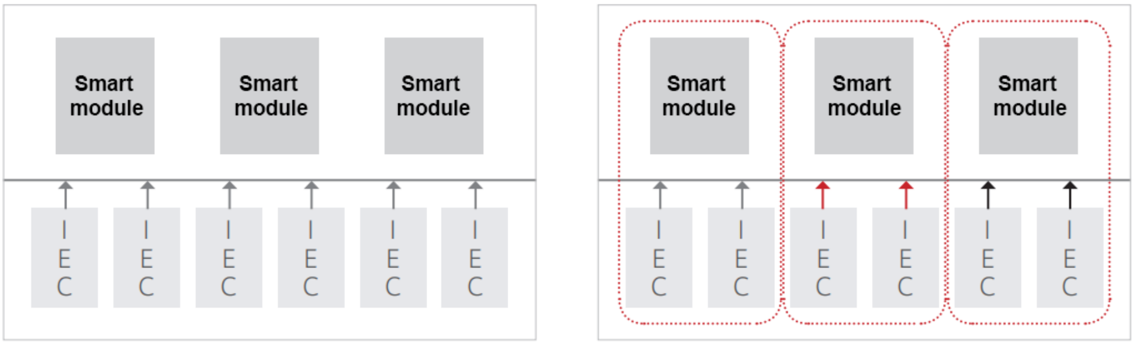


Figure 7-1 *Partitioning and linkage between IEC units and IT equipment*

Definition of the teamwork control function: In one group, one unit is the master unit and the others are slave units. The master unit calculates the teamwork control requirements and delivers control commands.

① Traditional Teamwork Control

A traditional teamwork control typically consists of 32 units working in collaboration to optimize the thermal load distribution and reduce the power consumption. The teamwork control functions include:

- **Backup:** When a unit in the group is faulty, the backup unit starts to operate automatically, improving system reliability.
- **Rotation:** The backup unit works as an operating unit periodically, and each unit in the group works as a backup unit in turns. The operating time of each unit is similar, improving the average service life.
- **On-demand operation:** The number of operating units varies depending on the thermal load power in the data center to meet requirements promptly and eliminate hot spots.
- **Anti-competitive operation:** This function avoids multiple units operating in opposite status (such as humidification and dehumidification, cooling and heating) at the same time to save the overall energy.
- **Automatic teamwork control:** If a communications cable in the group is disconnected, two teamwork control networks are automatically formed, and a new master unit is automatically selected for teamwork control.

② AI-based Intelligent Teamwork Control

The main function of the traditional teamwork control is to improve the reliability of the data center. It has limited effect on the linkage control and energy-saving of multiple IEC systems. In actual operation, the outdoor temperature and humidity, and server load rate change in real time. How to make all the IEC systems in the group run in the most energy-saving state is a new challenge.

AI-based intelligent teamwork control dynamically adjusts the number of running IEC systems and the cooling capacity output in the group based on the changes of the outdoor temperature and humidity and server load rate, while ensuring that the temperature and humidity in the data center are within the preset range. In addition, AI-based intelligent teamwork control optimizes the running combination to achieve the lowest overall energy consumption and optimal PUE. This is shown in the following figure.

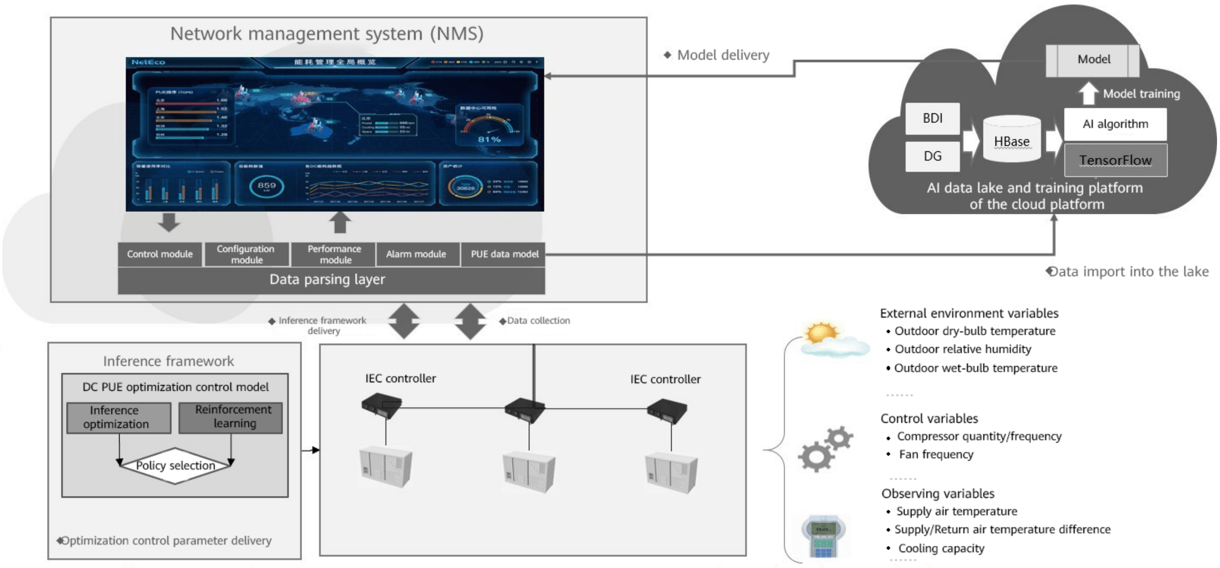


Figure 7-2 AI-based intelligent teamwork control of IEC units

The implementation procedure is as follows:

① A large number of sensors and meters are installed in the data center. They generate a large amount of data, including the running parameters of the IEC system, temperature parameters of the cold and hot aisles in the data center, and rack air intake parameters.

② The running parameters of the IEC units are collected by IEC unit controllers. The information in the data center, such as the temperature, is collected by the data collection unit. These original data is reported to the network management system (NMS).

③ The NMS cleans and processes the original data collected in real time, and saves the data to the database.

④ The data lake of the cloud platform obtains the cleaned data from the NMS, converts the data into training data through feature engineering, and trains the energy consumption model using the training data. After passing the evaluation, the energy consumption model is delivered to the inference service of the NMS.

⑤ The inference service of the NMS uses the energy consumption model and the latest collected data to generate the optimal control policy, and delivers the control policy to the IEC unit controllers. By controlling the running status and parameters of the IEC units, the overall energy consumption can be reduced.

The figure below shows the detailed implementation process.

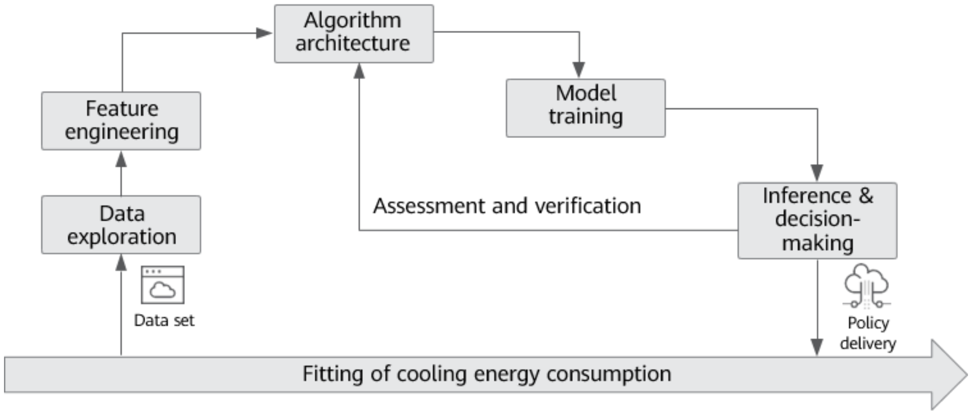


Figure 7-3 *AI-based intelligent teamwork control policy of IEC units*

Data collection:

Collect IEC unit running parameters, such as the fan speed, compressor speed, supply air temperature, IT load, temperature of the cold and hot aisles in the data center, and outdoor environment. One data center is used as an example to build an optimization model. Diversified running data of three cooling modes (dry mode, wet mode, and hybrid mode) is collected at more than 700 locations for months.

Data governance:

Use automatic governance tools to identify the collected data and implement dimension reduction, noise cancellation, and cleaning to generate high-quality training data. Huawei provides a powerful cloud platform service. 100 million pieces of original data can be processed within one hour, and data of 30 minutes can be cleaned within seconds, providing high-quality data for subsequent model training.

Table 7-1 *AI-based data governance interpretation*

Data meaning interpretation	Unify the data dictionary and input and output of the data lake on the cloud platform using data collection standards.
Data quality improvement	Evaluate the data quality based on the general quality evaluation algorithm, restriction rules of the physical attributes of cooling devices, and experts' experience, generate a quality evaluation model for the data center energy-saving domain to quickly identify data problems, shorten the data feedback process, and improve data preparation efficiency.
Data processing automation	Generate data cleaning rules based on the understanding of the services, accumulate the data rules through the data lake on the cloud platform, generate training datasets in one-stop mode, and support quick reuse by different data centers.

Feature engineering:

Data and features determine the upper limit of the AI algorithm. Features of the IEC system can be generated by the horizontal and vertical processing on features of the same type of device using feature creation.

Based on correlation analysis of feature engineering and service domain knowledge, relationship factors are obtained through repeated analysis and calculation, and key feature parameters closely related to the PUE are found. As a result, the number of feature dimensions is reduced from more than 700 to more than 20, such as the IEC system fan speed, supply air temperature setpoint, environment parameters, and IT load. Precise feature selection lowers the requirements on model complexity, reduces the difficulty in hyperparameter optimization, and improves the effect, execution efficiency, and explainability of the model.

