



数字中国万里行
China Digital Journey

Hyperscale Cloud **2018 Data Center** *China's Investigation Report*

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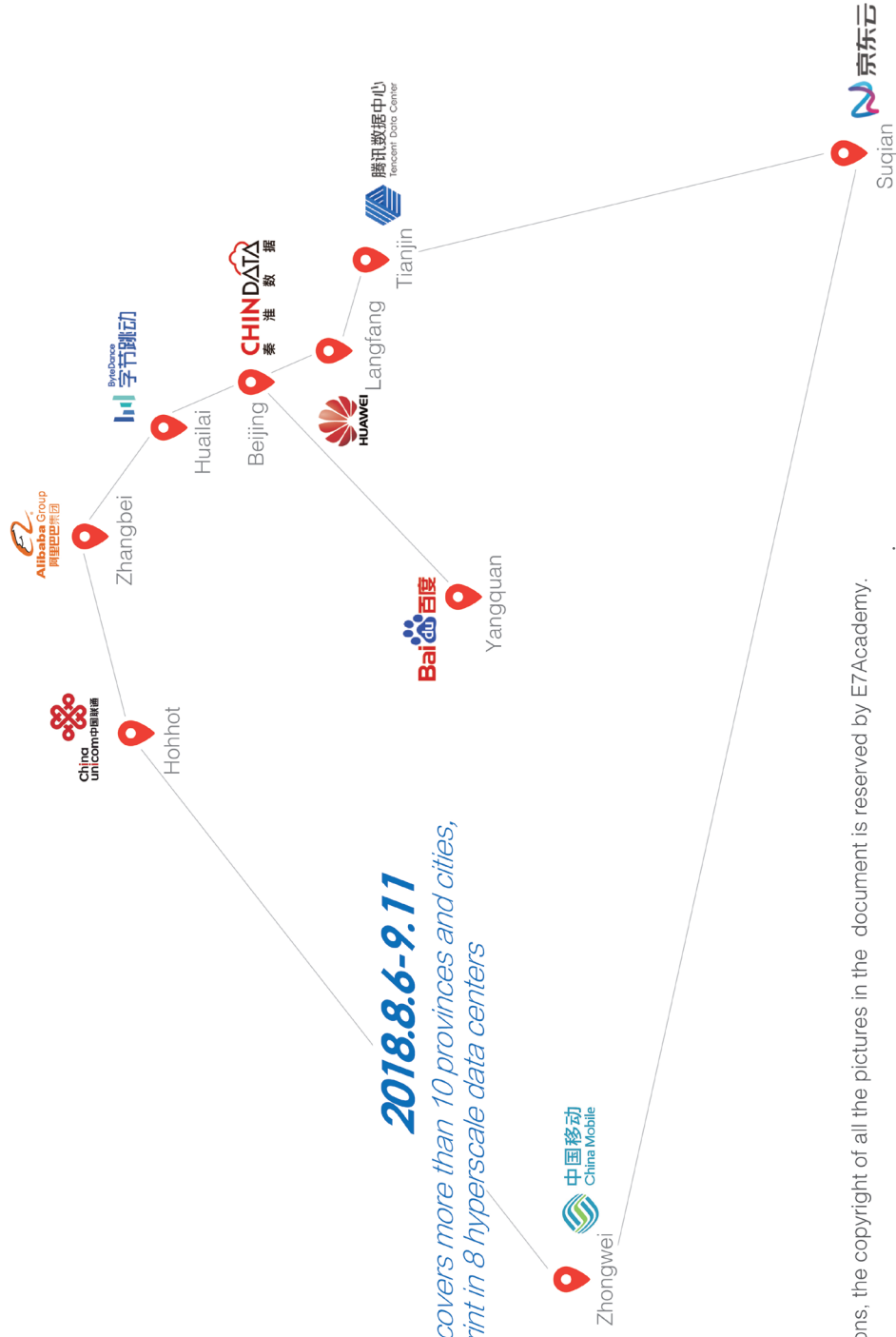
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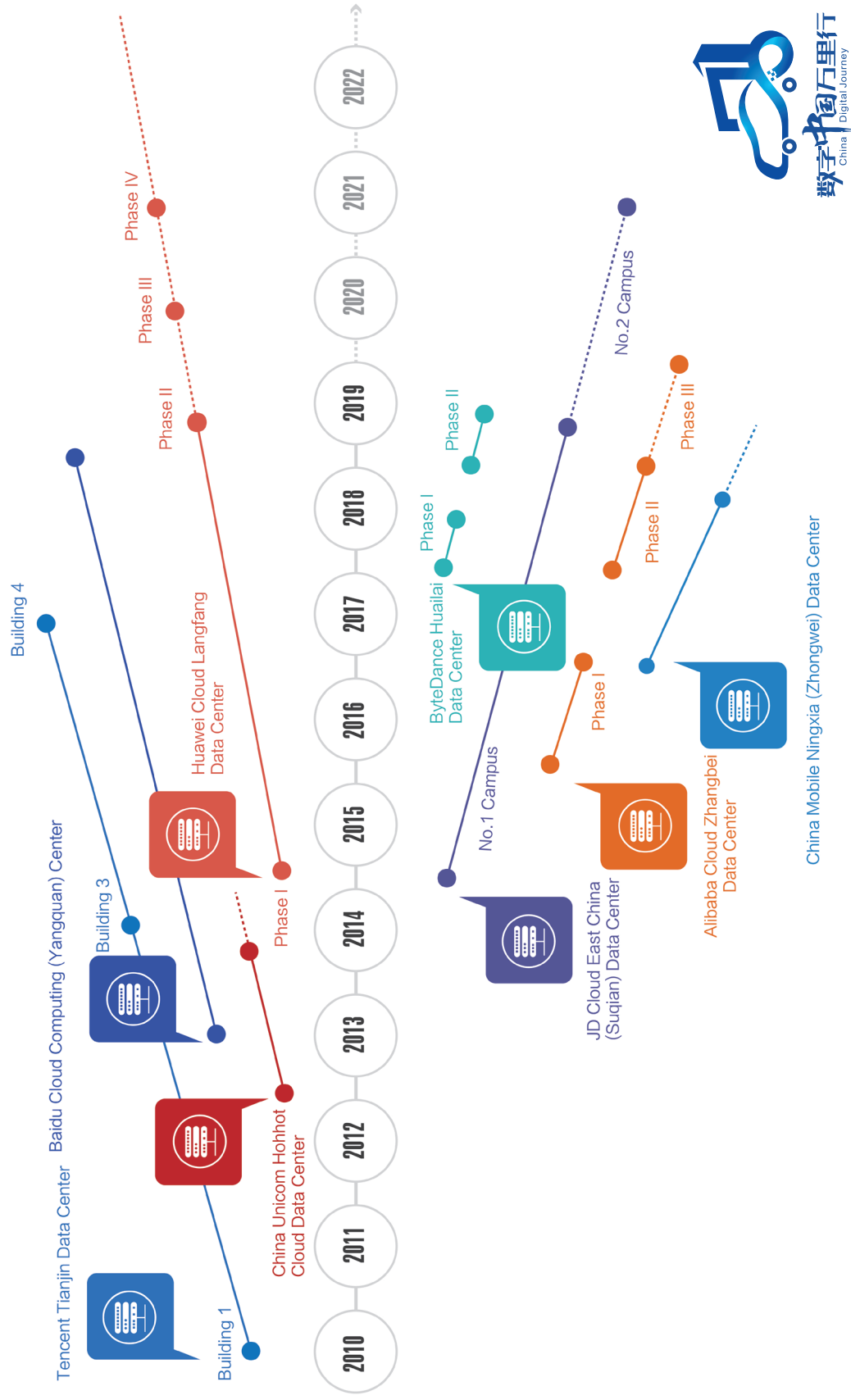
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Chapter 1

Infrastructure competition behind the Internet and Cloud Computing

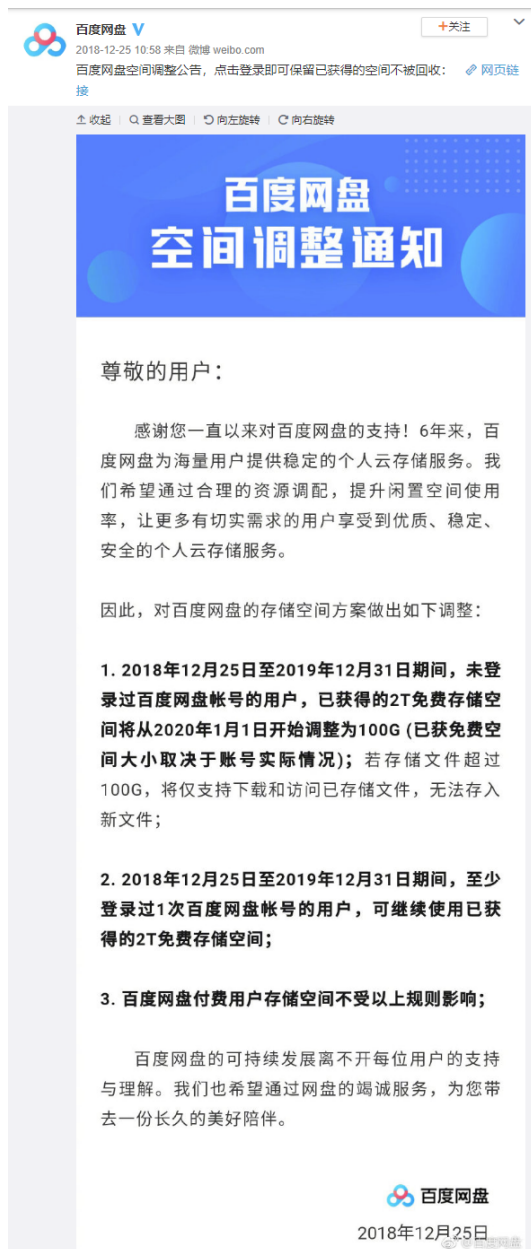
There are two highlights of the hyperscale data centers either self-built or customized by the large cloud computing and internet companies in China. First of all, China is almost as developed as international advanced level in the hyperscale data center constructions. However, in terms of quantities, the number of hyperscale data centers does not match the big market size and the development potential in China. To illustrate the development of cloud and data center industry in China, Beijing E7Academy Co. initiated the “2018 China Digital Journey - Data Center Tour in Northern China” from August 6 to September 11, 2018, with a journey of more than 5,000 kilometers from North China to Northwest China and East China across 10 hyperscale and large-scale data centers which are self-built or customized by Tencent, Huawei Cloud, ChinData, ByteDance, Alibaba, China Mobile, China Unicom, JD.com and Baidu.

In the past two decades, the Internet has changed our lives and work;

In the past decade, cloud computing has gradually entered into more and more enterprises.

From the consumers to the enterprises, the Internet and the cloud computing have become commonplace. However, the infrastructure that supports the rapid growth of the Internet and the cloud computing has not get sufficient attention in China.

Taking WeChat which we use every day for example, the daily login of WeChat in August 2018 exceeded 1 billion person-times. On the Symposium on Cloud Computing (SoCC'18) held in mid-October 2018, a paper published by Tencent showed that the WeChat business system ran more than 3,000 services on over 20,000 servers.



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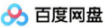
尊敬的用户:

感谢您一直以来对百度网盘的支持! 6年来, 百度网盘为海量用户提供稳定的个人云存储服务。我们希望通过合理的资源调配, 提升闲置空间使用率, 让更多有切实需求的用户享受到优质、稳定、安全的个人云存储服务。

因此, 对百度网盘的存储空间方案做出如下调整:

1. 2018年12月25日至2019年12月31日期间, 未登录过百度网盘帐号的用户, 已获得的2T免费存储空间将从2020年1月1日开始调整为100G (已获免费空间大小取决于账号实际情况); 若存储文件超过100G, 将仅支持下载和访问已存储文件, 无法存入新文件;
2. 2018年12月25日至2019年12月31日期间, 至少登录过1次百度网盘帐号的用户, 可继续使用已获得的2T免费存储空间;
3. 百度网盘付费用户存储空间不受以上规则影响;

百度网盘的可持续发展离不开每位用户的支持与理解。我们也希望通过网盘的竭诚服务, 为您带去一份长久的美好陪伴。

 百度网盘
2018年12月25日

If the electricity consumed by one server is 400W (Watts), a total of 70 million kWh will be consumed by 20,000 servers in one year; if PUE=1.5, taking into account an additional electricity consumption of 35 million kWh required for the cooling, power supply and other relevant fields of the data center infrastructure, total electricity consumption would reach over 100 million kWh every year.

On Alibaba's "Singles' Day" Shopping Festival of 2018, the transaction volume reached RMB213.5 billion. According to data released by the NUCC, the number of transactions on the Singles' Day reached 1.17 billion, with the transaction processing exceeding 92,000 per second at the peak. To support these transactions, over 10,000 servers were needed.

The data storage of Baidu Netdisk had reached 200PB in 2015, which required a storage space of 600PB at least according to the three-copy

On December 25, 2018, Baidu Netdisk announced that the free storage space would be reduced from 2TB to 100GB, whereas the paid users would not be affected. Because of the influx of competitors around 2013, the China cloud disk companies competed for users by launching the free large-capacity cloud storage, which was obviously unsustainable due to the apparent violation of market rules. As a winner of the competition, Baidu Netdisk has been sustained for a long time (according to announcement, the adjustment will take effect as of January 1, 2020)

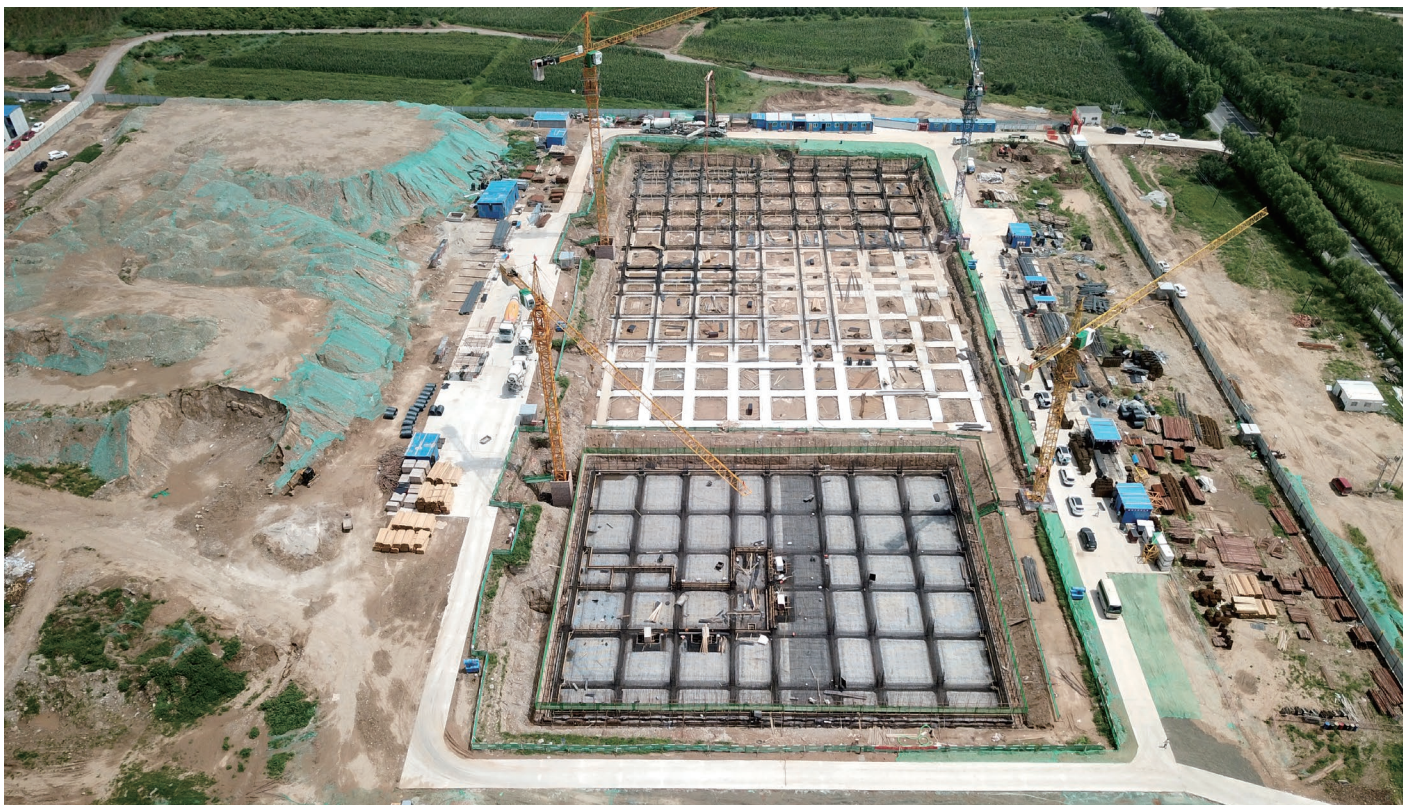
mechanism. To this end, about 13,000 servers equipped with 12* 4TB hard drives were required. The increase in data storage volume over time will also drive a continuous increase in the total number of servers.

Video applications require even more consumption of the computing and storage capability. ByteDance's Toutiao (TopBuzz) and Douyin (Tik tok) grew rapidly in business and obtained over 100 million daily active user (DAU) in July 2017. According to the third-party statistics, the daily playback of Douyin alone had exceeded 1 billion times. Correspondingly, the number of servers of ByteDance had grown rapidly from 20,000~30,000 in early 2017 to more than 170,000 in mid-2018.

The cases mentioned above are just one or two applications of the Internet giants. At the level of the entire company, the scale of the infrastructure is even more amazing. Still taking Tencent as an example, the number of servers in its data center campus in Binhai, Tianjin alone has exceeded 100,000, and Tencent is also the enterprise which is most likely to own 1 million servers at first in China.

Cloud computing also has a high demand for infrastructure, because it is used for carrying massive applications from many enterprises - although the scale of a single application is difficult to match the “national applications” such as WeChat, the total number of enterprise applications is huge. In early December 2015, Tencent announced that the number of its servers had exceeded 500,000. According to an internal source at that time, within two years, half of the newly added Internet Data Center (IDC) resources will be taken by Tencent Cloud business.

Two years have passed, it is unclear whether the estimate has been realized or not. What we can see is that on August 22, 2018 during the 2018 China Digital Journey - Data Center Tour in Northern China, the Tencent North China Information Technology Industry Headquarters Base was stationed in the Huailai Ring Capital New Generation Information Technology Demonstration Zone. According to the agreement, Tencent will invest in three data center bases in Huailai County, Zhangjiakou City, covering a total area of 1,050 mu (approximately 700,000m²), with each covering an area of 350 mu (approximately 233,333.3m²). After



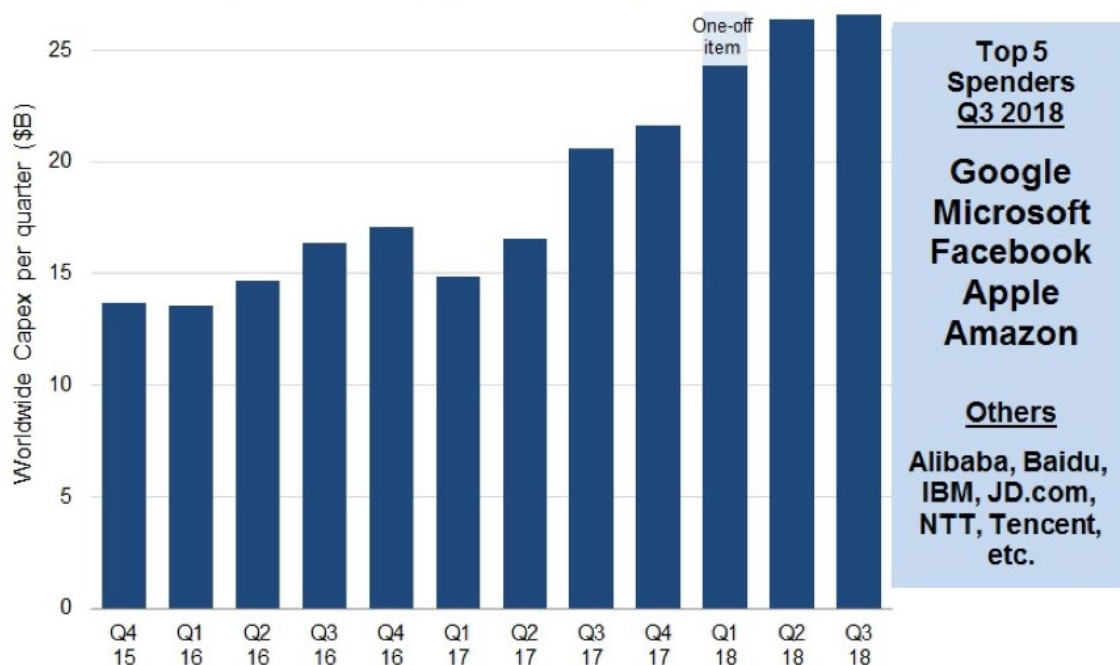
completion of these bases in 2022, about 1 million servers will be installed.

After being completed, it not only will become the largest data center base of Tencent in the North China, but also Tencent will spend four years installing servers, the number of which is more than the total of Tencent's current servers, in Huailai, in order to construct a "comprehensive cloud computing industrial base which has the largest scale and the highest level in the development history of Tencent in a non-core city."

Tencent's such huge investment in infrastructure construction is a little earlier than the new round of organizational restructuring including the build-up of the Cloud and Smart Industries Group (CSIG). It also conforms to the law of cloud computing business development that gives priority to infrastructure.

Amazon Web Services (AWS), as the leader in the public cloud market, owns the world's largest IT infrastructure: according to the Worldwide Quarterly Server Tracker 2017Q2 published by International Data Corporation (IDC), Amazon itself accounts for more than 10% of the server shipments, namely, the quarterly purchase of over 250,000 servers. As the continuous growth of AWS business, these figures are gradually climbing.

Hyperscale Operator Capex Growth



Source: Synergy Research Group

Google, Microsoft, Amazon, Apple, and Facebook (FAMGA) are the top five hyperscale operators in capital expenditure (CapEx), accounting for 70% of the entire market (\$26 billion USD) in the third quarter (Q3) of 2018. The funds are mainly used for the expansion and equipment of the hyperscale data centers. (source: Synergy Research Group)

At present, it is widely speculated in the industry that Amazon has 4 million or 5 million servers in total, which is twice or more of the sum of servers owned by Baidu, Alibaba and Tencent (BAT). It is certain

that Google, Microsoft and Facebook own more than 1 million servers respectively. Apple also frequently invests more than \$1 billion USD in data center construction (unfortunately, its expansion is not very smooth in Europe). However, compared with the European and American markets, China's cloud computing market has greater growth potential and provides a broader imagination for infrastructure construction.

China's Internet companies has become global, which makes China the world's second largest market. After growth and expansion in China, China's Internet giants have gone to the international market and compete with the international giants such as AWS, Microsoft and Google. For example, Alibaba not only has entered the ranks of global public cloud leaders (ranked the fourth), but also has overtaken Microsoft and ranked the second in APAC Region, and Tencent has also entered the top five in APAC Region.

Public Cloud Leadership by Region – Q3 2018

Rank	Worldwide	North America	EMEA Region	APAC Region	Latin America
Leader	AWS	AWS	AWS	AWS	AWS
#2	Microsoft	Microsoft	Microsoft	Alibaba	Microsoft
#3	Google	Google	Google	Microsoft	Google
#4	Alibaba	Salesforce	IBM	Google	Salesforce
#5	#5= IBM #5= Salesforce	IBM	Salesforce	Tencent	IBM

Source: Synergy Research Group

The rankings of the top five public cloud providers worldwide as well as in the North America, EMEA Region (Europe, Middle East & Africa), APAC Region and Latin America, including the China providers Alibaba (Alibaba Cloud) and Tencent (Tencent Cloud) (source: Synergy Research Group)



/ Data center consolidation driven by Cloud Computing

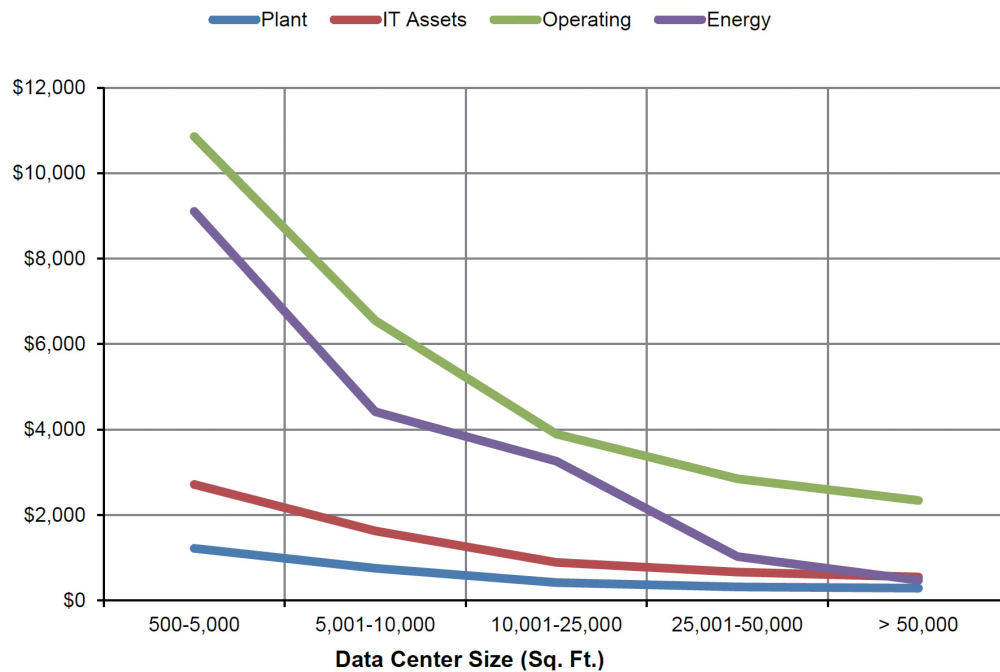
There are so many servers in the data center, but the definition of "data center" is not as clear as that of the server. In addition, due to the different classification and statistical methods adopted by various research institutions, there is also a large difference in the figures from different sources.

The National Green Data Center Pilot Program jointly issued by the Ministry of Industry and Information Technology, the National Government Offices Administration and the National Energy Administration in March 2015 pointed out that: the pace of construction of data centers has accelerated significantly

worldwide, with the total amount exceeding 3 million; China's data centers are developing rapidly, with the total amount exceeding 400,000.

The Worldwide Datacenter Installation Census and Construction forecast, 2018–2022 released by IDC in February 2018 pointed out that: the total number of data centers worldwide reached the peak of 8.55 million in 2015, and then continued to steadily decrease; the total capacity of data centers reached the peak of more than 168 million square meters in 2017, which is expected to decline from 2018 and to 152 million square meters by 2022.

Recently, Gartner's data have been cited more frequently: There were about 444,000 data centers worldwide in 2017, including 422,080 Rack/Computer Room, 14,460 midsize data centers, 5,732 enterprise data centers and 1,341 large data centers, while this figure is expected to be reduced to approximately 422,000 by 2020. In 2017, the number of racks deployed worldwide reached 4.933 million, and the number of servers installed exceeded 55.7 million. It is estimated that the number of racks will exceed 4.98 million and the number of servers will be close to 63 million by 2020. The total number of racks increases slightly, while the power of single rack increases more obviously.



As the scale of the data center grows, all types of unit cost will decline. However, the marginal effect will decrease gradually after a data center grows to a certain scale (Source: Ponemon Institute, August 2016)

Even with less than 3 million single deployments, there is still a very big difference between Gartner's and IDC's data. However, they both have a common trend that: Gartner estimates that large and midsize data centers will continue to grow; while IDC shows a trend of moving from the internal data center of enterprises to the data center of service provider (SP) in both the quantity and capacity dimensions.

If the "server consolidation" trend that emerged ten years ago has moved from server virtualization to cloud computing, then it corresponds to a consolidation of more small- and medium-scale user-side data centers

into a small number of large-scale SP-side data centers at the infrastructure level of cloud computing.

Just as server virtualization can increase efficiency and reduce cost by consolidating the workloads on multiple low-end servers with low utilization onto a single mid-range or high-end server, the larger-scale data centers are more advantageous in the terms of the shared cost of plant, IT assets, operating and energy. For example, according to the Ponemon Institute's research on 41 data centers of 31 companies in 2016, the annual cost of IT load per KW of the small-scale data center (500~5,000 sq ft, i.e., about 46.5~465m²) was about \$26,495 USD and that of the large-scale data center (larger than 50,000 sq ft) was about \$5,467 USD - more than ten times the difference in area, unit costs vary by nearly five times.

However, a bigger data center is not always a better one. AWS believes that although the data centers of 60~120MW or larger are easy to build, a too large data center has a slow reduction of cost but a higher risk of maintenance within a single data center. Therefore, it is better to build multiple "moderate-scale" data centers which are better redundant and easier to maintain. So, AWS chooses the scale of single data center of 25~32MW, accommodating 50,000~80,000 servers.

As time goes on, the standard for defining the scale of data center will also change. For example, some insiders state that: a data center with a capacity of 20MW can be regarded as a hyperscale data center five years ago, while which corresponds to a scale of 40~400MW at present.

Note: The American market tends to measure the scale of a data center by its power supply capability rather than its land area, which also allows for a more intuitive measurement of its capability to carry the operating of servers. What does 400MW mean? The Nimitz-class nuclear-powered aircraft carrier of the United States which is a 332.8m-long and 40.8m-wide 100,000t class huge carrier with a draught of 11.3m can be driven to sail at a speed of 30 knots ($\approx 56\text{km/h}$) by two A-4W pressurized water reactors with a single power of 130,000 horsepower and a total power approximate to 200MW (194MW).



/ Hyperscale data centers in China

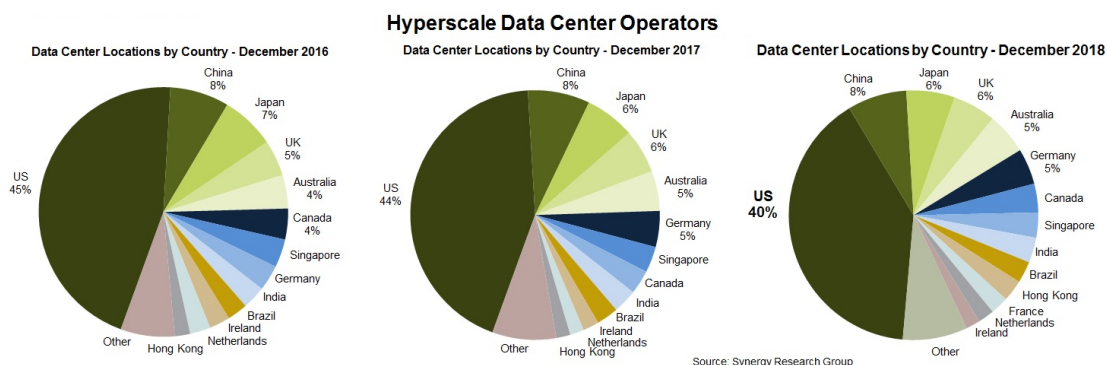
The Synergy Research Group announces the number of hyperscale data centers worldwide at the end of every year: the number of hyperscale data centers in the world has just reached 300 at the end of 2016, which exceeded 390 one year later with the launch of data centers in China, India and Malaysia.

A high yearly growth rate of 30% is difficult to maintain. The newly released data show that the growth rate in 2018 has dropped to 11%, and the total number of hyperscale data centers has reached 430. However, the Analyst and R&D Director of Synergy Research says that there are still 132 hyperscale data centers under planning or construction. From this point of view, it is still very hopeful to achieve the estimate made by Synergy Research at end of 2017 that the number of hyperscale data centers worldwide will exceed 500 by the end of 2019.

According to the statistics, the United States and China rank the first and the second separately. With close observations, compared with the United States which once accounted for half of the total number of hyperscale data centers worldwide, China, ranking the second, does not open up the gap with the two island countries (Japan and Britain), which seems to be inconsistent with the identity of the world's second

largest Internet market but shows its huge development potential. In the third quarter of 2018, Alibaba's capital expenditure (CapEx) led the hyperscale operators among the "Top Five" hyperscale operators (the aforementioned "FAMGA").

It should be pointed out that the share of the United States has dropped from 44% to 40%, which does not mean that its leadership is challenged. In 2018, the new data centers were set up in 17 different countries (and regions), of which the United States and Hong Kong accounted for the most part; and from the perspectives of hyperscale operators, the total number of data centers owned by Amazon and Google is more than half of the total. Obviously, even if the number of data centers set up in the United States had not increased ($390 \times 0.44 \approx 430 \times 0.40$), the leading Internet and cloud computing companies of the United States have no sign of slowing down in their global expansion.



The distribution proportion of the world's hyperscale data centers: China's leading advantages are not obvious despite of being ranked number 2 in terms of market shares worldwide. Although the share of the United States has dropped to 40%, it is still more than the sum of the shares of the 2nd to 6th countries (China, Japan, Britain, Australia and Germany account for 30% in total). In addition, Hong Kong, China is counted separately, taking nearly 3% in 2018

As for the problem pointed out in the previous section, how to define a "hyperscale data center" is also a question. Synergy Research does not publicly explain the quantitative definition for hyperscale data centers but states that its research is based on the distribution analysis of the data centers of 20 major cloud and Internet service companies (including the largest SaaS/IaaS/PaaS operators, and the search, social network, e-commerce and gaming companies) in the world. Interestingly, 24 companies are included in the statistics of 2016 and 2017, of which the listed business types do not include gaming.

Does this mean that while the growth momentum of data centers is turning to a hyperscale, their owners are also consolidated? In 2017, each of the 24 companies owned 16 data center sites as an average. As the top four companies, Amazon/AWS, Microsoft, Google and IBM all operated data centers in 45 or more geographic locations, and also owned at least three in each of the four regions: North America, APAC, EMEA (Europe, Middle East & Africa) and Latin America. In 2018, the top four companies was not changed, but the number of data center locations owned by each of them had grown to 55 or more (it seems that there should be a company that had significantly dragged down others before, but set up at least 10 data center locations in 2018).

The data centers of Oracle and Alibaba are also widely distributed, while large-scale data centers of other companies are mainly concentrated in the United States (Apple, Twitter, Facebook, eBay and Yahoo; and LinkedIn was included in 2017) or China (Tencent and Baidu). The Chinese giants have to change the

status quo that the bigger ones become bigger and the stronger ones become stronger.

The quantitative definition for hyperscale data centers can be referred to the Guiding Opinions on Construction Layout of Data Centers (hereinafter referred to as the Guiding Opinions) jointly issued by the Ministry of Industry and Information Technology, the Development and Reform Commission, the Ministry of Land and Resources, the State Electricity Regulatory Commission and the National Energy Administration in January 2013, which states that a hyperscale data center refers to a data center with a size greater than or equal to 10,000 standard racks. Here, the standard rack is a conversion unit with a power of 2.5 kilowatts (KW).

In other words, if calculated by the power, the total capacity of a hyperscale data center must be above 25MW.

According to this definition, Tencent Tianjin Data Center, as the first stop during the 2018 China Digital Journey - Data Center Tour in Northern China, is definitely a hyperscale data center for its configuration of 4,800 6.5KW or 8KW racks (cabinets). If Tencent Tianjin Data Center, as the first data center campus in China to announce the number of servers exceeding 100,000, is not qualified, there will be few data centers in China that can be called hyperscale ones.

Furthermore, according to the power alone, a data center with 50,000 servers can basically meet this standard.

China telecom operators still used the number of racks to evaluate the size of data centers. Taking the China Unicom Hohhot Cloud Data Center visited during the China Digital Journey as an example, it has built 3 computer room buildings, two of which have been put into operation, each with 3,800 4.4KW racks. If taken into account of 3 computer room buildings, the total number of racks exceeds 10,000, so it is also a hyperscale data center.

In the Guiding Opinions, it is recommended to focus on factors such as climatic environment and energy supply during the construction of hyperscale and large-scale data centers. It is also encouraged that the hyperscale data centers, especially those based on disaster recovery and other applications with low real-time requirements:

- shall be first constructed in the Class I area with cold climate (the number of days with the average temperature in the coldest month of $\leq -10^{\circ}\text{C}$ and the daily average temperature of $\leq 5^{\circ}\text{C}$: $\geq 145\text{d}$) and sufficient energy;
- may also be constructed in the Class II area with suitable climate (the number of days with the average temperature in the coldest month of $0\sim 10^{\circ}\text{C}$ and the daily average temperature of $\leq 5^{\circ}\text{C}$: $90\sim 145\text{d}$; or the number of days with the average temperature in the coldest month of $0\sim 13^{\circ}\text{C}$, the average temperature in the hottest month of $18\sim 25^{\circ}\text{C}$ and the daily average temperature of $\leq 5^{\circ}\text{C}$: $0\sim 90\text{d}$) and sufficient energy.

“Sufficient energy” means that the power generation is greater than the power consumption. Together with climatic conditions (including air quality), the densely populated mega-cities such as Beijing, Shanghai, Guangzhou and Shenzhen are not suitable for constructing hyperscale data centers. In July 2014, the General Office of the People's Government of Beijing Municipality issued the Catalogue of Prohibitions and Restrictions on New Industries in Beijing (Edition 2014), and it was clearly defined under the categories of information transmission, software and information technology service industries formulated by the



Beijing Municipal Commission of Economy and Information Technology that: it is forbidden to construct and expand data center in the whole city, except for the cloud computing data centers with PUE<1.5. In the Edition 2018 released in early September 2018, the corresponding PUE value is further reduced to less than 1.4, and construction and expansion of data center are completely banned in the central city and sub-center of Beijing City.

In early November 2018, the General Office of the People's Government of Shanghai Municipality forwarded the Three-year Action Plan of Shanghai Municipality for Promoting the Construction of the New Generation of Information Infrastructure to Enhance Urban Energy Level and Core Competence (2018-2020) formulated by the Shanghai Municipal Commission of Economy and Information Technology, which required in the section - "Promoting data center layout and accelerator system construction" that: coordinate space, scale and energy use, strengthen the regional coordination in the Yangtze River Delta region, invest in the high-end green data centers, and control the number of new racks within 60,000 and the total scale of racks within 160,000. Promote energy-saving technical transformation and structural adjustment of data centers to meet that the PUE of the existing data centers subject to transformation shall not be higher than 1.4 and that of the newly constructed data centers shall be lower than 1.3. Conduct research on computing resource deployment plans and resource allocation schemes, and implement technical trials and model studies. It is suggested that based on the data center structure, computing centers based on central processing unit (CPU), graphics processing unit (GPU), etc., shall be constructed. Computing acceleration resources for artificial intelligence (AI) shall account for 50% of the total rack number of new data centers.

Among the eight hyperscale data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China, except that the Tencent Tianjin Data Center which was put into operation at the end

of 2010 and the Huawei Cloud Langfang Data Center which was reconstructed from factory building are relatively close to the densely populated core cities, the other six are kept at a sufficient distance from the core cities. Most of the eight hyperscale data centers are self-built or customized by the Internet and cloud computing companies, and only two are constructed by telecom operators. All the eight data centers use free cooling and natural energy as much as possible to provide Internet and cloud computing services under the premise of energy saving and emission reduction.

This report will analyze the exploration and practice made by the eight major data centers in the Northern China which are visited during the China Digital Journey from eight main perspectives such as cooling, power supply, network and modularization of data centers that directly affect the construction and operation efficiency of data centers, to reveal their efforts and attempts to improve their efficiency, and to provide the data center constructors with references.



Chapter 2

Cooling: utilization of free natural resources with more air and less water

“Broadening sources of income and reducing expenditure” to reduce electricity consumption in the cooling process are the main methods to reduce the PUE of a data center: broadening sources of income refers to making full use of natural cooling resources to minimize the working time of mechanical cooling; reducing expenditure refers to shortening the cooling path to reduce loss of cooling capacity during transmission. The water-side free cooling is a kind of cooling architecture widely used in the China data centers, but indirect evaporative cooling has a tendency to surpass it.

PUE value is a key indicator to measure the energy efficiency of data centers. For data center owners, especially the giants owning hyperscale data centers, the reduction of PUE value not only means the saving of operating expense, but also the social responsibility that enterprises shall take. Energy saving and emission reduction are a global mission, and as one responsible big country, China has previously promised to reduce carbon emissions by 40% to 50% by 2020 (compared to 2005). Specifically for the data center industry with huge electricity consumption, all provinces and cities have issued and implemented relevant limiting documents. For example, the Beijing Municipality specifies that the PUE value of new and expanded data centers must be reduced from the previous requirement of less than 1.5 to less than 1.4; while the Shanghai Municipality specifies that the PUE value of new data centers must be less than 1.3.

Power usage effectiveness (PUE) is a measure to determine the energy efficiency of a data center. The PUE value is the total power quantity in the data center divided by the power quantity used to run IT equipment such as computers in the data center. Therefore, the PUE value is expressed in the form of a ratio, and the closer the quotient is to 1, the higher the overall efficiency is. Data center infrastructure efficiency (DCIE) is the reciprocal of PUE and is expressed as a percentage, the closer this percentage is to 100%, the higher the overall efficiency is. PUE was originally proposed by the Green Grid and was published as a global standard under ISO/IEC in 2016.

To reduce PUE, it is necessary to correctly understand the composition of the PUE value: the ratio of the total electricity consumption of a data center to the electricity consumption of the IT equipment. The essence of reducing the PUE value is to reduce the numerator as much as possible, that is, the total electricity consumption of the data center. Except for the electricity consumption of the IT side, the energy consumption of the data center infrastructure side (facility) is mostly used in the cooling, such as chiller, air conditioner and other cooling equipment.

Therefore, reducing the electricity consumption during the cooling process is the main methods of reducing PUE. Specifically, it is to make full use of the natural cooling resources to minimize the working time of mechanical cooling, or even no chiller; meanwhile, it is to shorten the cooling path to reduce loss of cooling capacity during transmission. The combination of these two means is the so-called "broadening sources of income and reducing expenditure".

All the eight data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China use the natural cooling resources with different levels in combination with their own environment, and also reduce the transmission loss by using multiple technologies; and there are multiple data centers having an annual average PUE of less than 1.3 or even reaching 1.1.



/ Starter: water-side free cooling + micro-modules

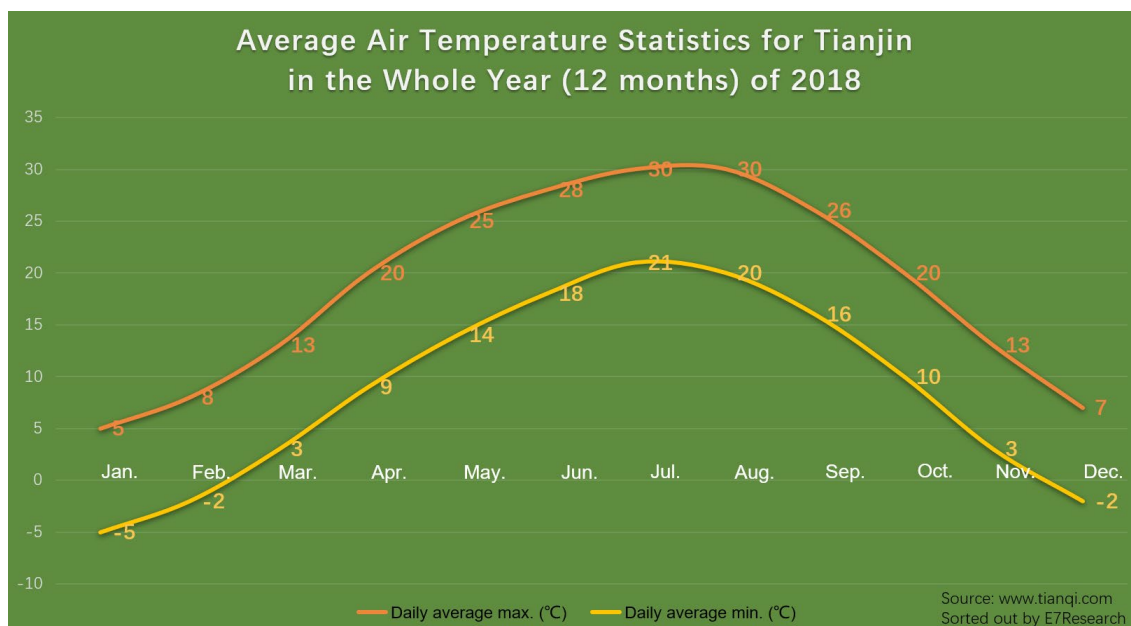
Tencent Tianjin Data Center is the starting point and also the oldest data center during the 2018 China

Digital Journey - Data Center Tour in Northern China.