Algorithm architecture:

Derivative variables, including the cooling capacity and air volume, are introduced based on deep learning and the physical laws of the cooling system. The cooling system is decoupled with power prediction objects split at the device level to eliminate irrelevant input and improve prediction precision. Intermediate variable information is leveraged to increase the model complexity for model training. Internal prediction errors are analyzed to facilitate model architecture evolution, and parameter optimization. The outputs of multiple models are combined to further improve the model prediction precision.

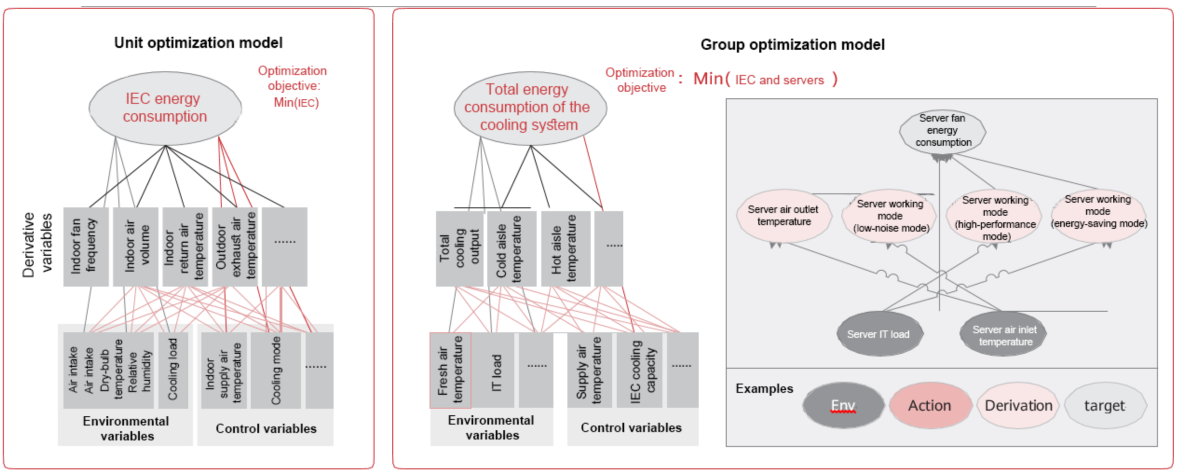


Figure 7-4 AI-based intelligent teamwork control algorithm architecture of IEC units

Model training:

Model training includes model selection, hyperparameter optimization, and model evaluation and verification. For derivative models, algorithms with good prediction effects are chosen for training and hyperparameter optimization in two modes: small-granularity hyperparameter optimization (310,000 combinations) and fast optimization (12,000 combinations). Deep neural networks are used to normalize the features, build an energy consumption model, and repeatedly train the model, so as to avoid local optimal parameter problems in the non-convex neural network optimization.

Different division methods of training data and test data are used in model cross-verification to ensure the model generalization capability. Historical data that does not change greatly or is greatly different from the current working conditions are picked out to improve the model prediction precision for the latest working conditions. Algorithms are used to filter out unsatisfactory models during training to improve the overall model prediction capability.

Inference and decision-making:

Online inference: Optimization algorithms such as the genetic algorithm or greedy algorithm are used to find the control parameter combinations that best meet the current IT load, outdoor environment, and service assurance requirements from the 15 million original cooling policies of all control parameter combinations. The prediction and optimization decision models are delivered to the NMS to calculate the optimal control parameters in the current state in real time.

Optimization mode: Optimization modes are classified into steady-state optimization and non-steady-state optimization. It takes a long time for the cooling system to reach the steady state after parameter adjustment. The online inference model for steady-state optimization is limited by the duration for the system to reach the steady state, resulting in low efficiency. Reinforcement learning is non-steady-state optimization. The next iteration can be performed before the system enters the steady state, shortening the system convergence time.

Energy-saving effect evaluation

Solution 1: Compare the energy consumption during AI optimization with the average energy consumption in the time range of the approximate working conditions (outdoor environment and IT load) in the historical data.

Solution 2: Compare the actual cooling energy consumption in the system after AI parameters are delivered with the cooling energy consumption of the traditional teamwork control parameters under the same working conditions predicted based on the model and teamwork control parameters.

Take one data center as an example (as shown in the following figure). Eight IEC units are configured in N+1 mode. Overall optimal PUE is achieved with 50% server load rate and six running IEC units (40% cooling output of each unit).