As the first self-built hyperscale data center of Tencent, Tencent Tianjin Data Center has a full name of "Tencent Tianjin R&D and Data Storage Center" on Baidu Map and "Tencent Data Backup Center" on AMap. In fact, it can now carry all types of business of Tencent, including the self-developed business and Tencent Cloud's business, with the latter accounting for 20% to 30%.

Tencent Tianjin Data Center is located in Binhai New Area, Tianjin City, where is almost at the same latitude as Beijing and has an average annual air temperature of 12~15°C, so this site can fully use the natural cooling resources before and after the winter.

The construction of Tencent Tianjin Data Center was commenced in 2008, the buildings were topped out in October 2010, and it announced in May 2018 that this data center campus was the first one in China with the number of servers exceeding 100,000. With a total building area of about 93,000m², it consists of 4 buildings, which are arranged counterclockwise starting from the main entrance. Building 2 is the comprehensive office building in a quite different shape, the other three buildings are computer room buildings, designed with one floor underground and three floors aboveground.



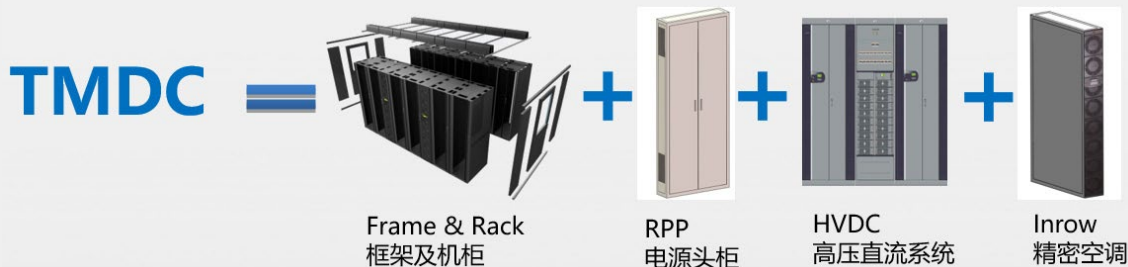
Average Air Temperature Statistics for Tianjin in the Whole Year (12 months) of 2018 (Source: www.tianqi.com)

Building 1 which was put into operation at the end of 2010 belongs to Tencent's second-generation data center, with the combination of traditional raised floor downflow supply with cold aisle containment technology; Buildings 3 and 4 which were put into operation in 2014 and 2017 respectively adopt the Tencent's third-generation data center technology, i.e., Tencent Modular Data Center (TMDC) technology, by redesigning cooling, power supply, network, cabling and other equipment into micro-modules, prefabricating them at the factory, assembling and deploying them on site, which can shorten the deployment cycle and reduce the error rate.



The Tencent Tianjin Data Center Campus is surrounded by the high-rise buildings. The chilled-water storage tanks are located close to Building 1, between Building 1 and 2. Building 3 has the largest capacity, which is about the sum of Building 1 and 4

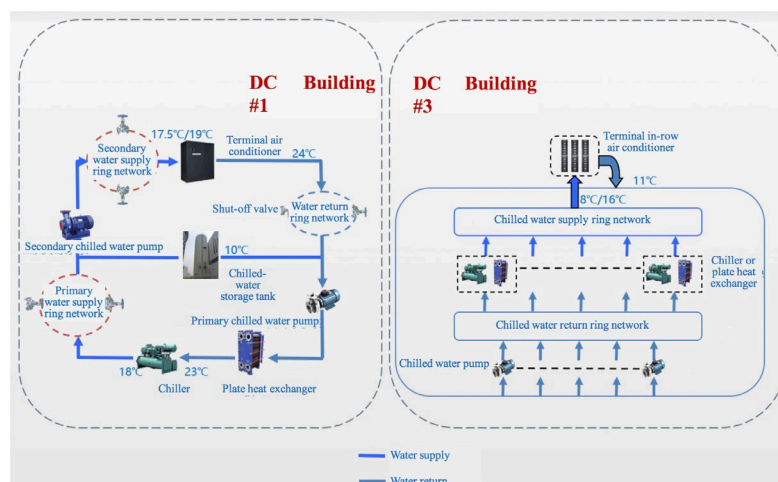
The TMDC technology refers to the rapidly deployable data center model which is built entirely in accordance with the modular design concept. With this technology, the data center is composed of multiple identical micro-modules; with racks as the basic units, these micro-modules consist of cooling module, power supply module, and the independently operable units for network, cabling and monitoring, and all the components are prefabricated at the factory and transported to the site for assembly, and can be flexibly disassembled. TMDC is prefabricated and deployed with the micro-module as the smallest independent unit, and it consists of four parts: frame & rack, remote power panel (RPP), high-voltage DC (HVDC) system and precision in-row air conditioner. The upper limit for the total power of TMDC is 120KW, with an average of 6.5KW distributed to each internal rack of MDC. However, in fact, the power of each rack can be flexibly adjusted as long as the total power of the entire MDC does not exceed the upper limit.





Wiring at upper part and water path at lower part for the micro-modules in the computer room of Tencent Tianjin Data Center
(Source: Tencent Data Center)

Tencent Tianjin Data Center adopts the water-side free cooling architecture, of which the three computer room buildings are equipped with cooling and heat exchange equipment and complex water circulation pipelines (including mains supply access and diesel generators) on the first floor, with the cooling water reservoir on the first underground floor for use by the cooling tower (evaporating tens of tons of water per day) installed on the roof, and with server racks and other IT equipment as well as the electric and cooling support systems on the second and third floors.



The cooling architecture of Building 3 is simpler (Source: Tencent Data Center)

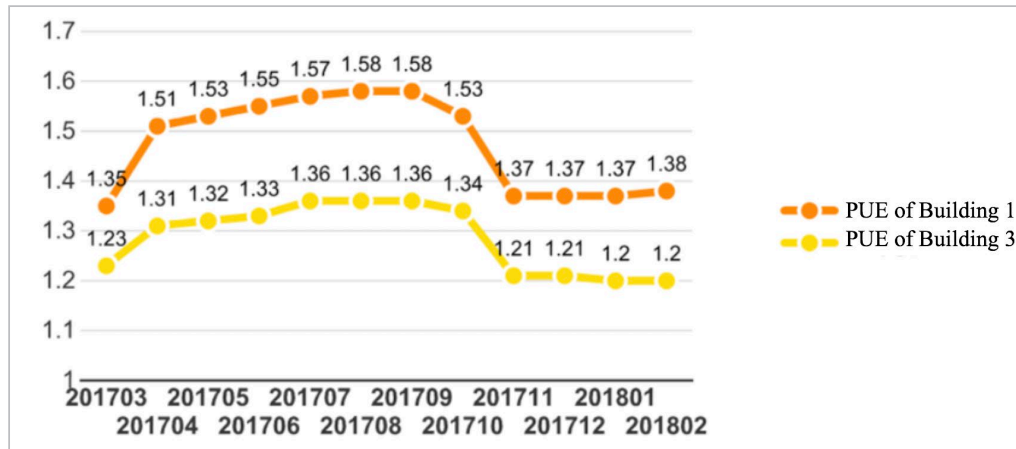
A data center constructed in phases usually has different degrees of iteration in specific technological realization. Compared with Building 1, the chilled-water storage tank in the chilled water system is removed and the BA system is changed to a parallel connection of equipment starting from Building 3, realizing higher overall reliability and redundancy. The chilled-water storage tank is a kind of back-up cooling resource used for storing chilled water for the air conditioning system of computer room, but the emergency ventilation system can also serve as a backup cooling resource in winter, and there are 7 chillers in Building 3, which are also used as a backup in a “6+1” configuration.



Cooling towers and water pipelines on the roof (Source: Tencent Data Center)

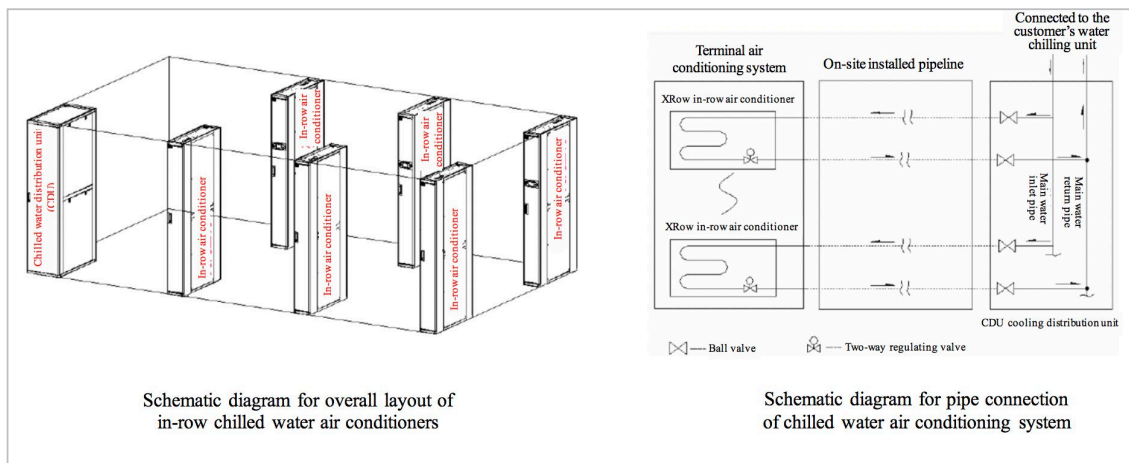
The water system is simplified by eliminating the chilled-water storage tank, so as to remove unnecessary redundancy. Another major change in the cooling path occurs in the computer room, that is, the chilled water is delivered directly to the terminal in-row air conditioner of the micro-module, realizing an air supply distance (to the server) shorter than that of the air conditioner and raised floor downflow supply mode of Building 1. This in-row cooling technology can save more than 4% of energy for the data center, which is also an advantage of TMDC.

With the combination of two kinds of cooling subsystems (cold aisle containment: 5%~10%; in-row cooling: >4%) and improvement of two kinds of power supply architectures [HVDC + mains direct supply (8%), and power distribution architecture (4%)], TMDC can save energy by about 24% in total. According to the test data provided by Tencent, the PUE of Building 3 is 0.16~0.22 lower than that of Building 1, which can be as low as 1.2 in winter, and also has the highest value in summer equivalent to the lowest value of Building 1 in winter, showing a remarkable energy saving effect.



Thanks to the cold natural climate in Tianjin, Tencent Tianjin Data Center adopts water-side free cooling, and starts the saving mode, turns off the chillers and uses the outdoor natural cooling resources to cool the servers in winter. Therefore, there is a significant decline process of PUE. Even for the Building 1 using the traditional raised floor downflow supply technology, the PUE is reduced to 1.3~1.4, with an annual average value of less than 1.5; while for the Building 3 using the TMDC technology, the PUE can be as low as 1.2, with an annual average value of less than 1.3. Proper use of the superior natural cooling resources can significantly reduce the PUE of the data centers. The Huawei Cloud Langfang Data Center which is not far from Tianjin and closer to Beijing also adopts a similar water-side free cooling architecture to a certain extent to cooling the data center (Source: Tencent Data Center)

The reduction of PUE means the saving of power consumption. Taking Tencent Tianjin Data Center as an example, if the average power consumption of the servers is about 400W, the annual electricity consumption of 100,000 servers will be 350 million kWh. If the PUE is 1.5, the annual electricity consumption will be 525 million kWh, and if the PUE is reduced to 1.2, then more than 100 million kWh can be saved per year. With an expenditure of hundreds of millions of RMB, even if an efficiency improvement of "only" 1% is realized, it means a cost saving of millions of RMB.



Schematic Diagram for Cooling System in Tencent Micro-modules (Source: Tencent Data Center)

As is well known, the air quality in the Beijing-Tianjin region is not good, which has a certain impact on the cooling scheme of the data center. Building 1 of Tianjin Data Center has tried adopting the partial natural air cooling mode, but the project is forced to an halt due to the high sulfur content in the air. Therefore, the water-side free cooling architecture with water as the intermediate medium is indeed suitable for the data centers in the Beijing-Tianjin region. For example, the Huawei Cloud Langfang Data Center also adopts the technical architecture of the water-side free cooling + micro-module data center.

Located between Beijing and Tianjin, Langfang quite close to Beijing urban area, only a little bit farther away than Yizhuang Economic-Technological Development Area in the suburban areas of Beijing, but it is more advantageous in terms of land and power supply. Therefore, it becomes a concentration area of data centers comparable to Yizhuang and Wangjing area, accommodating the data centers of the three major telecom operators (China Mobile, China Unicom and China Telecom). Before constructing or customizing data center, JD and ByteDance also take Langfang as the main base of data center.

The construction of China Mobile Data Center (located in Langfang, Hebei) was commenced in April 2017, and the Phase I Project which could accommodate 8,000 racks was originally scheduled to be delivered in July 2018. However, the project was stopped due to frequent rainstorms in summer and had not yet been completed during the visit of the China Digital Journey team, but some of the racks had been installed in place to meet the task of 4,000 racks delivery in the earlier stage, showing a high demand evidently.

The Huawei Cloud Langfang Data Center, located in the Huawei Langfang Production Base Campus in Langfang City, Hebei Province, is “only 1km away from Beijing”, which is closer to the Beijing urban area than the data centers (in Langfang) of the three major telecom operators. In Phase I, 4,500 8KW racks equipped with about 90,000 servers have been delivered and put into operation, with a building area of 54,000m². The reserved land of 700 mu (approximately 466,666.7m²) is planned in the campus, so a total of 50,000 8KW racks can be delivered year by year, and this data center campus finally can accommodate more than 1 million servers.



The Huawei Langfang Production Base Campus: the rear building with deep gray roof is the Huawei Cloud Langfang Data Center, the other similar building is the Laboratory Data Center, and the green spaces on the left and front left are the reserved land for the data center planned in the campus

The Huawei Cloud Langfang Data Center - Phase I Project is a two-storey building reconstructed from a factory building, with a relatively large storey height: the first floor is 9m high, used for installing infrastructure such as power distribution room and chiller room; the second floor is 6m high, mainly accommodating the IT room and support equipment of the data center. The cooling tower is built on the roof, and the diesel generator is also located outdoors, with a partial double-deck deployment.

Because of their geographical proximity, Langfang has a climatic condition similar to that of Beijing, where the natural cooling resources can be utilized for a long period throughout the year. The Huawei Cloud Langfang Data Center - Phase I Project adopts the water-side free cooling architecture, for which the chilled water cooling efficiency is improved by 30% through the refined energy efficiency optimization based on AI algorithm, the operating efficiency of the chillers is improved in combination with medium-temperature chilled water (13/18°C), and the free cooling time is also increased, with full free cooling time of more than half a year and the total time of full free cooling and partial free cooling of nearly 8 months.

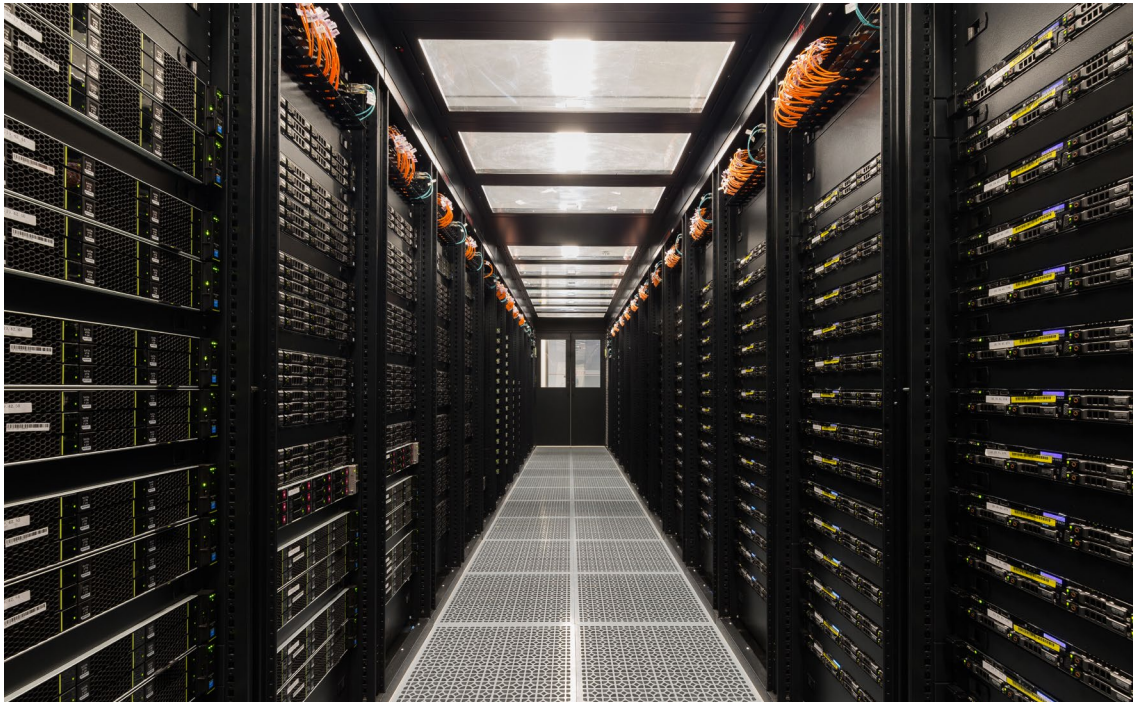
Wet bulb temperature(°C)	Full-year accumulated time(hours)	Proportion(%)	Cooling type
$\geq -16^{\circ}\text{C}, \leq 9^{\circ}\text{C}$	4,673	53.35	Full Free Cooling
$> 9^{\circ}\text{C}, \leq 14^{\circ}\text{C}$	1,075	12.28	Partial Free Cooling
$> 14^{\circ}\text{C}$	3,012	34.38	Electric cooling

Note: In Langfang, the extreme maximum wet bulb temperature is 29.2°C, and the extreme minimum wet bulb temperature is -16°C (Source: Huawei)

It is quite common to reconstruct the old factory buildings into data centers in the core areas of cities, with Wangjing area in Beijing as the most typical example. The factory buildings usually have higher storey height, large bays, fewer floors and ample power supply, which are all needed by the data centers. The Huawei Cloud Langfang Data Center adopts the micro-module computer room that integrates the power supply and air-conditioning terminals, to further reduce the workload of the reconstruction.

The warehouse-type micro-module of Huawei is provided with cold and hot aisle containment and integrated with a gas fire-fighting system. The design of cold and hot aisle containment can save energy by about 5% compared with that by the mode with cold aisle containment only, and the key point is that the micro-module becomes a relatively independent computer room protection zone and is isolated from the large bay of the whole building, without interference with the water fire-fighting system of the latter or destruction of the structure of the original building.

Usually data centers use air and water for the cooling system. China's data centers in the core areas of cities generally adopt the water system as an intermediary layer. Water isolates the internal and external air, which can prevent the internal equipment of the computer room from being affected by the poor outdoor air quality. The data centers in the northern region, even in Shanghai, also adopt the water-side free cooling so as to utilize free cooling at least in winter.



JD Cloud East China Data Center equipped with the IT module of cold aisle containment and raised floor downflow supply architecture

Ten data centers were visited in total during the 2018 China Digital Journey - Data Center Tour in Northern China, among which the Tencent Tianjin Data Center, Huawei Cloud Langfang Data Center and ChinData Wangjing Data Center, together with China Unicom Hohhot Cloud Data Center, China Mobile (Zhongwei & Langfang) Data Centers, and JD Cloud East China Data Center, all adopt the architecture consisting of (external) water-side free cooling and (internal) cold aisle containment and generally support the micro-module technology, with the main difference in the choice of in-row air conditioner or raised floor downflow supply. Only ChinData Wangjing Data Center is similar to Building 1 of Tencent Tianjin Data Center, which adopts a combination of cold aisle containment with raised floor downflow supply, and equips the in-row air conditioners only for the high-density modules such as network super-core.

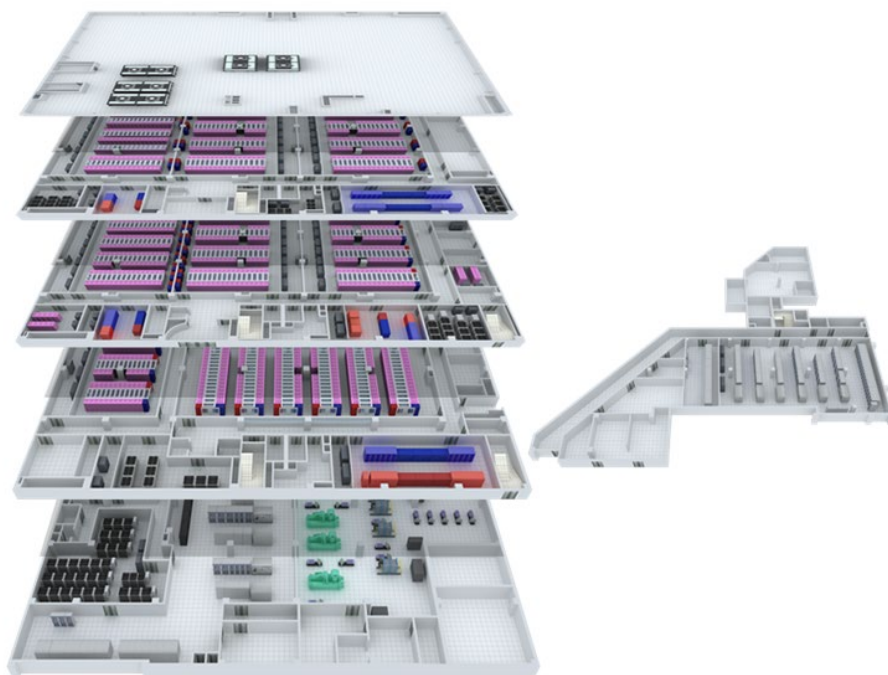
The main advantage of the combination of micro-module with in-row cooling is that the use of precision in-row air conditioner close to the heat source can shorten the cold air flow path, so as to reduce the loss of the cooling capacity during the transmission process, improve the cooling efficiency, and reduce the PUE. If the hot aisle is also use containment, the air flow will only circulate in the micro-module space, so that the requirement for the building is further reduced.

As for the raised floor downflow supply, a cold pool is built under the floor, so that increasing the floor height can increase the capacity of the cold pool. For example, when the elevated floor is raised to 1m, the short-time fault of cooling system will be better addressed in comparison to 800mm- or 650mm-high floor. Increasing the width of the cold aisle can match the higher power density. For example, the ChinData Wangjing Data Center has two kinds of cold aisle widths: two pieces of floorboards and three pieces of floorboards.



The cold aisles of different width in the ChinData Wangjing Data Center (the standard size of the floorboard is 600×600mm), which can be compared according to the stacking density of servers on the racks

In-row cooling not only shortens the airflow path, but also can perform precise cooling according to the load of the IT equipment, so that the micro-module can flexibly adapt to different power density requirements. Under the premise of sufficient power supply capacity, the micro-module can be upgraded to a higher power level by increasing the number of in-row air conditioners. Tencent executes a strategy that the racks with different power densities can coexist in one micro-module, but the total power of the micro-module does not exceed the limit value. ChinData Wangjing Data Center also adds in-row air conditioner in the core module of the network to cope with higher power density and eliminate local hot spots.



For a typical multi-storey data center equipped with water-side free cooling architecture, the core components of the water system are located on the highest position (cooling tower on the roof) and the lowest floor (chiller + plate heat exchanger) respectively.

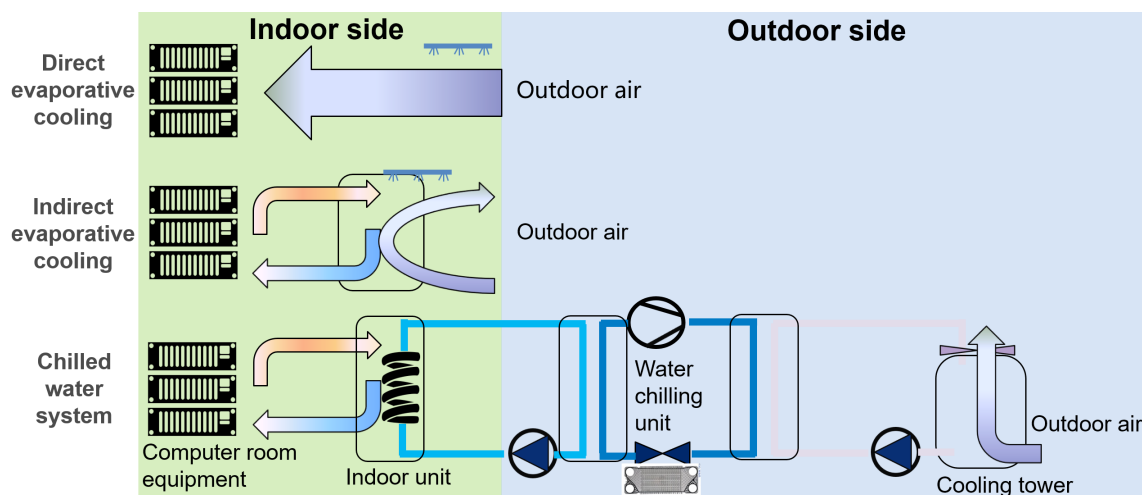


The architecture of the water-side free cooling system is very mature and complex as well: the cooling water is cooled by the external air in the cooling tower located outdoors (usually on the roof), enters the cooling station through the cooling water pipeline, exchanges heat with chilled water by passing through the plate heat exchanger, and then the chilled water after cooling down enters the air conditioner of computer room through the chilled water pipeline, and finally sends cold air to the servers. In summer or other high-temperature seasons, it is also needed to start the chillers for supplementary cooling. In addition, the cooling water system requires a reservoir, and the chilled water system is also provided with a chilled-water storage tank.



/ Fresh air cooling and direct evaporative cooling

If the outdoor cold air is directly introduced into the computer room without using water as the intermediate heat transfer medium, the water system including cooling tower, plate heat exchanger, chiller, and cooling water and chilled water pipelines can be removed to significantly shorten the cooling path and greatly reduce the complexity of the cooling system.



If the outdoor cold air enters the computer room directly, or exchanges heat with the air in the computer room, the complex water system including the chiller can be removed to greatly simplify the cooling architecture (Source: Shenzhen Envicool Technology Co., Ltd.)

In areas with good air quality, fresh air cooling architecture can be adopted. The so-called "air quality" is mainly measured from the three perspectives: temperature, humidity and cleanliness.

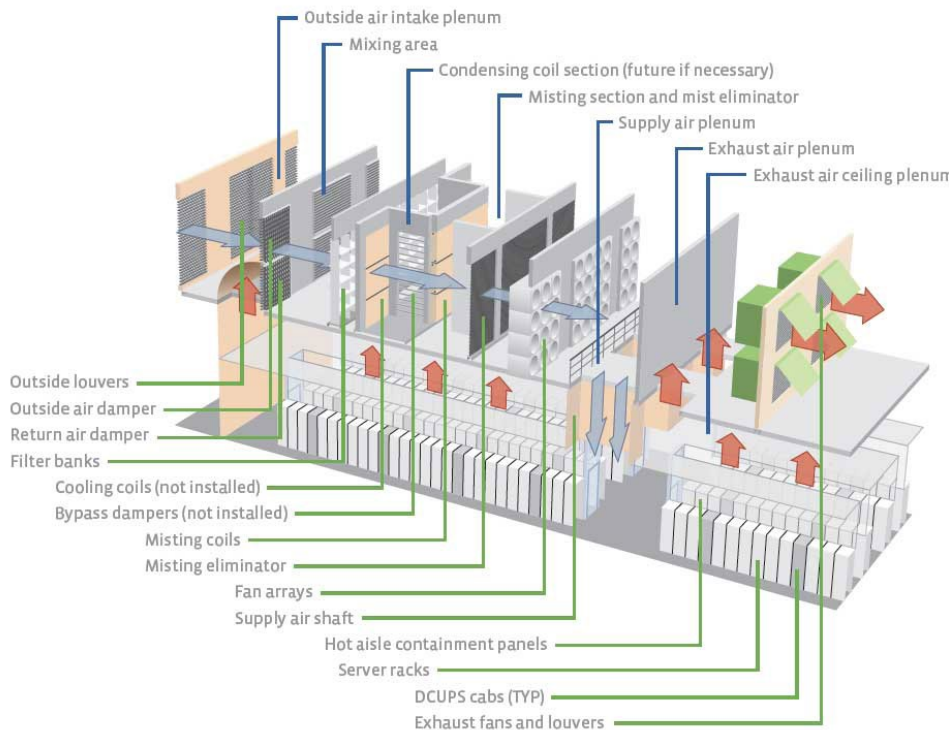
In areas with low temperature, high dryness and less air pollution, the air can be simply filtered and then directly sent to the data center to the computer room for cooling servers and other IT equipment. In areas with suitable climatic conditions, fresh air cooling can be adopted in winter, at night and even in most time of the whole year.

When the cooling conditions of the computer room cannot be met but the air is still relatively dry in summer, around noon time or in the case that the outdoor air temperature is high due to other factors, water mist can be sprayed into the air according to the principle of dry and wet bulb temperature difference so that a large amount of heat energy can be absorbed during water evaporation and the air temperature drops while the air humidity is increased, and then the air with a low wet bulb temperature is "directly" sent to the IT equipment of the computer room for the purpose of heat dissipation, which is the direct evaporative cooling technology.

Facebook's self-built data centers widely adopt the direct evaporative cooling architecture, among which the first self-built data center commissioned in 2011 in Prineville, Oregon, USA has an annual average PUE as low as 1.07 by making full use of the local natural conditions with dry climate. It is also one of the most energy-efficient hyperscale data centers in the world.

In general, the higher the dry bulb temperature is, the greater the dry and wet bulb temperature difference will be, and the stronger the evaporative cooling capacity will become. However, the increase of the relative humidity is obviously limited: in the summer of 2011 after the Facebook Prineville Data Center was put into operation for a short period, the cold air (80°F, approximate to 26.7°C) containing high water content (relative humidity: 95%) was incorrectly delivered due to the error of the building control system, causing many servers to restart after being wet or automatically shut down due to short circuit. Later, Facebook canceled the plan of further increasing the relative humidity and temperature of Prineville Data Center - Phase II.

Open Compute Project Data Center



Schematic diagram for direct evaporative cooling system in Facebook Prineville Data Center: Prineville is located in the central Oregon, with a dry climate and a maximum temperature of 40°C in summer, but this data center does not have equipment such as chillers but fully adopts the direct evaporative cooling. The entire data center is a two-storey building, with the first floor for installing IT equipment and related supporting equipment and the second floor for installing spray-type direct evaporative cooling system. (Source: Data Center Knowledge)

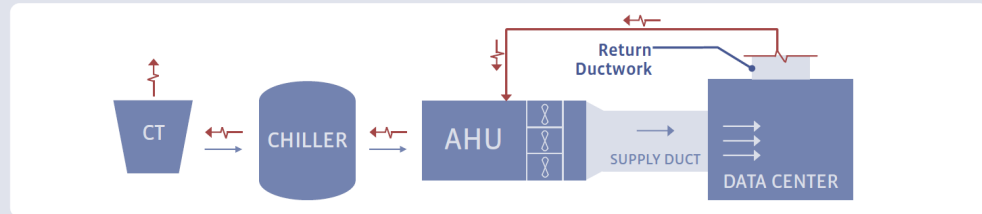
Therefore, the direct evaporative cooling system can be equipped with direct expansion (DX) air conditioning unit to offer supplementary cooling when the external air temperature and humidity are too high. For example, Facebook's data center in Forest City, Iowa installs DX cooling coils to cope with the "once-in-50-years" extreme weather conditions.

When the external air temperature is too low, the cold air entering the data center can be mixed with the hot air flowing out of the computer room in a certain proportion (mixed air), and then the mixed air at a suitable temperature is sent to the computer room.

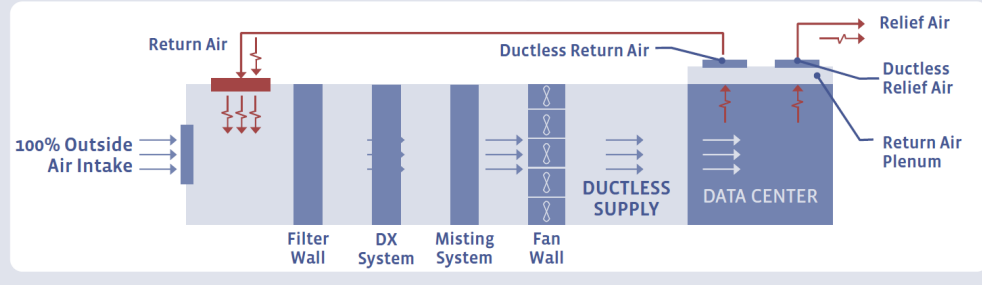
Fresh air cooling and direct evaporative cooling architectures require the compliance of the data center building design with the airflow organization requirements. For example, Facebook's data center places the cooling system on the second floor (or "attic" floor), so that the external air passes through the vertical drain louver to enter the cooling system on the second floor:

- when the external air is too cold, it reach the right temperature by mixing with the return (hot) air of the data center;
- the mixed air is then filtered into the evaporative cooling zone, and (when evaporative cooling is required) the misting system sprays the atomized water vapor which passes through the mist eliminator to get rid of water leftover;

Typical Datacenter Cooling

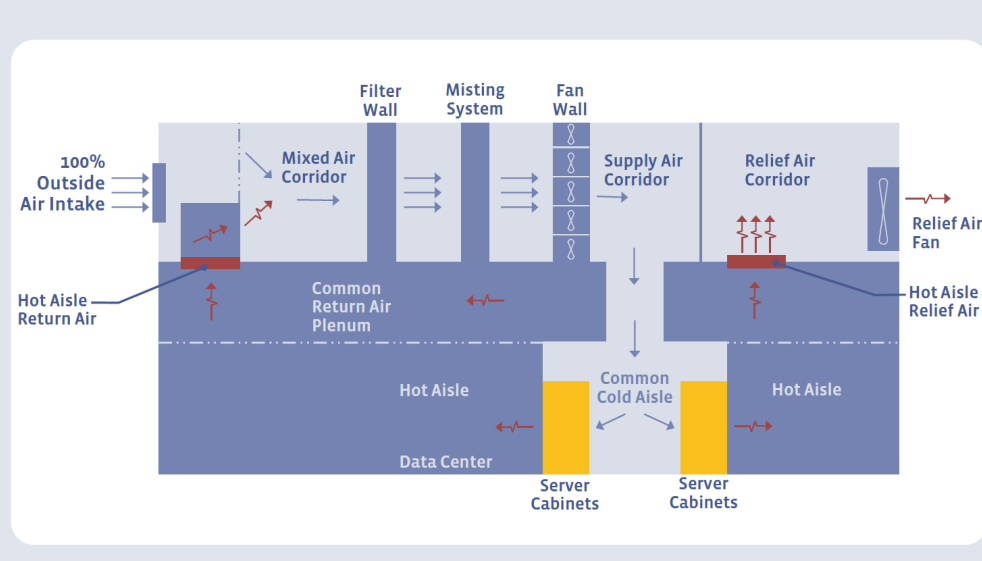


Facebook Data Center Cooling



Compared to the traditional data center cooling method (the upper diagram), Facebook's data center removes the chiller and the water (air) pipeline system into and out of the data center, although the lower diagram seems to be more complex (Source: Facebook)

PRN1 Datacenter Cooling



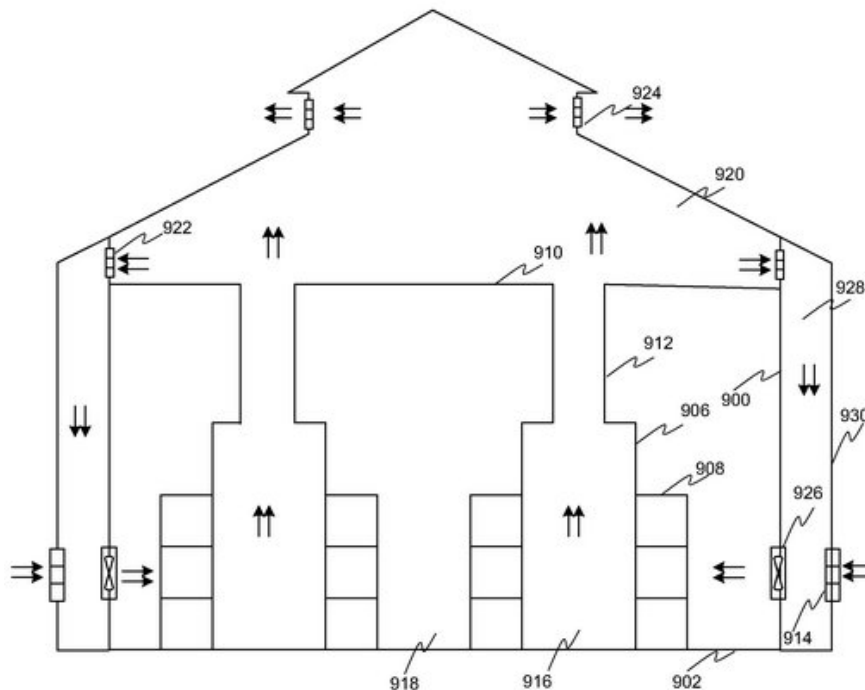
Airflow organization for the Facebook Prineville Data Center - Phase I Project

- Finally, the cold (wet) air enters the air supply zone through the fan wall, and is sent to the inside of the data center by the principle of air convection (i.e., the hot air flow rises and the cold air sinks). After passing through the server racks, the air enters the hot aisle containment, and then is discharged upwards along the ceiling to the outside, or part of the air returns to the mixed air zone and joins the next cycle.

Yahoo which is one step ahead completely takes the entire data center building as an air handler. Yahoo! Compute Coop, referred to as Y!CC or YCC, draws on the design of the “chicken coop” so that the cold air is sucked in through the adjustable louvers on the side walls of the building, and after being heated by the IT equipment such as servers, the air rises to the attic on the roof of the building by natural convection and is finally discharged to the outside through the adjustable louvers on both sides. If the external air temperature is too high, evaporative cooling will be started. If it is too low, the air will return to the air intake zone for air mixing through the adjustable louvers on both sides of the ceiling.

Yahoo has implemented the concept of “chicken coop” in the data center constructed in Lockport, a western city in New York. It is said that fresh air cooling is adopted in this data center in 99% of the time in the whole year and (direct) evaporative cooling is adopted in the rest time, realizing a design PUE as low as 1.08. Compared with the design of the conventional water-side cooling equipment, this data center can save water of about 36 million gallons (about 136,000 tons, exceeding the displacement of the largest aircraft carrier) every year.

In 2010, the U.S. Department of Energy (DoE) rated YCC as the best energy efficiency design and awarded Yahoo a sustainable appropriation of USD9.9 million through its Green IT Program. On January 13, 2011, the U.S. Patent Office granted Yahoo the Patent No. 20110009047A1 - "Integrated Building Based Air Handler for Server Farm Cooling System".



Schematic diagram for the Yahoo's "chicken coop" patent (Source: Data Center Dynamics)

Back to the data centers visited during the China Digital Journey, Baidu Cloud Computing (Yangquan) Center deploys the fresh air cooling system in some computer room modules, but Alibaba indeed makes the largest investment in the technical route of fresh air cooling and direct evaporative cooling. The Alibaba Cloud Data Center for Beijing 2022 Winter Olympics in Zhangbei has adopted the “chicken coop” style design in Phase I Project of the No.2 Campus. The building is a two-storey structure, and the first floor is 7.5m high and is used for arranging electromechanical equipment, while the second floor is 9m high and leaves sufficient space for the rise of hot air. It is relatively rare in China that the second floor (computer room floor) of a data center is higher than the first floor (equipment floor). It is a typical structural feature of chicken coop that louvers are densely arranged on both sides of the raised strip-shaped attic area on the roof of the building.



The most common grounds between the Cape Codder's chicken coop (left) and the Yahoo's “chicken coop” data center (right) are the raised attic in the middle and the louvers on both sides

The Zhangbei area featuring low temperature, dry air and less pollution is suitable for deploying the fresh air cooling and direct evaporative cooling systems. The above advantages partially come from the altitude of more than 1,400m: when the altitude is increased by every 1,000m, the air temperature drops by about 6°C, so the air temperature in Zhangbei is at least 8°C lower than that in Beijing, and the annual minimum air temperature may be -38°C (minus 38 degrees Celsius) in this area.

At a higher altitude, there is strong wind in Zhangbei, preventing the fog in the distance from entering. Zhangbei is a national-level poverty-stricken county with no heavy industry, which means less local pollution sources and good air quality. The combination of good air quality and low temperature allows the utilization of fresh air cooling for 346 days in the whole year.

Despite this, Alibaba is still cautious in the Alibaba Cloud Zhangbei Data Center - Phase I Project, and adopts the fresh air cooling for only one of the two computer room buildings in the No.2 Campus. In addition to supporting the mixed air, this design can also close the inner circulation in case of sand-dust and other weather conditions. The two parallel computer room buildings are connected in a “工” shape by a cooling station in the middle, the cooling towers are arranged on the roof and the chilled-water storage tanks are arranged on the sides to form a complete water-side free cooling system to provide cooling resources for other computer rooms.

For the No.1 Campus (Phase I Project), the water-side free cooling architecture is fully adopted, with the cooling station and the two-storey computer room building connected by the overhead pipelines. However,



The inside of the roof attic area of Alibaba Cloud Zhangbei Data Center No.2 Campus - Phase I Project: please pay attention to the louvers on the left and right sides as well as the top light steel structure (Source: Alibaba Group)

thanks to the superior natural conditions in Zhangbei and the optimized operation and maintenance of the campus, the real-time PUE of the Phase I Project does not exceed 1.30 in the hottest season of the year, and the average annual PUE is as low as 1.20.

Upon the verification of fresh air filtration and humidification technology during the Phase I Project, the fresh air cooling architecture is adopted in a large area in these two campuses since the Phase II Project, but from the outside observation, the facilities such as chilled-water storage tank and cooling tower are retained to cope with unfavorable weather conditions.