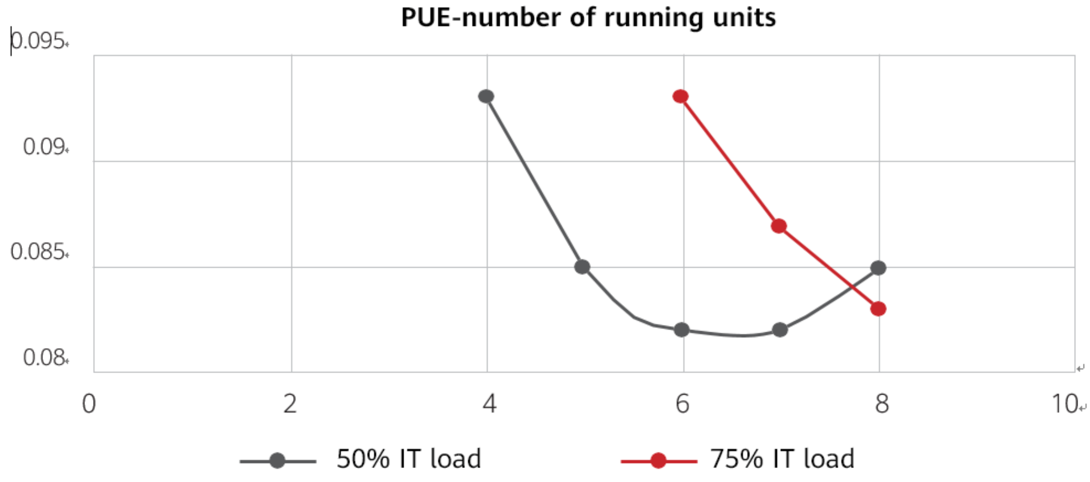


Figure 7-5 *Energy-saving effect evaluation for AI-based intelligent teamwork control of IEC units*

When a single IEC unit runs at different temperatures and humidity of the outdoor environment and different cooling capacity outputs, an optimal switching point of the running mode exists to achieve the lowest energy consumption. During actual running, the system automatically performs optimization control on different running modes based on the changes of the server load rate and temperature and humidity of the outdoor environment to achieve the lowest energy consumption and optimal energy efficiency.

Take one IEC unit as an example (as shown in the following figure). When the outdoor temperature is 10°C and the load rate is 50%, the lowest energy consumption and optimal energy efficiency are reached under wet mode.

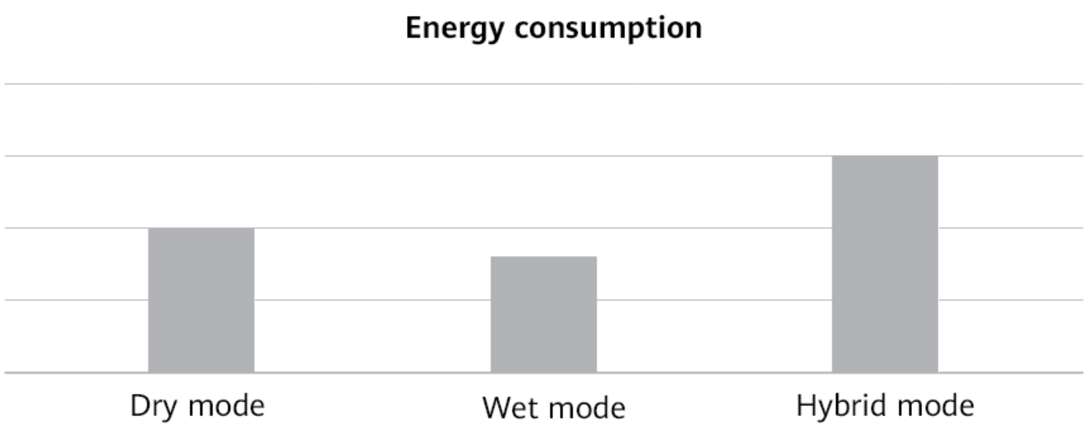


Figure 7-6 *Energy consumption comparison of the IEC unit at 10℃ and 50% load*

In addition, in hybrid mode, when the cooling capacity and supply air temperature remain unchanged, an optimal working status of the internal components in one unit exists to achieve the minimum energy consumption. During actual running, the optimal running status of internal components under the current cooling capacity can be calculated based on the built-in AI model to achieve the lowest energy consumption and optimal energy efficiency.

Take one IEC unit as an example (as shown in the following figure). When the outdoor temperature is 20°C, the load rate is 75%, and the outdoor fan rotational speed is 80%, the lowest energy consumption and optimal energy efficiency are reached in running status 2.

- **Running status 1:** Internal fan running at 80% speed, external fan running at 100% speed, water pump started, compressor rotational speed 1900 rpm, and supply air temperature 25°C.
- **Running status 2:** Internal fan running at 80% speed, external fan running at 80% speed, water pump started, compressor rotational speed 2700 rpm, and supply air temperature 25°C.
- **Running status 3:** Internal fan running at 80% speed, external fan running at 60% speed, water pump started, compressor rotational speed 3600 rpm, and supply air temperature 25°C.