The Alibaba Cloud Zhangbei Data Center No.2 Campus - Phase I Project: it consists of two computer room buildings with the structural features of the chicken coop, which are connected by a cooling station in the middle; pay attention to the four chilled-water storage tanks on the side of the cooling station



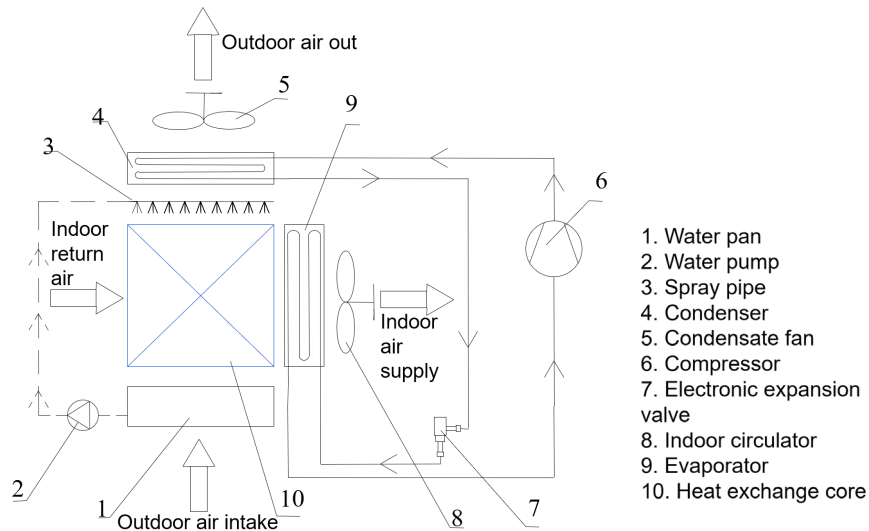
The Alibaba Cloud Zhangbei Data Center No.1 Campus - Phase II Project reflects the chicken coop style of the buildings, the fresh air cooling and direct evaporative cooling features, and the water-side free cooling features such as cooling tower and chilled-water storage tanks. All is for one purpose: making full use of natural cooling resources to save the operating expense (OpEx) even if the capital expenditure (CapEx) is increased



/ Direction: indirect evaporative cooling

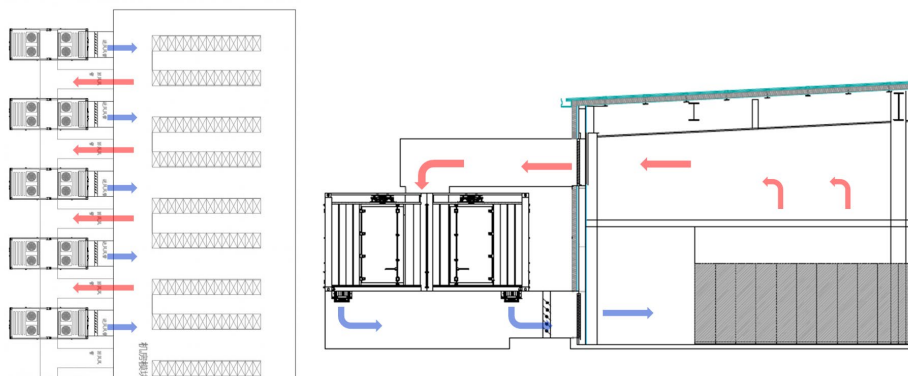
Both fresh air cooling and direct evaporative cooling technologies introduce external air into the data center, so the requirements for the air quality are high, especially cleanliness and relative humidity, as both pollutants and moisture in the air may cause damage to the equipment. In the environment, such as densely-populated areas, where the air quality cannot meet the requirements of direct evaporative cooling, indirect evaporative cooling technology can be used. After being cooled (wet bulb temperature reduced) by the evaporation process, the external air does not enter the data center, however, it exchanges the heat with the hot air inside the data center through the heat exchanger, which not only achieves the purpose of utilizing the external natural cooling resources, but also ensures the isolation of the air inside and outside the data center.

It can be seen that in the evaporative cooling process, the core technical principles of indirect and direct ones are the same, however, the air does not enter the computer room, and the air in the computer room is cooled by "air-to-air" (without going through "water-to-water") heat exchange. From a macroscopic point



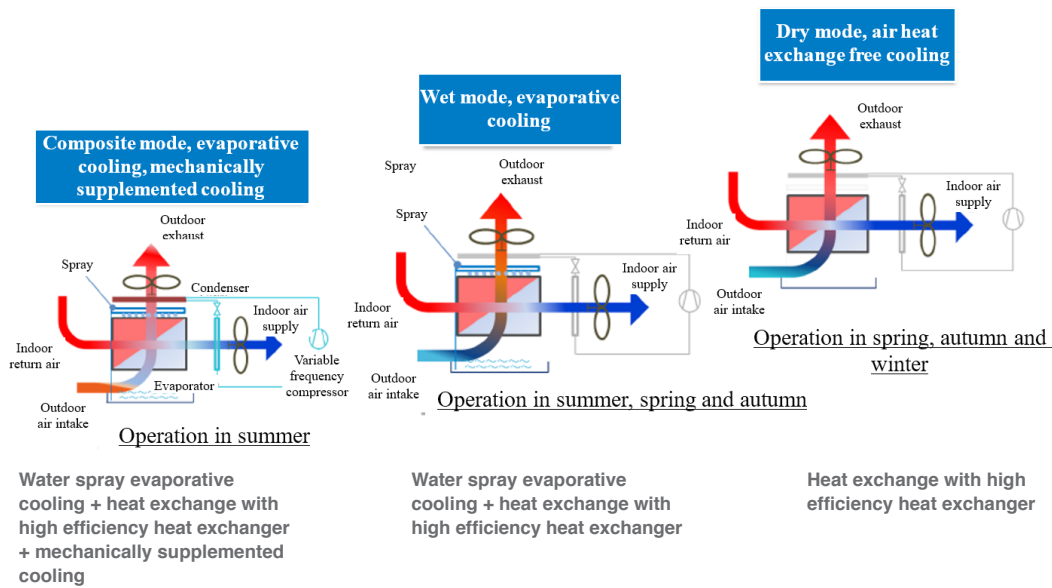
The principle of indirect evaporative cooling technology: the return air inside the data center enters the indirect evaporative cooling equipment from the left side, and the external cold air enters from the bottom. Their flow directions form a “cross”, heat exchange is realized through heat exchange core, external cold air is released from the top after temperature rise, the indoor air that has been cooled down is sent back to the inside of the data center, and the process is circulated continuously. This equipment also integrates DX systems, consisting of 4, 6, 7, and 9, for mechanically supplemented cooling (Source: Shenzhen Envicool Technology Co., Ltd.)

of view, it can be considered that indirect evaporative cooling combines with the characteristic of direct evaporative cooling in cooling the air by water evaporation, and that of the water-side free cooling system in the heat exchange process between cooling water and chilled water - of course, the leading part of heat exchange is the air, so it is the same with direct evaporative cooling, which removes the complicated water system including the chiller and the water pipe, as well as the air conditioning terminal (indoor unit). However, there is one additional heat exchange process, while the efficiency of indirect evaporative cooling is still slightly lower than that of direct evaporative cooling, which has certain adverse effects on PUE.



Installation at the sides is the simplest deployment mode of indirect evaporative cooling module. The red arrow is the hot air return line of the computer room, and the blue arrow is the air supply line after cooling. The line of the outdoor air crosses with that of the indoor air through the heat exchange core, which is omitted here, the same below (Source: Shenzhen Envicool Technology Co., Ltd.)

As for indirect evaporative cooling, its biggest difference with direct evaporative cooling is that the internal and external air exchanges heat without contact, so there is no mixed air mode, but for the "dry mode" with external air exchanged directly without evaporation, "wet mode" with evaporative cooling and composite mode with mechanically supplemented cooling, both have a direct corresponding relationship.



Three operating modes of indirect evaporative cooling
(100% load. Source: Shenzhen Envicool Technology Co., Ltd.)

The fourth-generation data center "T-Block", launched by Tencent in 2016, was the start of small-scale experimental indirect evaporative cooling technology. The early large-scale deployment of indirect evaporative cooling technology in China was applied by the ByteDance (whose products include Toutiao/TopBuzz and Douyin/Tik Tok) Huailai Data Center which was built and put into operation in 2017.



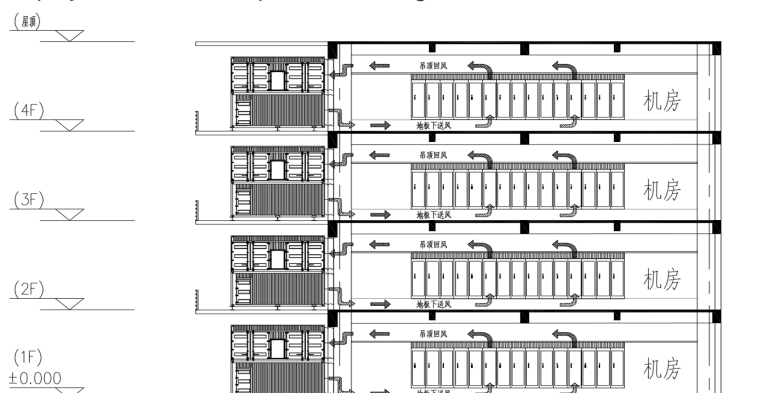
ByteDance Huailai Data Center on the afternoon of August 8, 2018: the completed 工 ("Gong", a Chinese character)-shaped building is Phase I Project, with a total of 4 computer room modules; Phase II Project (under construction, partially completed) is 王 ("Wang", a Chinese character)-shaped, with six computer room modules. Their middle part is the mechanical and electrical and office area, and the equipment similar to the container which are half surrounded by the red wall and are on both sides of the computer room modules are indirect evaporative cooling modules

ByteDance Huailai Data Center is located in New Media Big Data Industry Base, Guanting Lake, Huailai County and this customized data center is built by ChinData. Phase I Project takes only seven months from the commencement of construction to the overall delivery acceptance, and that of Phase II Project is further shortened to six months and a half. This is the first data center in China with a large flat prefabricated frame structure, with annual average PUE of 1.25, which can be attributed to the full adoption of the indirect evaporative free cooling module.

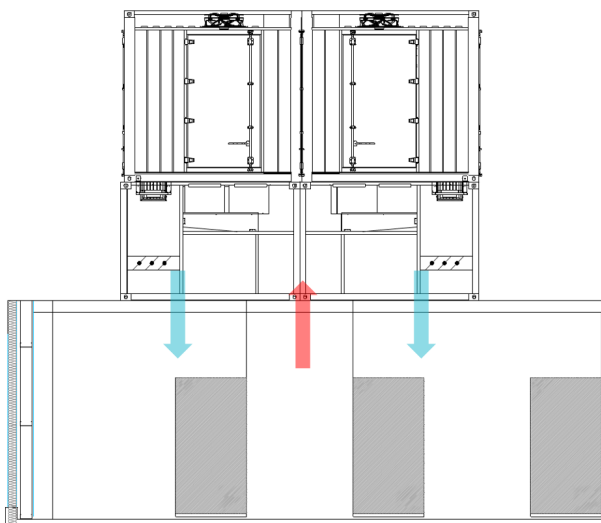


The return air inlet at one side of the ceiling above the computer room module in Phase I Project of ByteDance Huailai Data Center leads to indirect evaporative cooling module

Indirect evaporative cooling has a similar impact on data center construction styles as direct evaporative cooling. The data center adopting the direct evaporative cooling architecture has the air in mostly from the side of building, and has the air out from the side or top of building; the technical characteristics of the indirect evaporative cooling determine that the return air inlet and the air supply outlet shall not be too far apart, better arranged on the same plane. Therefore, indirect evaporative cooling equipment is usually deployed on sides or top of the building.



Multi-storey buildings can adopt the method similar to stack, and the indirect evaporative cooling module is still installed on the side. Underfloor air supply is adopted in the computer room in the example (Source: Shenzhen Envicool Technology Co., Ltd.)



The indirect evaporative cooling module can also be installed on the roof (Source: Shenzhen Envicool Technology Co., Ltd.)

Phases I and II Projects of ByteDance Huailai Data Center adopt the American large flat layout. The indirect evaporative cooling module is arranged on both sides of the computer room module, and both air return and supply are horizontal: the air in the internal hot aisle of the computer room rises to the ceiling, enters the indirect evaporative cooling module from the side return air inlet, cools after heat exchange, and then returns to the computer room from the lower air supply outlet.

Changes happen in the mechanical and electrical modules surrounding the computer room: in Phase I Project, the mechanical and electrical modules adopt traditional mechanical cooling system, and the equipment are arranged on the outer lateral wall of the module; after the operation verification, in Phase II Project, add the indirect evaporation cooling module on the top of the mechanical and electrical modules area, and both air supply and return are in up-down direction. Therefore, Phase II Project went further and became a data center based entirely on the indirect evaporative cooling architecture (DX module will be used for cooling replenishment if necessary).



The white container-like equipment half surrounded by the red enclosure on the right side is the indirect evaporative cooling module for cooling the computer room. Those in the white enclosure on the left side are the equipment for cooling the mechanical and electrical modules and the equipment is replaced by the indirect evaporative cooling module installed on the top of mechanical and electrical modules area in Phase II Project



/ Energy efficiency is not a universal metrics for measurement

The water-side free cooling system is much more complicated than various air-side free cooling systems. This effect is mainly reflected in the construction, operation and maintenance processes, which will be detailed later. A system cannot be judged for its advantages over others just from the perspective of energy efficiency. Especially in the case of fully utilizing natural cooling resources and without chillers, the lengthy steps of the water-side free cooling system may not necessarily increase the energy loss. For example, for the Google data center adopting water-side free cooling and the Facebook data center adopting direct evaporative cooling, both their PUEs can be below 1.10.



One computer room module in Phase I Project of ByteDance Huailai Data Center

Among the data centers visited during the 2018 China Digital Journey, the ones with highest and lowest values of PUE are all based on the water-side free cooling architecture. Among the 8 hyperscale data centers, China Unicom Hohhot Cloud Data Center is the only one whose PUE is higher than 1.5 (regardless of special circumstances such as low load). When the chiller is started in summer, the PUE can reach 1.6, and when water-side free cooling is used in winter, the PUE can reach 1.4, but the annual average PUE is still below 1.5.

As an operator's data center, China Unicom Hohhot Cloud Data Center must first ensure security and availability, rather than pursuing extreme energy efficiency. Moreover, Hohhot has the lowest electricity price in the country (0.26 RMB/kWh), and a slightly higher PUE will not put too much pressure on costs.

Baidu Cloud Computing (Yangquan) Center has the lowest annual average PUE of 1.10. In 2016, the figure was 1.11~1.12. In the morning of September 11, 2018, the team of the China Digital Journey visited

this data center, while the large monitoring screen showed a temperature of 15°C, and the real-time PUE values of the No. 1~4 computer room modules were between 1.070~1.195, with a general value of about 1.143.

Google's water-side free cooling data center can achieve a PUE value of around 1.10, thanks to its location with a good natural environment, e.g., Finland Hamina Data Center, which is transformed from an abandoned paper mill, with seawater used for cooling; since there are only 7 days a year on an average that the temperature does not meet the requirements of free cooling system in Belgium, Google raised the temperature of the computer room to be more than 27°C.



Baidu Cloud Computing (Yangquan) Center looks like a glowing light bulb, and it is inspired by the bear's paw of Baidu Logo. You can roughly see the chilled-water storage tanks placed next to the building and a variety of cooling equipment on the roof, mainly cooling towers, as well as indirect evaporative cooling modules. There is even a module that has solar panel installed on the roof

Although Yangquan's climatic conditions have no obvious advantages compared with Beijing, Baidu Cloud Computing (Yangquan) Center increases the inlet air temperature of the server to maximize the use of natural cooling resources, and the time of using free cooling system throughout the year reaches 96%: about 10% of the time is in pre-cooling mode, that is, the temperature is reduced by the plate heat exchanger, and then further by chillers, so the time with chiller totally turned off accounts for 85%. That is to say, the total time of relying solely on mechanical cooling for the whole year is only over 300 hours, about two weeks.

In terms of shortening the air supply path and avoiding unnecessary losses, in the Google data center, the air conditioner coil is placed directly above the hot aisle, where the hot air from the two rows of back-to-back server racks gathers and rises naturally in the hot aisle containment between the racks, is cooled

through the air conditioner coil on the top, and then the cooled air is taken away by the fan on the coils and floats to the entire computer room. The cold air naturally sinks back to the cold aisle side of the rack and is drawn into the server to restart the next cycle. The airflow organization is very short and efficient throughout the process, with little loss of cooling capacity during the transfer.



Baidu takes pride in its OCU (Overhead Cooling Unit), which is more advanced: in the OCU, the overhead coil is not equipped with a fan, while the fan at the rear of the rack is used to draw in the cold air, which further simplifies the cooling system. After the hot aisle is completely closed, the temperature difference between air return and supply of the air conditioner is very high, and the whole airflow line conforms to the natural convection law of hot air rising and cold air sinking, so the small air volume of the air conditioner is required, the load added to the (rack) server fan is not so heavy, and the loss that is transferred to the IT side can also be negligible.



Air conditioner coil installed above the hot aisle (and rack)

It can be seen that the data centers with a high proportion of free cooling time throughout the whole year (above 80%), such as ByteDance Huailai Data Center, Alibaba Cloud Zhangbei Data Center, Baidu Cloud Computing (Yangquan) Center, generally adopt a scheme of hot aisle containment, taking the entire computer room as a large cold pool. This scheme can avoid equipment fault caused by excessive temperature rise in some areas after partial equipment fault.



Standing on the ceiling of the ByteDance Huailai Data Center, you can see the hot aisle down.

CLF (Cooling Load Factor), which is defined as the ratio of the power consumption of cooling equipment in the data center to the power consumption of IT equipment, can be used to measure the utilization of natural cooling resources by the data center. For example, the annual average CLF of the ByteDance Huailai Data Center is less than or equal to 0.093, which means the power consumption of cooling equipment accounts for less than one-tenth of the power consumption of IT equipment, indicating sufficient utilization of outdoor natural cooling resources.

Larger cold pools require more cooling capacity, while the size of the cold pool is relatively limited even if the space under the floor is counted in the scheme of cold aisle containment. However, this is not a big problem when the cooling resources is almost free.



Alibaba Group
阿里巴巴集团

In the computer room compartment of Alibaba Cloud Zhangbei Data Center, the whole computer room is taken as a cold aisle, with diffuse air supply of fan wall in the distance, the facilities such as the components of the hot aisle and the cable trays above the door and the rack are installed well, and the deployment will be completed only after pushing the racks into the computer room in rows, connecting the wires and configuring them (Source: Alibaba Group)

Alibaba Cloud Zhangbei Data Center and ByteDance Huailai Data Center adopt the diffuse air supply mode of opening at one side in the computer room to simplify the layout, which is very suitable for the cases where the air supply distance is not long and the power of a single rack is not particularly high. Take the ByteDance Huailai Data Center as an example. There are 11 sets of racks in each compartment, 2 rows of hot aisle containment for each set, 14 * 7.2 KW racks for each one with a total of 308 racks. In order to improve the air supply efficiency, Phase II Project has adjusted the position of the air supply outlet so that it is facing the cold aisle at the front end of the rack, optimizing the airflow organization.



Indirect evaporative cooling module between the Module Buildings 7-8 of Baidu Cloud Computing (Yangquan) Center (Source: Baidu)

It is a great advantage of self-built data center to experiment and iterate a variety of technologies. Baidu has deployed CRAH (Computer Room Air Handler), OCU, free air cooling (Baidu calls it as AHU) and other technologies in Baidu Cloud Computing (Yangquan) Center. Indirect evaporative cooling module is also installed between two computer room modules, which is called as IDEC (Indirect Direct Evaporative Cooling) by Baidu. In the JD Cloud East China Data Center, indirect evaporative cooling module is also installed on the top of Module Building 3.

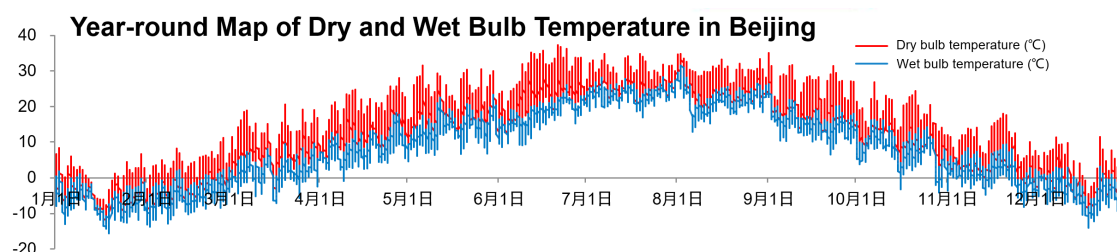


Partial of No.1 Campus in JD Cloud East China Data Center, the four equipment in the lower part of the central location are indirect evaporative cooling modules. The above plot across the road is planned to be the No.2 Campus, and the white building at the upper right is the dedicated 110KV substation

As mentioned above, the main problem of the water-side free cooling system is not the energy efficiency and PUE, but the system complexity, land occupation, and construction speed. Therefore, No.2 Campus of JD Cloud East China Data Center, and new self-built/customized data center projects of Baidu and Tencent will adopt indirect evaporative cooling architecture.

The indirect evaporative cooling architecture has good environmental adaptability, so that it can replace the water-side free cooling architecture in the core area of cities where air quality is not very good, especially the edge data center. For example, Tencent, whose large-scale data centers are still mainly located in the core urban areas, its fourth-generation data center technology (T-Block), and mini-TBlock which mainly targets edge computing scenarios, focus on indirect evaporative cooling architecture. Even in the southern cities with higher temperatures, natural cooling resources can be used in winter.

However, this does not mean that the water pipes will disappear from the computer room. In recent years, with the popularity of artificial intelligence and other applications, high-power components such as GPU have been widely used, and the power consumption of CPU, FPGA, and ASIC has been continuously risen, driving the power density of racks to increase rapidly, e.g., for the GPU server racks adopted by Baidu Cloud Computing (Yangquan) Center, its power exceeds 10kW.



The largest difference between the dry and wet bulb temperatures in Beijing is 17.6°C, and the average difference between dry and wet bulb temperatures in summer, spring and autumn is 4.8°C, which can better meet the requirements of indirect evaporative cooling (Source: Shenzhen Envicool Technology Co., Ltd.)

If the power density continues to increase, air-cooling technology will be difficult to meet the cooling needs of the server, and various liquid cooling technologies are being explored in the industry. Baidu Cloud Computing (Yangquan) Center has prepared a water-cooling back door for the rack and high-power density server, and its second-generation GPU server adopts a cold plate liquid cooling technology. Alibaba has deployed a medium-sized immersion liquid cooling system in Phase II Project of No. 1 Campus in Alibaba Cloud Zhangbei Data Center.



Thanks to the scale economy effect of large-scale data center, Internet and cloud giants have the ability and willingness to experiment and implement innovative technologies to reduce construction and operating costs. From plan, construction to operations, they have complete control over their self-built data centers. Their self-built or customized data centers have at least two of the following characteristics:

1. Taking into consideration of all the costs during the lifecycle of the data centers from built-up to operations, sometimes it is necessary to increase the construction cost (CapEx) so as to reduce the OpEx in the long run;
2. These data centers easily catch the eyeball of the public. They may adopt new technologies to overall optimize the data centers and expand in location and scale according to their own business requirements and cost, which may further serve as a role model in the data center industry.

The customized or self-built data centers are better at adopting innovative technologies for upgrading. From constant iterations, they see evident benefits with very fast speed. This virtuous cycle gradually penetrated in the whole data center industry.

Appendix: Server Reference Models

In this report, to simplify calculations, the server power consumption is estimated at 400W. The prototype is a 2U computing & storage equalization server equipped with a dual-slot Intel Xeon Gold 5118 processor, 256GB memory, and 12 * 10TB Seagate Exos X10 helium-filled hard disks.

The Intel Xeon Gold 5118 processor is a replacement for the Xeon E5-2650 v3/v4, with the same TDP (Thermal Design Power) of 105W. The CPU of this grade is very popular in the enterprise and Internet markets in China, but in general it will not be equipped with so many hard disks, and due to CPU utilization, the power consumption of the whole equipment is usually within 300w. Taking the rack-scale server we see at Baidu Cloud Computing (Yangquan) Center as an example, 34 * 1U nodes based on dual-slot Xeon E5-2650 v3 have a total power consumption of 8.8kW, with an average of less than 260W per node.

Servers oriented towards cloud computing applications tend to have higher configuration and power consumption, for example, they may be equipped with a CPU with TDP of up to 165W (Xeon Platinum 8176 or Xeon Gold 6150), larger memory and NVMe SSD, and the overall power consumption will easily reach 600W or more. As shown in Chapter 6, the 1U server used in the Microsoft Azure Data Center has a power consumption of 625W.



Chapter 3

Power supply: guaranteeing availability, removing redundancy and being distributed

The electric energy saved by natural cooling resources can be used to power more servers, so the improvement of energy efficiency directly reflects the ability to support the business. In order to ensure the operation of the servers, a hyperscale data center has invested heavily in substation and diesel generator, and reduced unnecessary losses by optimizing the power supply path and rationally removing redundancy. The architectures such as mains direct supply, high voltage direct current and distributed battery have been applied to different degrees.

For a modern and highly-utilized hyperscale data center, the electricity bill in the life cycle accounts for most of the operating expense, and even exceeds the capital expenditure of infrastructure.

On May 15, 2018, Shanghai AtHub Co., Ltd. issued the Announcement on the Company Receiving the Letter of Intent for Demand from Alibaba (hereinafter referred to as "the Announcement"), which stated: On May 14, the Company received the Letter of Intent for Demand of five data centers, namely, ZH13, GH13, JN13, NW13, and HB41, from the Procurement Department of Alibaba (China) Co., Ltd. (hereinafter referred to as "Alibaba"). With the rapid business development of Alibaba Group, Alibaba intends to cooperate with the Company to construct data centers in the future. The data center projects related in the Letter of Intent for Demand shall be delivered within 18 months from the commencement date. After the above-mentioned intentional projects are completed and put into operation, the Company will obtain income by charging data center service fee from Alibaba during the operation period.



No.2 Campus of Alibaba Cloud Zhangbei Data Center under construction, the remote side is the substation of the Campus
(August 10, 2018)

We speculate the geographic locations corresponding to the codes of the five data centers as follows:

- ZH13 should be in Hangzhou, Zhejiang;
- GH13 should be in Heyuan, Guangdong;
- JN13 should be in Nantong, Jiangsu;
- NW13 should be in Ulanqab, Inner Mongolia;
- HB41 should be in (Bashang?), Hebei

"According to the Confirmation Letter of Construction Project Management Entrustment Demand attached to the Letter of Intent of each project, the Company is the manager of construction projects, and the project civil construction is carried out by the Company on behalf of Alibaba. Dedicated systems related

to the infrastructure of data center (including equipment such as diesel generator sets, cooling systems, uninterruptible power supplies and racks) will be invested, constructed and operated by the Company, which will also hold the property right and be responsible for providing cloud data center hosting services.

After the above-mentioned intentional project is completed and put into operation, the Company will obtain income by charging data center service fee from Alibaba during the operation period... According to different payment methods of electricity service fee, the service settlement method is classified into the following two modes:

Settlement mode 1: the electricity service fee in the project operational cost is paid directly by the customer to the power supply department.

Settlement mode 2: the electricity service fee in the project operational cost is paid directly by the Company to the power supply department.

According to the preliminary calculation based on the operation data of the historical cooperation project between the Company and Alibaba, after the above intentional project is completed and put into operation, during the operation period, if the settlement mode 1 is adopted, the total data center service fee is about RMB4.044 billion; if the settlement mode 2 is adopted, the total data center service fee is about RMB8.28 billion. The calculation is based on the unit electricity price of the current large industrial power users of the power supply branch at the location of each project.”

The service period of this intentional project is 10 years from the date of acceptance.

We can get a simple conclusion: according to the total or average price, the 10-year electricity fee of the five data centers have exceeded the sum of their capital expenditure and (excluding electricity fee) operating expense.



Phase I Project of ByteDance Huailai Data Center: the white building at the foot of the mountain (top right of the picture) is a substation

According to the large industrial electricity price (flat section) in the Electricity Price List of the Five Cities of Yunfu, Heyuan, Meizhou, Shaoguan and Qingyuan executed on May 1, 2018, we calculate at 0.45 RMB/kWh, and according to the reference model with each server power consumption of 400W, we can get the following conclusions:

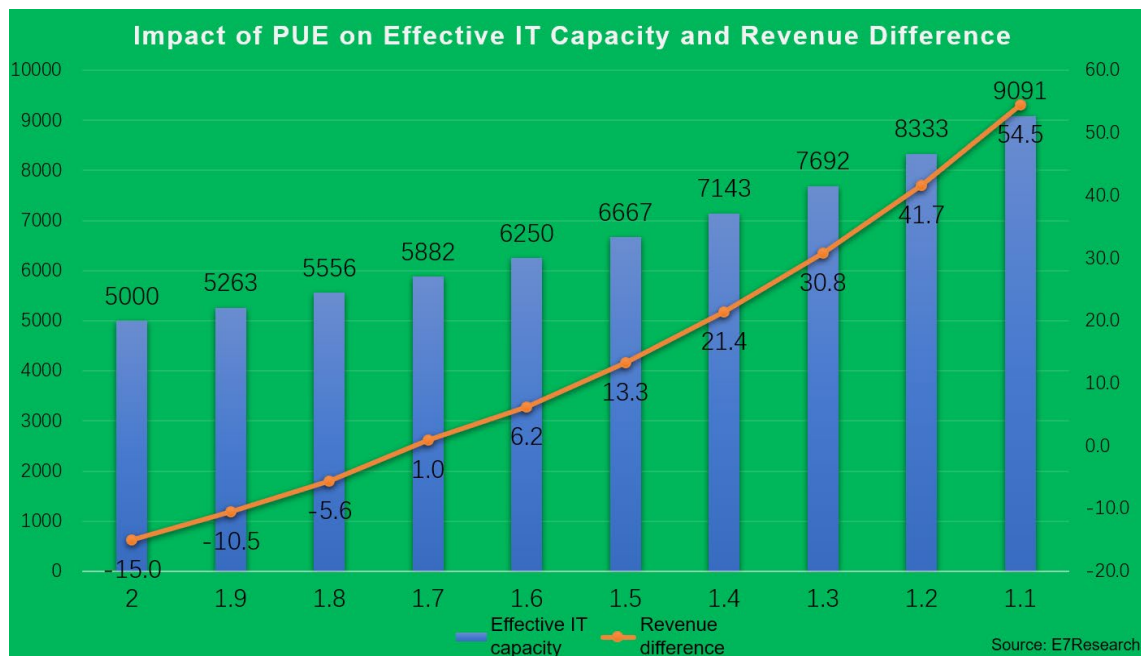
If PUE = 1.5, a total of nearly 180,000 servers can be supported;

If PUE = 1.2, a total of nearly 224,000 servers can be supported;

The extra servers supported by the saved electricity almost equals to a data center.

Therefore, reducing PUE not only means improving energy efficiency - from the perspective of business, but also represents an increase in effective IT capacity (the power actually consumed by IT equipment, the denominator part of PUE), which can support more IT equipment such as servers.

From the perspective of IT (business), since the power supply capacity is limited (income increase is difficult), lowering PUE (expenditure reducing will be better) can increase the capacity of the server, that is, the effective IT capacity, to support more business. For data center hosting suppliers, it is also one of the ways to increase revenue.



Impact of data center PUE on effective IT capacity and revenue difference: assume that the total power supply capacity of a data center is 10,000 KVA, then take the average PUE 1.7 of China's data centers published by the Green Grid as the baseline. When PUE is 1.7, the effective IT capacity is 5,882. If the PUE of the new data center limited by Beijing and Shanghai as not higher than 1.4 and 1.3 is taken in the calculation, the effective IT capacity is 7,143 and 7,692 respectively, while the revenue difference is 21.4% and 30.8% respectively - the difference is huge; and if PUE is taken as that of Baidu Cloud Computing (Yangquan) Center of only 1.1 in calculation, the effective IT capacity difference is 3,209, and the revenue difference is more than 50% (Source: E-Academy)

The electricity price is directly related to the operating expense. Going back to the announcement analyzed above, which has listed the cost compositions, which varies greatly, of the data centers in five different

places under two settlement modes: in economically-developed and densely-populated areas (meaning both land and electricity prices are high), the capital expenditure and (other) operating expenses of data center are high, and the total electricity fee of 10 years are about 50% higher; while in areas with sparse populations and abundant resources (meaning both land and electricity prices are low), the capital expenditure and (other) operating expenses of data center are low, and the total electricity fee of 10 years can be as low as 40% of the former. Of course, the capital expenditure shall not include the land price, and the specific scale of each data center will be different. Here is only a general directional conclusion.

The specific projects are as follows:

Project name	ZH13	GH13	JN13	NW13	HB41	Total
Total income of operation period (settlement mode 1, CNY1 billion)	1.191	.554	1.191	.554	.554	4.044
Total income of operation period (settlement mode 2, CNY1 billion)	2.679	1.191	2.625	.766	1.019	8.280

Compare the capital expenditure and operating expense of the above five data centers according to their locations (Source: Shanghai AtHub Co., Ltd.)



/ Lifeline: transformer substation and diesel generator

The data center is a large consumer of electricity. Take a data center campus with 300,000 servers as an example, the required power supply capacity may reach 200MW, which is equivalent to the power output of a Nimitz-class nuclear-powered aircraft carrier (the world's largest aircraft carrier with full-load displacement of 100,000t and two nuclear reactors).



China Mobile Ningxia (Zhongwei) Data Center is closely adjacent to the substation and its distance advantage is comparable to that of JD Cloud East China Data Center and Alibaba Cloud Zhangbei Data Center. There are many data centers in the Zhongguancun Science and Technology Park - West Cloud Valley in Zhongwei City shown in the picture, including several substations

In order to ensure power supply, hyperscale data center generally tends to build dedicated substations in the surrounding areas. For the data centers far away from the core cities, such as Alibaba Cloud Zhangbei Data Center, Baidu Cloud Computing (Yangquan) Center, ByteDance Huailai Data Center and JD Cloud East China Data Center, specially constructed substations can be seen near the campus. At the same time, the high availability of the power supply system requires that the power supply system of a campus shall come from two (or more) different substations, such as the ChinData Wangjing Data Center, which introduces two mains from Cuigezhuang Substation and Donghu Substation respectively. From Donghu to Wangjing, it will pass through Metro Line 14 along the way. In order to obtain the mains, ChinData does not hesitate to invest tens of millions of yuan to bypass the subway line.



ChinData Beijing Wangjing Data Centers use two substations from different directions, which cross the Metro Line 14 and Line 15 respectively (Source: ChinData)

Another major investment in securing data center power is diesel generator. The core of diesel generator is diesel engine, and both of them are widely used in military equipment such as warships and tanks. The output power of data center-class diesel generator is usually between those of the ship and tank/armored vehicle: for example, many data centers are equipped with diesel generator sets of 1,800KW, which is higher than those for Chinese Navy's Guangzhou-class (052B) destroyer (about 1,500KW single power); while the diesel engine power of China's 99 A main battle tank is "only" a little more than 1,100 KW (1,500hp), which is able to drive the nearly 60t armored chariot at a speed of 60km per hour. Each of the four main shafts of the 100,000t Nimitz-class aircraft carrier is equipped with a diesel engine with power of 8,000KW as an emergency host in case of failure of nuclear propulsion system.

In terms of quantity and total power, the configuration of diesel generator in a hyperscale data center has reached a very high level. Taking Huawei Cloud Langfang Data Center as an example, it is equipped



The diesel generators outside Huawei Cloud Langfang Data Center: 9 generators one set, and 7 for each of the other four sets, with a total of 37 generators. The gray ground across the road with diesel generators is the supporting oil depot

with 37 diesel generators (7 or 9 generators as a set, with N+1 redundancy) outdoors, if calculated at a unit price of RMB3 million, the investment only in purchasing diesel generators is over RMB100 million, therefore resulting in high cost of maintaining the high availability of cloud computing.

This is not a small amount of money. On the basis of ensuring stable operation of the data center, large-scale data center builders have begun to find ways to save investment in diesel generator procurement. For example, in the ByteDance Huailai Data Center built by ChinData, Phase I Project is equipped with 14 diesel generators, and the two sets of N+1 redundancy. The server capacity of the Phase II Project has increased by 50%, however, the number of diesel generators is 18 instead of 21. After removing the intra-set redundancy, by relying on inter-set redundancy and the Phase I parallel operation design, the power required for the normal operation of the data center can still be ensured, while reducing the procurement investment of 3 diesel generators means saving the cost of tens of millions RMB.

Where the diesel generator is installed is also worth discussing. When conditions permit, the diesel generators can be placed outdoors (data center side or roof) in containers. The advantages are that it does not occupy the space of the building, and the layout of the intake and exhaust pipes can be ignored, which is convenient for modular construction. However, diesel generator has problems in low temperature start-up, especially in the cold northern area in winter. Currently, the common way to solve such problem is to



14 diesel generators of Phase I Project in ByteDance Huailai Data Center in use (regular drill)

use the campus heating and other means. Even in Zhangbei County, where the temperature can reach -38°C , Phase I Project of No.1 Campus in Alibaba Cloud Zhangbei Data Center also adopted this method, i.e., to install the diesel generator outdoors in containers.

Another point of view is that if diesel generator is placed outdoors, the heating conditions are challenging. Therefore, in Phase I Project of No.2 Campus in Alibaba Cloud Zhangbei Data Center, more than $1,000\text{m}^2$ have been added to each computer room building to accommodate the diesel generators inside the room and arrange boilers for heating. Electric roller shutter door is adopted for the (air intake) of the diesel generator room, which automatically opens after a few seconds of power failure. From the current status, the "indoor genre" has prevailed in Zhangbei County, and in Phase II Projects of the two campus, the diesel generators have been installed indoors.

Therefore, whether the diesel generator is put indoors or outdoors is not necessarily related to the latitude and temperature of the data center. Beijing and Huailai data centers built by ChinData, and Huawei Cloud Langfang Data Center all arrange the diesel generators outdoors in containers, while the Baidu Cloud Computing (Yangquan) Center in their south arranges the diesel generators in the dedicated power stations at both sides of the "bear's paw". The southernmost JD Cloud East China Data Center, located in Suqian City, Jiangsu Province, north of the Huaihe River, also adopts the method of arranging diesel



Phase I Project of No.2 Campus in Alibaba Cloud Zhangbei Data Center, where 8 diesel generators are put at one side of the computer room building, and the roller shutter door for the air intake and exhaust pipes can be seen from this perspective

generators in the diesel generator room, and selects compact diesel generator set with 2,200KW to save space occupied.



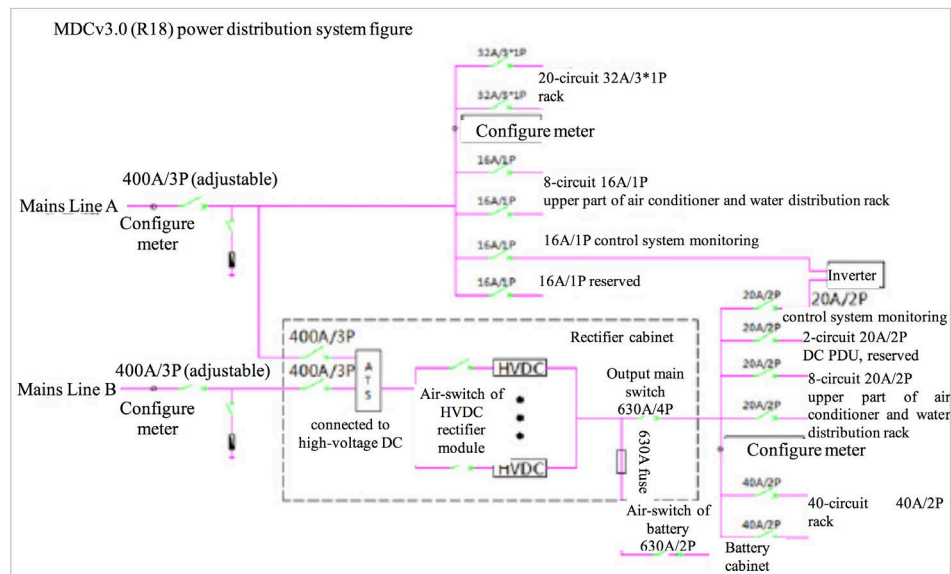
Diesel generator room of JD Cloud East China Data Center



/ Power distribution architecture: HVDC and direct supply of mains

The power supplied to the data center is mainly consumed in two major parts: ensuring the normal operation of the servers and cooling the servers. After most or all of the cooling capacity of the data center comes from natural cooling resources, the electricity consumption in the cooling system is mainly reflected in the process of conveying the cooling capacity (by pump or fan). That is to say, after the electricity consumption in the cooling system is greatly reduced, the focus of "reducing expenditure" is turned to reduce the loss in the power transmission process.

The method to reduce the power loss is mainly to reduce the conversion and the redundancy reasonably. Compared with the traditional dual UPS (2N UPS) power supply architecture, the self-built or customized data centers of Tencent, Baidu, and Alibaba generally adopt the architecture of one mains supply plus one high-voltage direct current, which follows the above concept.

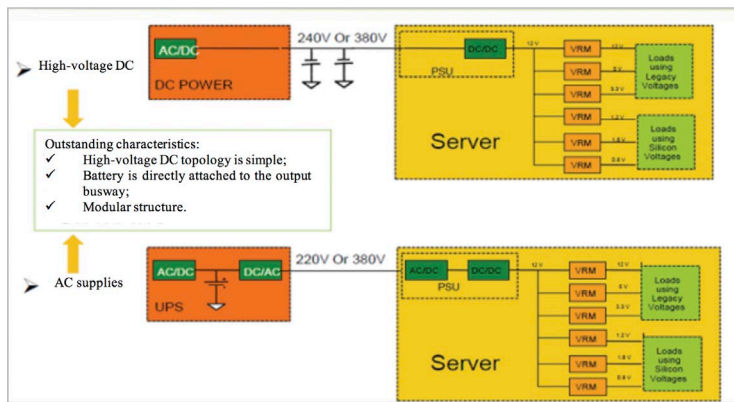


Tencent MDC's power distribution architecture, where single rack power consumption can reach 13.5KW, total IT load of the entire module is 144KW (Source: Tencent Data Center)

HVDC (High-Voltage Direct Current) can be understood as "DC UPS", because it has one time less of (DC-AC) inversion process, while the efficiency has been improved. Not only that, but the high-voltage DC system also has the advantage of modularity, and can adjust the configuration flexibly according to the load situation, and is easy to be integrated to the micro-module data center. Tencent lists eight advantages of high-voltage DC:

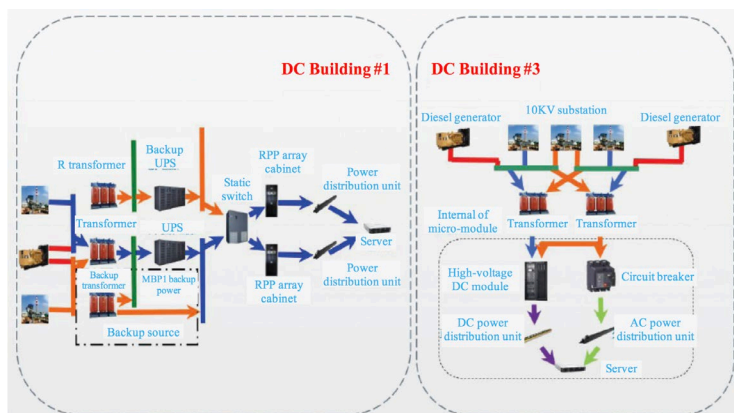
- It reduces two times of conversion, enabling higher efficiency.

- It replaces UPS, eliminating explosion hazards.
- The battery is connected to the busway, which is more reliable.
- The AC power modules of existing server devices can be used directly in DC environment.
- Modular hot plug for easy maintenance.
- It can save energy by tuning into hibernate state, and thus solve the light load problem.
- It can be directly operated in parallel for expanding capacity.
- The human body is more resistant to DC.



The high-voltage DC at the power supply side has one time less of DC-AC inversion than UPS, and the PSU (power supply unit) at corresponding server side also reduces AC-DC conversion (Source: Tencent Data Center)

With the adoption of TMDC, the power distribution architecture of Tencent Tianjin Data Center has been transformed to one line of mains plus one line of high-voltage DC from Building 3. The other line is changed to mains direct supply, because the conversion link is simply eliminated, so the efficiency improvement is more obvious.



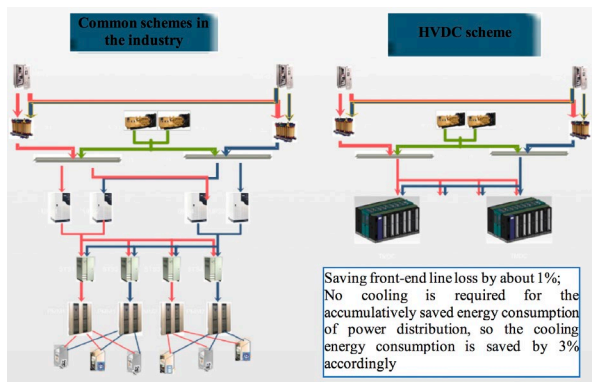
Power distribution architecture evolution of Tencent Tianjin Data Center (Source: Tencent Data Center)

The premise of mains direct supply is that the power grid has a fairly high stability, and the data center adds UPS or high-voltage DC to the power supply path mainly for lacking confidence in the reliability of the power grid. To remove the redundancy of one line, and minimize the adverse effects on the availability of the power supply system, the reliability of the mains direct supply must be high enough.