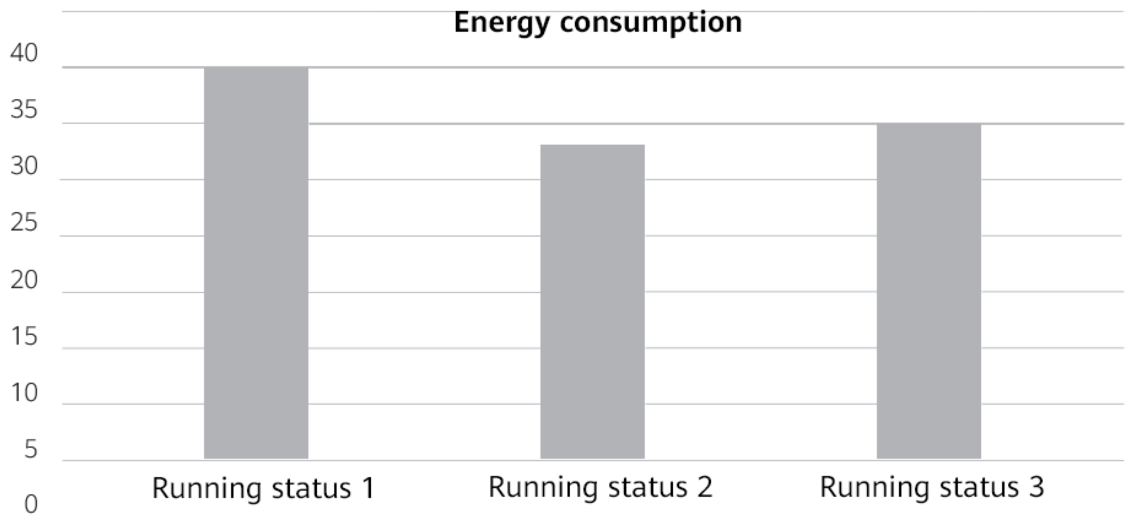


Figure 7-7 *Energy consumption comparison of the same cooling capacity output under different status*

7.2. AI-based Fault Prediction

The intelligent O&M of the IEC system includes the following aspects:

The IEC system contains a large number of components. The manual inspection workload is heavy and requires high professionalism, resulting in high inspection cost. The intelligent O&M is implemented using intelligent sensors, such as cameras, sound pickup devices, and vibration sensors, as well as intelligent algorithms to perform automatic inspection, identify exceptions, and periodically generate inspection reports of the IEC system. Data collection, data upload, model training, and policy delivery are similar to those described in the previous section.

The IEC system involves many inspection items, for example:

① For the fan, perform noise detection to check whether there is interference or foreign object during running, whether the fan jitters, and whether the fan current is normal.

② For the compressor, perform abnormal noise detection to check whether the compressor running parameters are normal, whether components such as the high pressure switch function properly, and whether the drive is normal.

③ For the water pump, perform abnormal noise detection to check whether the ports are loose and whether the pipes leak.

④ For the spray system, check whether the nozzle is dirty or blocked and whether there is foreign object in the water pan.

⑤ For other components, check whether the appearance is damaged, whether each component functions properly, whether the air filter is dirty or blocked, and whether water leakage occurs inside the component.

These inspection items require a large number of professional personnel and plenty of time, which is inefficient. To implement intelligent inspection, intelligent sensors, such as cameras and sound pickup devices, should be installed in appropriate positions inside the IEC system. The intelligent inspection can monitor internal components in real time and generate alarms in a timely manner when detecting exceptions. In addition, it can periodically perform comprehensive automatic inspection, label collected data such as voice and images, process data, analyze data, process models, and generate results using the built-in intelligent algorithms.

An inspection task starts periodically. After collecting the image and sound data, the intelligent inspection completes the inference and identifies exceptions on the edge side, and generates a detection task report for customers on the NMS. When the image or sound is abnormal, an exception warning is issued. Inspection on real-time onsite images and sounds is available for secondary judgment and confirmation.