Compared with Europe and the United States (especially the United States), China's overall environment has many disadvantages in building data centers. But there are also advantages, e.g., the large power grid is more stable. According to rough statistics, the reliability of power supply in many cities and rural areas in China can reach 99.9% and above. Coupled with another UPS or high-voltage DC, as well as supporting of external diesel generator, the overall availability can be ensured basically.

Unit	Power supply reliability rate (%)			Average power outage time (hours/household)			Equivalent total users
	Counting power limit	Excluding external influence	Not counting power limit	Counting power limit	Excluding external influence	Not counting power limit	
State Grid Corporation of China:	99.9692	99.9710	99.9693	1.34	1.27	1.34	1,322,082
North China	99.9700	99.9715	99.9700	1.31	1.25	1.31	338,118
State Grid Beijing Electric Power Company	99.9861	99.9875	99.9861	0.61	0.55	0.61	65,009
State Grid Jibei Electric Power Company	99.9364	99.9407	99.9364	2.78	2.59	2.78	31,278
State Grid Hebei Electric Power Company	99.9670	99.9690	99.9670	1.44	1.35	1.44	31,772
State Grid Shanxi Electric Power Company	99.9406	99.9422	99.9406	2.60	2.52	2.60	29,765
State Grid Tianjin Electric Power Company	99.9794	99.9814	99.9794	0.90	0.81	0.90	40,202
State Grid Shandong Electric Power Company	99.9742	99.9748	99.9742	1.13	1.10	1.13	140,092
Northeast China	99.9707	99.9721	99.9707	1.28	1.22	1.28	171,593
State Grid Liaoning Electric Power Supply Co., Ltd.	99.9792	99.9803	99.9792	0.91	0.86	0.91	82,276
State Grid Jilin Electric Power Supply Company	99.9734	99.9742	99.9734	1.16	1.13	1.16	39,907
State Grid Heilongjiang Electric Power Company Limited	99.9655	99.9677	99.9655	1.51	1.41	1.51	40,630
East Inner Mongolia Electric Power Company Limited	99.9023	99.9070	99.9023	4.27	4.06	4.27	8,780
East China	99.9796	99.9807	99.9796	0.89	0.84	0.89	422,274

The reliability of power supply in some cities in China can reaches 99.9% at the minimum (Source: Several Trends in Data Center Development presented by Zhang Tuo, Vice President of Hangzhou Cloud Tripod, in Data Center Summit 2018)



After the power distribution architecture is simplified, line losses and the number of power distribution equipment requiring cooling are also reduced (Source: Tencent Data Center)

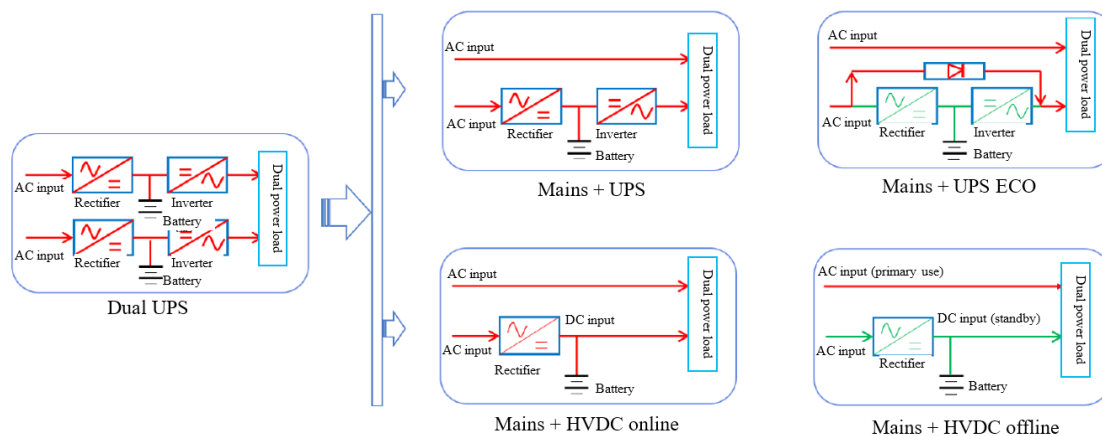
The data provided by Tencent show that the mains direct supply + high-voltage DC architecture can save energy for data center by about 8%.

Baidu Cloud Computing (Yangquan) Center has developed four electrical architectures around mains direct supply, which can be classified into two categories:

"Mains + UPS" can be understood as the predecessor of **"Mains + HVDC (online)"**, so there is no need for explanation;

"Mains + UPS ECO": When the mains is good in quality, the UPS supplies power to the load through bypass filtering with inverter and battery standby, which is equivalent to dual mains. The UPS "stands by" (ECO) and takes over when there is a problem;

"Mains + HVDC offline" goes one step further, usually HVDC is only used as a rectifier, which is a standby one.



Name	Dual UPS	Mains + UPS	Mains + HVDC online	Mains + UPS ECO	Mains + HVDC offline
Power Efficiency	90%	95%	96%	99%	99.5%

With the continuous iteration of the electrical architecture, the power supply efficiency is getting higher and higher (Source: Baidu)

Like the so called "no work is the biggest saving", the power efficiency from the dual UPS to the mains + UPS, the mains + HVDC online, the mains + UPS ECO, and the mains + HVDC offline, is all the way up, and finally that of the mains + HVDC offline (one DC for standby) architecture can reach up to 99.5%.



/ Battery: centralized and distributed

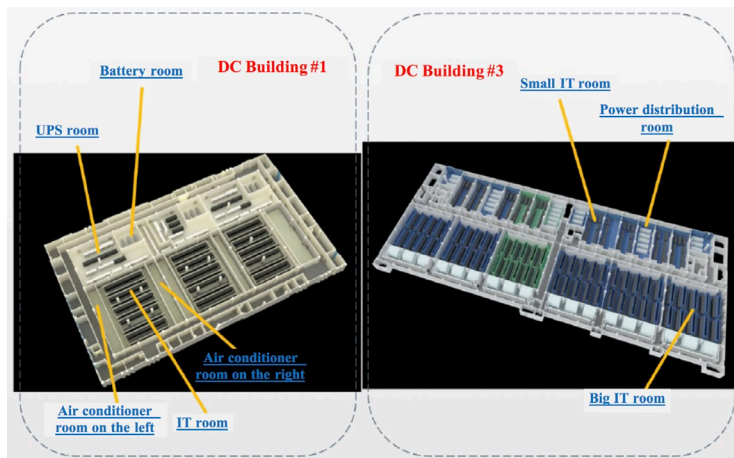
Both UPS and HVDC need the battery to ensure the power supply in the case of mains interruption. Usually, the data center will have a special battery room for centralized storage of the sealed valve-regulated lead acid battery (VRLA).



A battery room of JD Cloud East China Data Center (Source: JD Cloud)

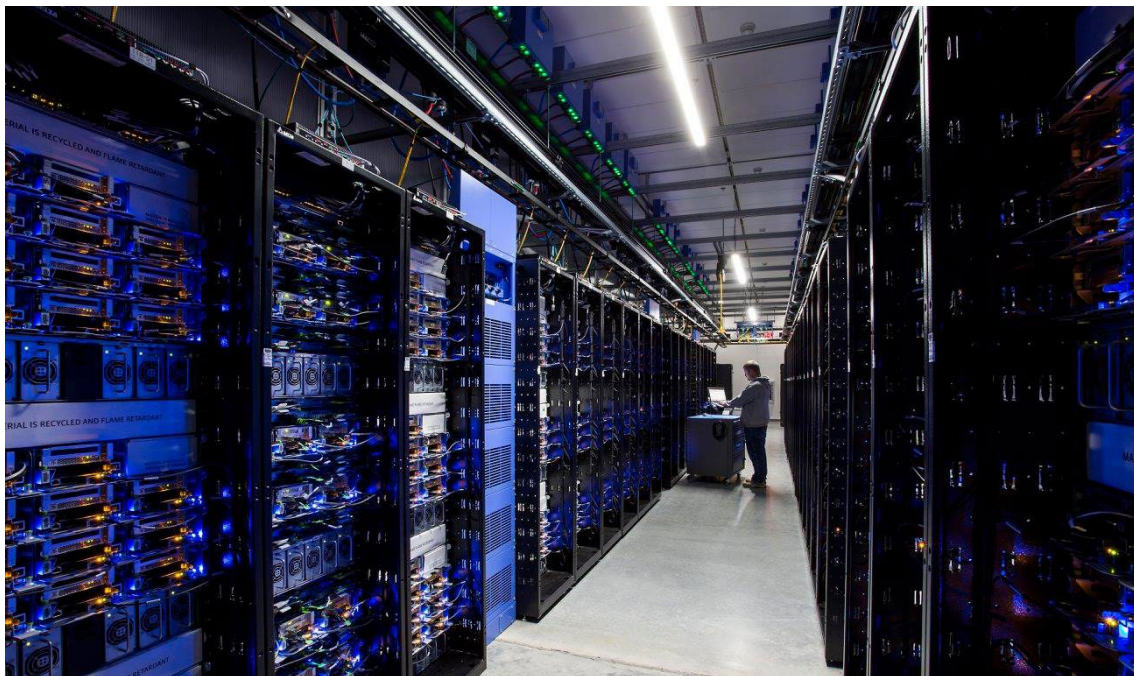
Two data centers that use micro-module technology have different ways to install the batteries. Tencent's TMDC directly integrates high-voltage DC systems (including battery cabinets) into the micro-modules, increases (or decreases) the quantity according to actual business needs (such as the number of servers), avoiding coarse-grain procurement, and saving the space for corresponding UPS room and battery room (from Building 3, the UPS has been added for the pump, so there is still small battery room).

The Huawei Cloud Langfang Data Center still uses battery room scheme instead of integrating the battery inside the warehouse-type micro-module. To be more precise, Huawei's warehouse-type micro-module has different roles of IT and power. There is no battery cabinet in the IT micro-module, but the latter can



The layout of Tencent Tianjin Data Center from Building 1 (the second-generation data center) to Building 3 (micro-module technology) reflects the increase in the proportion of IT room (computer room) (Source: Tencent Data Center)

be transformed into a dedicated warehouse-type power module, which can be regarded as a centralized battery scheme with moderate granularity. The data show that the battery cabinet in the warehouse-type power module is heavier and requires the ground bearing capacity of $2,000\text{kg}/\text{m}^2$. If the ground bearing capacity is not enough, steel plates or steel frames can be added under the base to share the weight of the battery cabinet.

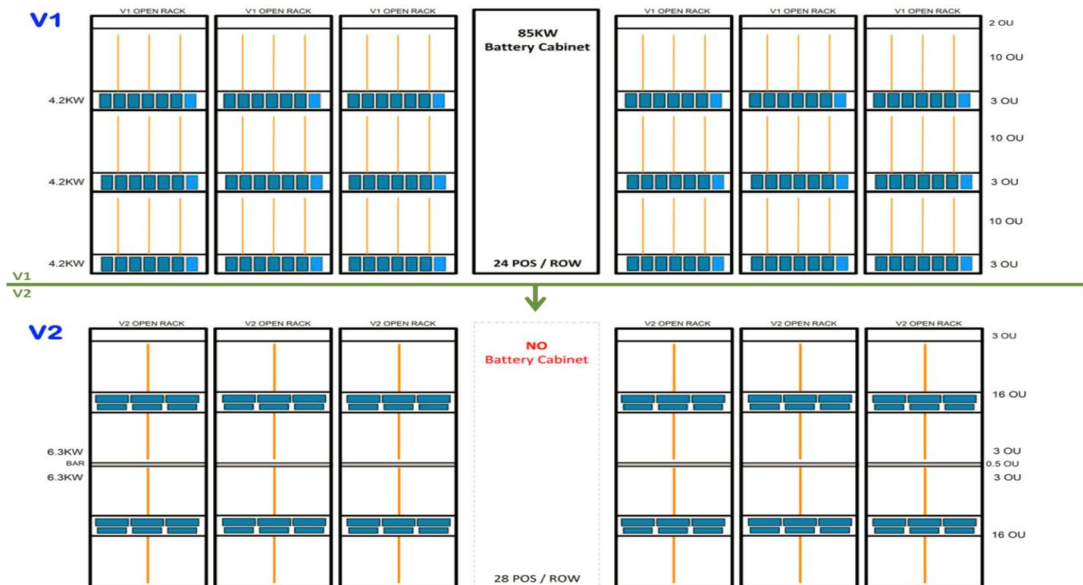


Altoona (Iowa, United States) data center formally launched in mid-November, 2014 by Facebook, the middle blue part of the left six racks is battery cabinet (Source: Facebook)

Facebook also used the scheme of putting the battery cabinet and the IT rack together in the Open Rack V1 generation, but it is not a micro-module, but a battery cabinet for every six server racks (three on each

side) (Open Rack). Each battery cabinet has 20 sealed VRLA batteries of 38Kg, and the total weight is not too large.

Baidu Cloud Computing (Yangquan) Center, like the Facebook data center of Open Rack V2 generation era, uses a rack-scale server integrated Lithium-ion battery, completely abandons the lead-acid battery and battery room, saving more than 25% of the infrastructure area, and providing more room space; see the chapter below on IT collaborated efforts for details.



From the centralized lead-acid battery cabinet of Open Rack V1 to the distributed Lithium-ion battery of Open Rack V2 (ORv2), the position of the battery cabinet is replaced by the rack loaded with the server, which increases the IT capacity. As the last of the "top four" (AMGF) in the Internet infrastructure in United States, Facebook has been pursuing a single rack power of 12.6KW from the early time (Source: Open Compute Project)



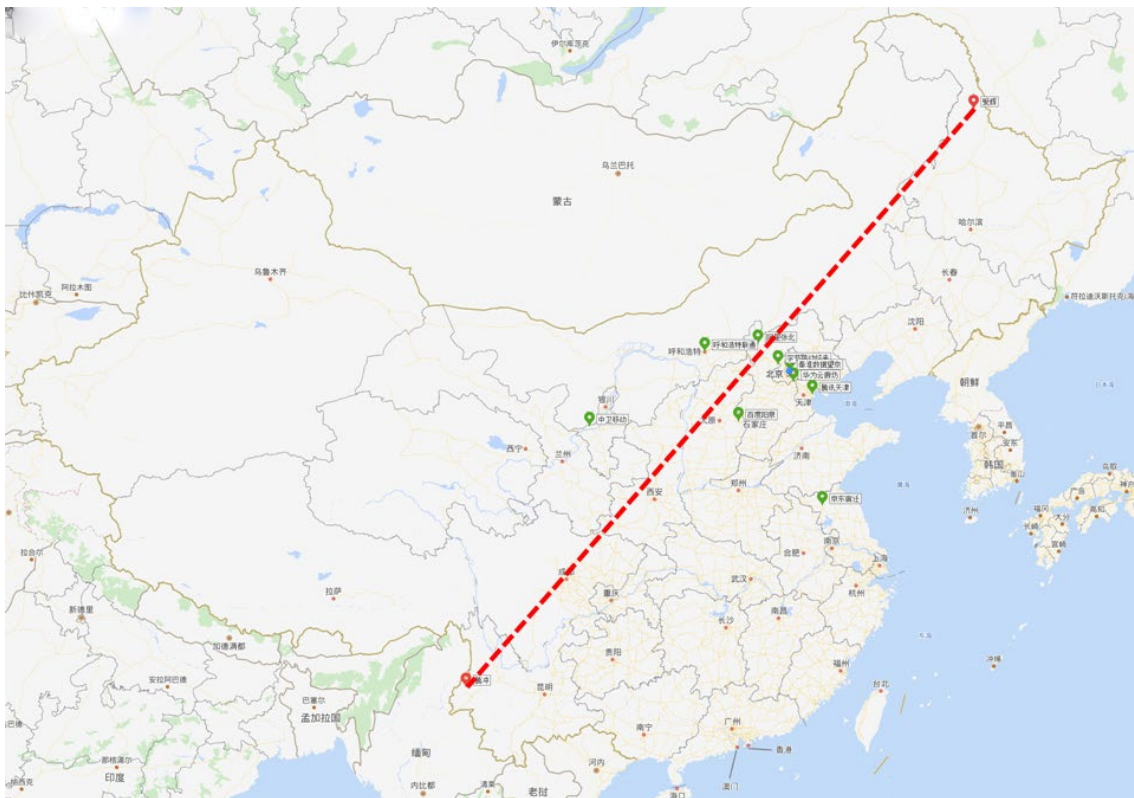
Chapter 4

Network: various companies showing their expertise

Since network latency directly affects the experience of the users of Internet and cloud computing businesses, a balance must be achieved between network conditions and natural conditions in hyperscale data layout. Internet companies can plan their own network layout based on different characteristics of the businesses. While cloud computing realizes high availability by multipoint distribution in local area, and the operators' data centers take network conditions as their best selling point.

In a data center, the goals of cooling, power supply and network are often inconsistent and even contradictory: while the places with better energy and cooling resources conditions are far away from metropolises, which have the best network conditions because both Internet and cloud computing serve the people and densely-populated areas are equipped with complete network infrastructure and have the shortest latency.

Different from Europe and the United States, a "Hu Huanyong line" (hereinafter referred to as "Hu line") divides China into two distinct areas: southeast and northwest. Most of the population lives on the right side of the Hu line, while high-quality resources are mostly distributed on the left side of the Hu line. Tencent Tianjin Data Center, Huawei Cloud Langfang Data Center, and China Mobile (Langfang, Hebei) Data Center are all located in the hinterland of Beijing-Tianjin region and enjoy good geographical locations.

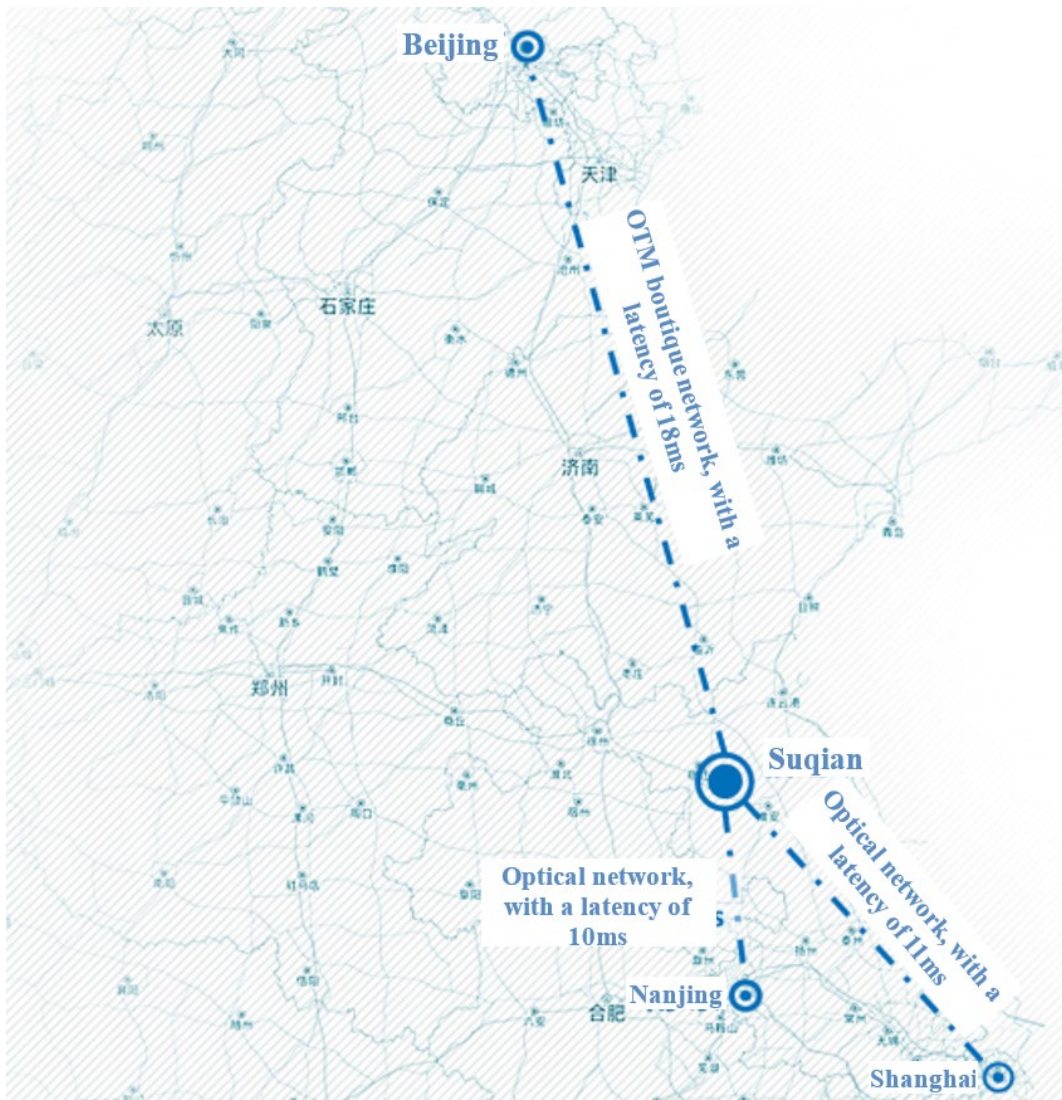


Hu line and the distribution of data centers visited during China Digital Journey (Source: E7Academy, based on Baidu map)

However, in these highly-industrial and densely-populated areas in the Beijing, Shanghai, Guangzhou and Shenzhen, it is very difficult to supply surplus electricity to informationization after ensuring industrial and household electricity. As mentioned in Chapter 1, Beijing and Shanghai have successively introduced new policies aiming at putting forward strictly requirements for energy efficiency so as to raise the threshold for building data centers. Land can be solved through plant building renovation, but it may not be so easy for PUE reaching the standard. Even if the site and energy efficiency are not a problem, in terms of the power consumption of a hyperscale data center, it is not suitable for machines to grab electricity from people.