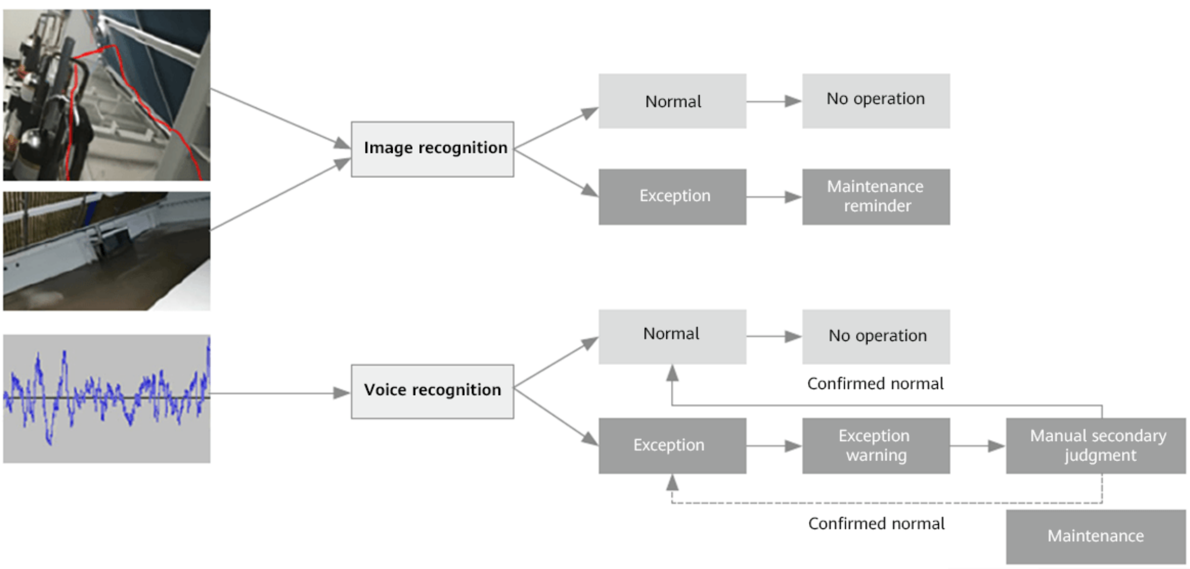


Figure 7-8 *AI-based fault prediction for IEC units*

8. IEC Solution Use Cases

IEC units were mainly installed on large flat floors or rooftops in the past. With the exponential growth of data centers, the footprint disadvantage of single-story or two-story data centers increases, and multi-story data centers are developing into the mainstream. However, the outdoor layout of cooling units hinders routine O&M. For IEC units, multi-story indoor application will become the mainstream option.

If an IEC unit needs to be used in a multi-story data center, the building design should be tailored and an independent equipment room should be deployed. The room is used to deploy the IEC unit, air duct, maintenance channel, and air exhaust shaft. Considering the characteristics of the IEC unit and the economical efficiency of the building, it is recommended that the length of the equipment room be 7–9 m (difference in floor quantity affects the size of the exhaust shaft). The net height under the beams should be at least 4.5 m. The units on different floors exhaust air outdoors to the top of the building through the air exhaust shaft to avoid hot air backflow. One or two hoisting holes are reserved on each floor. The dimensions of the holes match the dimensions of the units. After a unit is hoisted to the corresponding floor using the hoisting holes, the unit is moved to the desired installation position in the equipment room. The exhaust shaft needs to be set at an end of the unit. If the shaft is set between two units, the units cannot be moved horizontally, which will hinder subsequent maintenance or capacity expansion.

In general, a single-story building needs to include the computer room, power distribution room, and pipe and cable shafts to deploy one data center on one floor, facilitating phased construction and on-demand capacity expansion in the future.

① A data center in Chile

404 racks with the power density of 5 kW/rack are installed in this project. The IEC solution is used to reduce the pPUE to 0.079. Compared with a data center that uses the chilled water solution in the same area, the TCO is reduced by 19.3% in three years.

The annual meteorological data of Santiago, Chile, is as follows.

Month	January	February	March	April	May	June	July	August	September	October	November	December	Whole Year
Highest temperature in history °C (°F)	36 (97)	37 (99)	34 (93)	31 (88)	31 (88)	27 (81)	27 (81)	29 (84)	31 (88)	33 (91)	36 (97)	37 (99)	37 (99)
Average high temperature °C (°F)	29.7 (85.5)	29.1 (84.4)	26.9 (80.4)	23.3 (73.9)	18.7 (65.7)	15.2 (59.4)	14.9 (58.8)	16.7 (62.1)	19.0 (66.2)	22.3 (72.1)	25.4 (77.7)	28.4 (83.1)	22.47 (72.44)
Average low temperature °C (°F)	13.0 (55.4)	12.4 (54.3)	10.7 (51.3)	8.0 (46.4)	6.3 (43.3)	4.3 (39.7)	3.9 (39)	4.8 (40.6)	6.1 (43)	8.2 (46.8)	10.1 (50.2)	12.0 (53.6)	8.32 (46.97)
Lowest temperature in history °C (°F)	6 (43)	6 (43)	3 (37)	1 (34)	−3 (27)	−5 (23)	−6 (21)	−5 (23)	−2 (28)	−1 (30)	2 (36)	2 (36)	−6 (21)
Average precipitation mm (inch)	0.4 (0.016)	0.8 (0.031)	3.2 (0.126)	10.4 (0.409)	42.2 (1.661)	70.4 (2.772)	86.6 (3.409)	51.8 (2.039)	22.0 (0.866)	13.4 (0.528)	9.2 (0.362)	2.1 (0.083)	312.5 (12.302)
Average precipitation days	1	1	2	2	6	7	8	6	4	2	2	1	42
Average relative humidity (%)	54	59	63	68	75	79	76	75	72	67	58	53	66.6

Table 8-1 Meteorological data of Santiago, Chile

② A data center in Australia

This project is located in Sydney. 48 racks with the power density of 10 kW/rack are installed. The IEC solution is used. The PUE of the data center is reduced to 1.27, and the annual electricity expense is reduced by 13.6%. In addition, the IEC solution adopts the prefabricated and modular design, shortening the installation time to one month.

The annual meteorological data of Sydney, Australia is as follows.

Month	January	February	March	April	May	June	July	August	September	October	November	December	Whole Year
Highest temperature in history °C (°F)	45.8 (114.4)	42.1 (107.8)	39.8 (103.6)	33.9 (93)	30.0 (86)	26.9 (80.4)	25.9 (78.6)	31.3 (88.3)	34.6 (94.3)	38.2 (100.8)	41.8 (107.2)	42.2 (108)	45.8 (114.4)
Average high temperature °C (°F)	25.9 (78.6)	25.8 (78.4)	24.7 (76.5)	22.4 (72.3)	19.4 (66.9)	16.9 (62.4)	16.3 (61.3)	17.8 (64)	20.0 (68)	22.1 (71.8)	23.6 (74.5)	25.2 (77.4)	21.7 (71.1)
Average low temperature °C (°F)	18.7 (65.7)	18.8 (65.8)	17.6 (63.7)	14.7 (58.5)	11.5 (52.7)	9.3 (48.7)	8.0 (46.4)	9.0 (48.2)	11.1 (52)	13.6 (56.5)	15.6 (60.1)	17.5 (63.5)	13.8 (56.8)
Lowest temperature in history °C (°F)	10.6 (51.1)	9.6 (49.3)	9.3 (48.7)	7.0 (44.6)	4.4 (39.9)	2.1 (35.8)	2.2 (36)	2.7 (36.9)	4.9 (40.8)	5.7 (42.3)	7.7 (45.9)	9.1 (48.4)	2.1 (35.8)
Average precipitation mm(inch)	101.7 (4.004)	118.3 (4.657)	129.8 (5.11)	127.2 (5.008)	120.6 (4.748)	131.2 (5.165)	98.3 (3.87)	80.3 (3.161)	68.6 (2.701)	77.1 (3.035)	83.6 (3.291)	77.6 (3.055)	1,214 (47.795)
Average precipitation days	12.2	12.5	13.5	12.8	13.1	12.5	11.2	10.4	10.5	11.6	11.7	11.5	143.5
Average sunshine hours per day	7.1	6.7	6.4	6.4	5.9	5.5	6.4	7.1	7.2	7.2	7.8	7.6	6.8

Table 8-2 Meteorological data of Sydney, Australia

③ A data center in the UK

This project is a multi-story data center. Each floor has 528 racks and the power density/rack is 4.32 kW. The IEC units are installed on the second to seventh floors inside the building. The PUE of the data center reaches 1.16.

The annual meteorological data of London, UK is as follows.

Month	January	February	March	April	May	June	July	August	September	October	November	December	Whole Year
Highest temperature in history °C (°F)	17.2 (63)	19.6 (67.3)	24.2 (75.6)	29.2 (84.6)	32.8 (91)	35.6 (96.1)	36.5 (97.7)	38.1 (100.6)	35.2 (95.4)	29.6 (85.3)	20.8 (69.4)	17.2 (63)	38.1 (100.6)
Average high temperature °C (°F)	8.1 (46.6)	8.4 (47.1)	11.3 (52.3)	14.2 (57.6)	17.9 (64.2)	21.0 (69.8)	23.5 (74.3)	23.2 (73.8)	19.9 (67.8)	15.5 (59.9)	11.1 (52)	8.3 (46.9)	15.2 (59.4)
Average low temperature °C (°F)	2.3 (36.1)	2.1 (35.8)	3.9 (39)	5.5 (41.9)	8.7 (47.7)	11.7 (53.1)	13.9 (57)	13.7 (56.7)	11.4 (52.5)	8.4 (47.1)	4.9 (40.8)	2.7 (36.9)	7.5 (45.5)
Lowest temperature in history °C (°F)	−13.6 (7.5)	−9.5 (14.9)	−7.2 (19)	−3.8 (25.2)	−0.4 (31.3)	2.8 (37)	6.5 (43.7)	6.7 (44.1)	2.8 (37)	−4.6 (23.7)	−6.3 (20.7)	−12.0 (10.4)	−13.6 (7.5)
Average precipitation mm (inch)	55.2 (2.173)	40.9 (1.61)	41.6 (1.638)	43.7 (1.72)	49.4 (1.945)	45.1 (1.776)	44.5 (1.752)	49.5 (1.949)	49.1 (1.933)	68.5 (2.697)	59.0 (2.323)	55.2 (2.173)	601.7 (23.689)
Average sunshine hours per day	61.5	77.9	114.6	168.7	198.5	204.3	212.0	204.7	149.3	116.5	72.6	52.0	1,632.6

Table 8-3 Meteorological data of London, UK

④ 5A data center in Ireland

The data center covers an area of about 900 square meters and uses the IEC solution. The PUE reaches 1.15, which is tier IV. The system availability reaches 99.998%.

The annual meteorological data of Zurich, Switzerland is as follows.

Month	January	February	March	April	May	June	July	August	September	October	November	December	Whole Year
Highest temperature in history°C(°F)	16.9 (62.4)	19.3 (66.7)	23.2 (73.8)	31.3 (88.3)	32.4 (90.3)	36.4 (97.5)	37.7 (99.9)	36.2 (97.2)	32.5 (90.5)	28.7 (83.7)	23.8 (74.8)	17.0 (62.6)	37.7 (99.9)
Average high temperature°C(°F)	2.9 (37.2)	4.6 (40.3)	9.5 (49.1)	13.8 (56.8)	18.5 (65.3)	21.6 (70.9)	24.0 (75.2)	23.3 (73.9)	18.8 (65.8)	13.7 (56.7)	7.2 (45.0)	3.7 (38.7)	13.5 (56.3)
Average daily temperature°C(°F)	0.3 (32.5)	1.3 (34.3)	5.3 (41.5)	8.8 (47.8)	13.3 (55.9)	16.4 (61.5)	18.6 (65.5)	18.0 (64.4)	14.1 (57.4)	9.9 (49.8)	4.4 (39.9)	1.4 (34.5)	9.3 (48.7)
Average low temperature°C(°F)	−2.0 (28.4)	−1.6 (29.1)	1.7 (35.1)	4.5 (40.1)	8.8 (47.8)	11.9 (53.4)	14.0 (57.2)	13.8 (56.8)	10.5 (50.9)	7.0 (44.6)	2.0 (35.6)	−0.7 (30.7)	5.8 (42.4)
Lowest temperature in history°C(°F)	−20.8 (−5.4)	−24.2 (−11.6)	−14.4 (6.1)	−6.5 (20.3)	−2.0 (28.4)	0.9 (33.6)	5.3 (41.5)	4.0 (39.2)	−0.3 (31.5)	−5.5 (22.1)	−11.0 (12.2)	−18.5 (−1.3)	−24.2 (−11.6)
Average precipitation mm(inch)	63 (2.5)	64 (2.5)	78 (3.1)	83 (3.3)	122 (4.8)	128 (5.0)	124 (4.9)	124 (4.9)	99 (3.9)	86 (3.4)	79 (3.1)	83 (3.3)	1,134 (44.6)
Average snowfall	18.4 (7.2)	22.0 (8.7)	13.7 (5.4)	3.0 (1.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.8 (0.3)	8.0 (3.1)	19.1 (7.5)	85.0 (33.5)
Average precipitation days	10.5	9.3	11.9	11.4	12.4	12.7	12.3	11.6	10.2	9.9	10.3	11.4	133.9
Average snow days	4.8	5.2	3.2	0.7	0.0	0.0	0.0	0.0	0.0	0.1	1.6	4.8	20.4
Average relative humidity	83	78	72	69	71	71	71	74	79	83	84	84	77
Average sunshine hours per day	55	81	124	153	175	189	215	200	150	102	59	42	1,544

Table 8-4 Meteorological data of Zurich, Switzerland

⑤ A data center in Switzerland

The total IT load of the data center is 15.36 MW with 8 kW/rack. 120 sets of Huawei FusionCol8000-E are used to implement 100% free cooling throughout the year. The annual pPUE is 0.09.

The annual meteorological data of Dublin, Ireland is as follows.

Month	January	February	March	April	May	June	July	August	September	October	November	December	Whole Year
Highest temperature in history °C (°F)	18.5 (65.3)	18.1 (64.6)	23.6 (74.5)	22.7 (72.9)	26.8 (80.2)	28.7 (83.7)	31.0 (87.8)	31.0 (87.8)	27.6 (81.7)	24.2 (75.6)	20.0 (68)	18.1 (64.6)	31.0 (87.8)
Average high temperature °C (°F)	8.8 (47.8)	8.9 (48)	10.7 (51.3)	12.4 (54.3)	15.2 (59.4)	18.0 (64.4)	20.2 (68.4)	19.6 (67.3)	17.3 (63.1)	14.0 (57.2)	11.0 (51.8)	9.3 (48.7)	13.8 (56.8)
Average low temperature °C (°F)	3.9 (39)	3.9 (39)	5.2 (41.4)	6.4 (43.5)	9.0 (48.2)	11.6 (52.9)	13.5 (56.3)	13.3 (55.9)	11.4 (52.5)	8.8 (47.8)	6.2 (43.2)	4.5 (40.1)	8.2 (46.8)
Lowest temperature in history °C (°F)	−15.6 (3.9)	−13.4 (7.9)	−9.8 (14.4)	−7.2 (19)	−5.6 (21.9)	−0.7 (30.7)	1.8 (35.2)	0.6 (33.1)	−1.7 (28.9)	−5.6 (21.9)	−9.3 (15.3)	−15.7 (3.7)	−15.7 (3.7)
Average precipitation mm (inch)	62.6 (2.465)	46.1 (1.815)	51.8 (2.039)	50.2 (1.976)	57.9 (2.28)	59.2 (2.331)	50.5 (1.988)	65.3 (2.571)	56.7 (2.232)	76.0 (2.992)	69.4 (2.732)	68.7 (2.705)	714.6 (28.134)
Average precipitation days (≥ 1 mm)	12	10	11	11	11	9	10	10	9	12	11	12	128
Average sunshine hours per day	58.9	75.3	108.9	160.0	194.5	179.2	164.3	156.8	128.8	103.3	70.6	52.6	1,453.2

Table 8-5 Meteorological data of Dublin, Ireland

Scan the code for more information

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