Therefore, as for the locations of self-built or customized projects, the large- and medium-sized Internet companies have focused on a range within 200km from the core economic circle, i.e., around big and medium-sized cities, striving to achieve a balance between electricity, cooling, and network.

However, it should be noted that being closer to the core economic circle is only a prerequisite for shortening the network latency. In many areas around the core economic circle, the network infrastructure is not inadequate due to factors such as insufficient economic development, thus, relevant companies shall coordinate with local governments and operators to solve network issues while planning and constructing data centers. For example, the network from Beijing to Suqian originally had to route through Nanjing or Wuxi in the south instead of coming directly from Xuzhou in the north. After the construction of the JD Cloud East China Data Center, the network level of Suqian has been upgraded with the cooperation of the three telecom operators, by which the status of Suqian has been equal to that of Nanjing and Wuxi, so that the network from Beijing can take the shortest path to Suqian, namely, shortened to 700km from the previous 1,400km; correspondingly, the problem of the entire network latency has also been resolved.





Panoramic view of JD Cloud East China Data Center, with the 4 computer room buildings in No.1 Campus completed and delivered in phases

JD Cloud East China Data Center

JD Cloud East China Data Center, located in Suqian City in the north of Jiangsu Province, is the first self-built data center of JD. This data center, together with the Shanghai Data Center, which is also in East China, the North China Data Centers in Beijing and Langfang, and the South China Data Center in Guangzhou, form the four major service areas in China, covering most provinces and cities in China and providing infrastructure support for Jingdong Mall and JD Cloud business. Moreover, it is also one of the core data centers of JD Cloud backbone network node.

Suqian is 700km away from Beijing. Through the OTN boutique network, the latency is controlled within 18ms, and the latency of network to Shanghai and Nanjing is about 10 ms.

No.1 Campus (Phase I Project), covering an area of 200 mu (approximately 133,333.3m²), has a building area of 55,328m², consists of 4 single-storey data center buildings and can accommodate 6,000 IT racks. It was constructed from 2014 continuously and was delivered completely in December, 2018. Dual 110KV dedicated power supply, 2N-UPS configuration, and N+1 diesel generator system are adopted for the whole data center. Thanks to the modular design and construction, the power density of the racks inside the JD Data Center is in gradients, and can be adjusted to 4KW, 12KW, 20KW, etc. as needed, providing flexible support for JD's GPU server cluster and Docker cluster.

The data center is adjacent to Luoma Lake and has sufficient water supply as a support. The overall resources consumption of the data center has been effectively reduced through the combination of rainwater collection & reuse and zero wastewater discharge system and abundant rainfall in the regions of the Huaihe River, the heat recovery and heating combined pump unit with the fresh air system, the design of the green lighting system, etc., with the maximum design PUE less than 1.4 and annual average PUE less than 1.3.

No.2 Campus (Phase II Project), which is adjacent to No.1 Campus and covers an area of about 260 mu (approximately 173,333.3m²), is planned to build 4 data center buildings and support buildings (multiple-purpose building and power building). The data center building is a two-storey building with a total floorage of nearly 100,000 m², and it can accommodate 10,000 IT racks and has an operation capacity of 200,000 servers. Core data center building is expected to be delivered in mid-2019, 5,000 racks in December, 2019 and the whole data center in 2021. Indirect evaporative cooling (IEC) architecture is adopted, with annual average PUE ≤ 1.2 , and water consumption reduced by more than 60%.

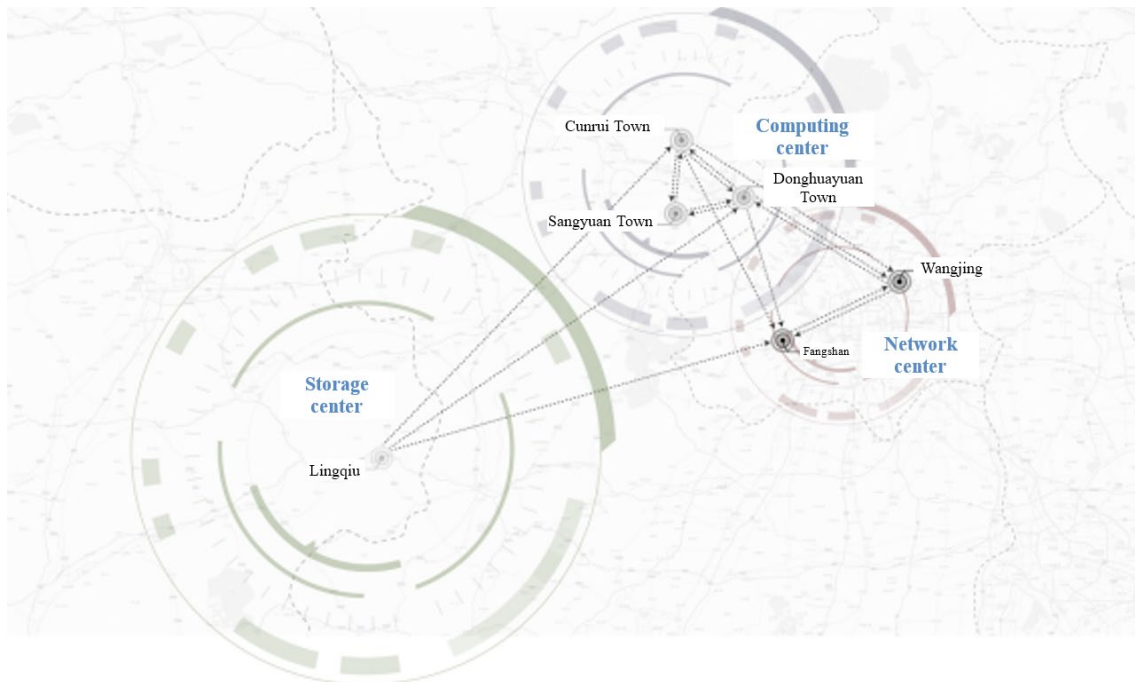
The data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China can be classified into three different types namely, Internet, cloud computing, and telecom operators according to different networks.

/ 1. Internet

For their own businesses, the Internet companies can make targeted layout by combining business characteristics with geographic location. Taking ByteDance as an example, it can take Beijing as the core of the network, since ChinData Wangjing Data Center is only over 60km away from the rented Langfang data center in the southeast (with shorter linear distance), and only over 80 km away from the customized Huailai Data Center in the northwest, with a round-trip network latency of only 1.4ms.

Huailai County, about 100km away from Beijing, is rich in energy and land resources. Because of short overall network latency, it can be taken as a computing core to alleviate the pressure of Beijing-Tianjin region;

Lingqiu County is far away, but the energy cost advantage is obvious. It is connected to Fangshan, Beijing, and Huailai as the computing core through the network, and can be taken as a storage core to carry some services with low real-time requirements.



The layout of ChinData's information technology industry bases around Beijing: taking Cunrui Town, Sangyuan Town and Donghuayuan Town in Huailai County as the computing centers, Wangjing and Fangshan in Beijing as the network centers, and Lingqiu County as the storage center (Source: ChinData)



/ 2. Cloud computing

As a kind of service for external customers, cloud computing requires higher availability. Each region is a cluster composed of two or more data centers (campuses) tens of kilometers apart, which are backups of each other so as to avoid simultaneous impact of power supply or natural disasters. Wherein, each data center campus serves as an Availability Zone (AZ).

Alibaba Cloud North China 3 (Zhangjiakou) Region is located in Zhangbei County, Zhangjiakou City, Hebei Province, where Alibaba has planned the first data center cluster with three-point layout among the China companies. Between the three campuses, double-route connections are adopted, and a sufficient distance is kept between two lines, which are buried under the tundra to ensure the lines will not be affected by excavators. Zhangbei is more than 200km away from Beijing, and is connected by multiple routes to ensure availability and realize a network latency of less than 3ms.



The Alibaba Cloud Zhangbei Data Center - No.1 Campus - Phase II Project was designed and built independently by Alibaba. The vacant land in the figure was the state on August 10, 2018 and the buildings were capped on October 29. Across the road is the Phase I Project. By observing carefully, you can see dense wind turbines at the distant near the skyline

According to the Zhangjiakou Daily, "The North Alibaba Cloud Base Project is implemented by Alibaba Group, with total planned investment of RMB20 billion, covers an area of 630 mu (approximately 420,000m²) and can accommodate 300,000 servers. The construction layout adopts 'one site and three centers', that is, one demonstration site, namely, the Alibaba demonstration site, and three mutual backup data centers...", of which two have been put into operation.



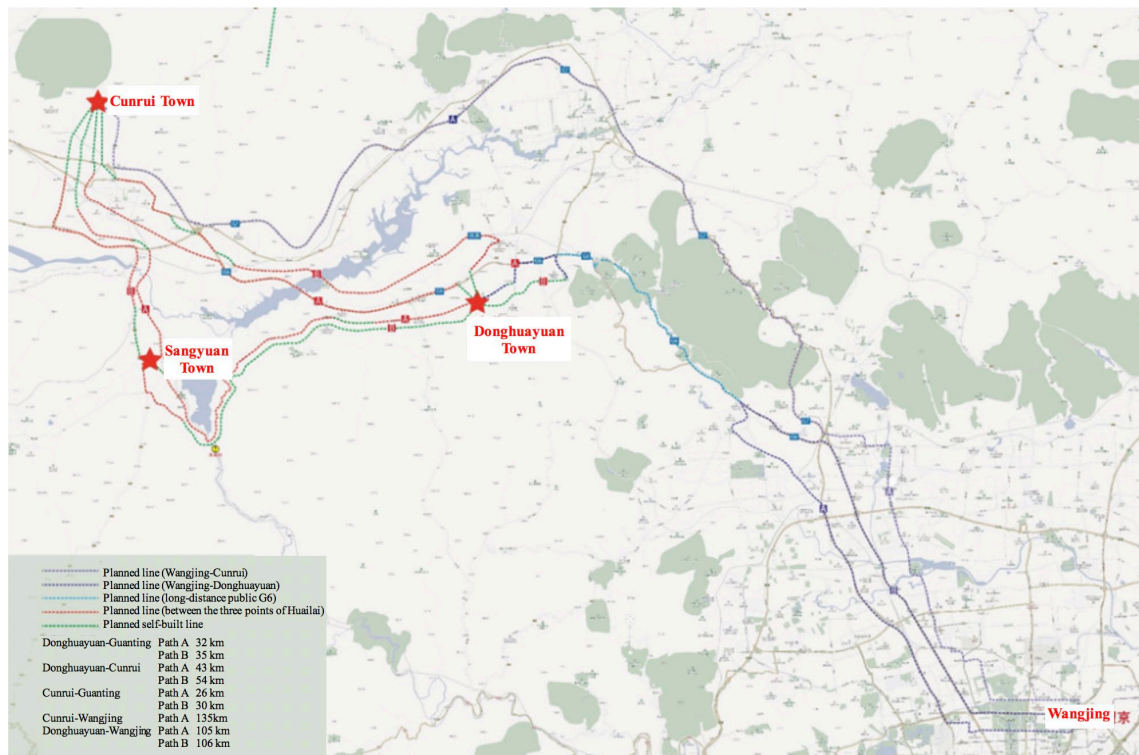
Company name	Quantity (1×10 ⁴ set)	Region	City
Tencent	>100	North China	Huailai
China Telecom	>100		Hohhot
China Mobile	>60		Hohhot
China Unicom	>50		Hohhot
Alibaba	>30		Zhangbei
Alibaba	>30		Ulanqab
Apple	>10	East China	Ulanqab
Alibaba	>30		Nantong
Tencent	>30	South China	Yizheng
Alibaba	>30		Heyuan
China Telecom	>100	Southwest China	Guiyang
China Mobile	>100		Guiyang
China Unicom	>100		Guiyang
Tencent	>10		Guiyang
Apple	>10		Guiyang
Amazon	>20	Northwest China	Zhongwei

Data center projects in some non-urban core area organized by Zhang Tuo, vice president of Hangzhou Cloud Tripod Data Technology Co., Ltd. North China, Northwest China and East China are the key areas investigated during 2018 China Digital Journey - Data Center Tour in Northern China, including each city in North China, while JD Cloud East China Data Center represents East China region. When we went to visit the China Mobile Data Center in Zhongwei, Ningxia, we also passed by the Amazon data center, which is only a few km away from the former. Moreover, we can see that Alibaba has a planned installed capacity of 300,000 servers in every landing city, which also reflects the idea of Alibaba Cloud's plans of data center built-up across China (Source: E7Academy)

Tencent sets data center clusters, with a total of 1 million servers, in three towns of Huailai, namely, Cunrui, Sangyuan and Donghuayuan. The three pairs of networks have a path length mainly between 30~40 km. The network paths from Beijing to Huailai include G6 Beijing-Tibet Expressway, G7 Beijing-Urumchi Expressway, Xinglongkou-yanqing Expressway + Yanqing-Chongli Expressway, Beijing-Zhangjiakou Railway and Beijing-Zhangjiakou High-speed Railway. At present, the path from Donghuayuan to Wangjing is about 105km, and that from Cunrui to Wangjing is about 135km.

The network between these data centers is already in the category of Data Center Interconnect (DCI) and is an important part of the cloud computing infrastructure.

From a macro perspective, Zhangbei and Huailai are separated by the Hu line, but both of them are not far away, while Zhongwei, Ningxia, where China Mobile and China Unicom established data centers successively and Hohhot, Inner Mongolia, where the top three telecom operators gather, are a bit too far. However, the network is precisely the core competitiveness of the telecom operators' data centers.



The planned network paths with a three-point layout in Huailai



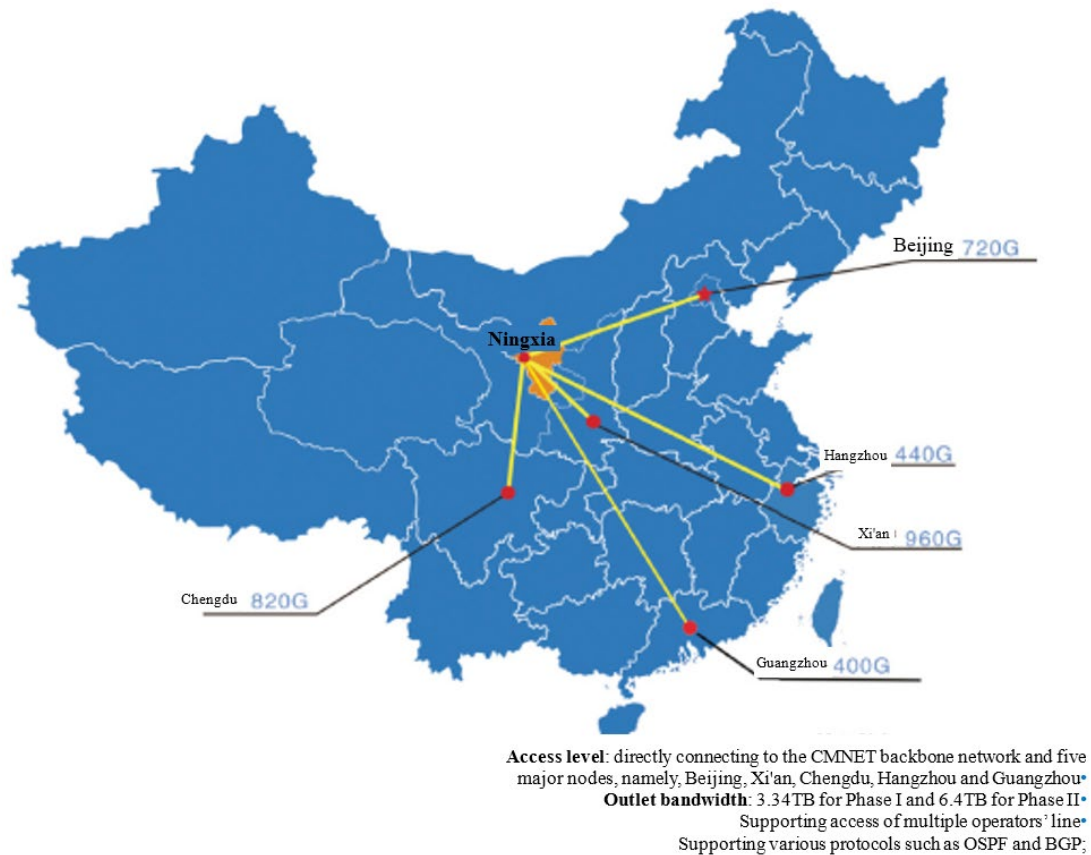
/ 3. Telecom operators

Although the resource-rich western region does not have equal network resources yet, but driven by the market and guided by policies, the operators with backbone network resources have started to make investments in the west. Built by China Unicom with all its efforts, China Unicom Hohhot Cloud Data Center, a national-level cloud data center, aims to meet the needs of high-end and mid-range users at different levels so as to attract China and international high-end information and R&D companies in the fields such as Internet, Internet of Things (IoT) and cloud computing. Presently, it has served Baidu, Alibaba, Huawei and other users. The data center, equipped with dual-route express optical cable system completely laid through pipeline, directly connects to two core nodes in Beijing of the 169 backbone network, realizing a latency of less than or equal to 5ms and a network outlet bandwidth of 1.5T (1,576G). Therefore, it is known as "one hop onto the backbone and an express connection to Beijing, Shanghai and Guangzhou".

China Mobile's new data center campus in Zhongwei, Ningxia has also been put into operation. It has a latency of less than 5ms to the backbone network, and directly connects to five major nodes, namely, Beijing, Xi'an, Chengdu, Hangzhou and Guangzhou. The outlet bandwidth of Phase I is 3.34T, while that of Phase II will reach 6.4T.

With the data centers of telecom operators such as China Mobile and China Unicom being put into

operation successively, the last shortcomings in the resource-rich northwest region will be remedied, and the contact between the eastern and western regions will be closer, which will not only enable the better use of western resources, but also lay a better foundation for business development in the eastern region.



Current network and bandwidth allocation of China Mobile (Ningxia) Data Center

China Mobile (Ningxia) Data Center

China Mobile (Ningxia) Data Center, located in Zhongguancun Science and Technology Park - West Cloud Valley, Zhongwei City, Ningxia Hui Autonomous Region, is 28 km away from the urban area of Zhongwei. It is one of the important nodes of China Mobile's strategic layout of IDC resources in China. The entire data center covers an area of nearly 130,000m² and can accommodate 18,000 racks. It is directly connected with the five major nodes in Beijing, Xi'an, Chengdu, Hangzhou and Guangzhou. The outlet bandwidth of Phase I is 3.34T.



China Mobile (Zhongwei) Data Center is located in the core area of the East Expansion Zone of Zhongwei Industrial Park. The west side of the plot is a construction land of China Unicom.

In Phase I Project, a total of two computer room buildings are planned, with a shared cooling station, which is a single building. The house generator room and the high-voltage distribution room are arranged in a centralized manner in the single building of the power center, and each generator set is provided with a corresponding oil storage room. The transformer and low-voltage distribution facility are installed in the high- and low-voltage distribution room in the computer room building respectively. A distribution room is set up in the cooling station, with 10KV secondary distribution and 0.4KV secondary distribution respectively arranged to supply power for the cooling station, the power center and the support and maintenance room.

At present, a data center computer room, a cooling station, a power center and a maintenance and support room have been completed, with a total building area of 39,270m². The entire data center is of reinforced concrete frame structure and a two-storey above-ground building with a total height of 10.55m to accommodate 19-foot 46U standard racks, whose power can be customized to 3KW, 5KW and 7KW as needed.

The data center computer room in No.1 computer room building of China Mobile (Ningxia) Data Center can provide 3,070 racks in total, containing a total of 16 computer room modules, classified into two sizes: 256m² (100 server racks) and 355m² (124 server racks). It can provide customized services from rack level to room level, and even to computer room level, to support customized services such as micro-modules, warehouse-style computer rooms, high-voltage DC systems, UPS and battery packs, allowing enterprises to have more flexible options and room for upgrades.

Zhongwei, Ningxia is located in the western resource-rich region, therefore, it can make full use of green energy such as wind energy and solar energy. At the same time, thanks to its superior natural cooling resources conditions, the cooling system of the China Mobile (Ningxia) Data Center adopts two modes of cooling, namely, high-voltage centrifugal water chilling units (N+1 redundancy) are used as air conditioning cooling resources for data center cooling in hot summer; while cooling towers + plate heat exchangers are used for data center cooling in winter, which can make full use of natural cooling resources and effectively reduce the annual average PUE of the data center.



Three computer room buildings and three oil engine (diesel generator) buildings have been completed in China Unicom Hohhot Cloud Data Center. Computer room buildings and operation & maintenance buildings are planned to be built on the vacant land on the left, and an 110KV substation on the right (beyond the figure).

China Unicom Hohhot Cloud Data Center

China Unicom Hohhot Cloud Data Center is located in Hongsheng Industrial Park, Xincheng District, Hohhot City, Inner Mongolia Autonomous Region, with a planned land area of 973 mu (approximately 648,666.7m²), a total building area of 598,000m², an investment of RMB12.3 billion, and a planned capacity of 34,500 server racks. Three computer room buildings have been completed, accounting for about one-third of the planned number, and more than 8,000 racks have been put into operation.

The data center is located at the intersection of the east-west and the north-south main optical cables, with a network latency of less than 3.5ms, and a design positioning of "one hop onto the backbone and an express connection to Beijing, Shanghai and Guangzhou". In the whole data center, the dual-route express optical cables are laid inside pipelines. The latency of directly connecting to the core nodes of Beijing is within 5ms, and the current outlet bandwidth is 1,576 Gb/s.

Hohhot, located in the northwestern part of China, has excellent natural resources. As a large number of power plants such as wind power plants and solar power plants are located there, its electricity price is the lowest in the country, which can greatly reduce the operating expense of the data center. It has typical continental climate in Mongolian plateau, with an annual average temperatures of below 10°C, which provides a rich natural cooling resources for the data center. China Unicom Hohhot Cloud Data Center adopts a mature water-side free cooling scheme, with two cooling stations operating independently, and two 500 m³ chilled-water storage tanks, which provide a backup cooling time of 15min. The air supply outlet in the data center is of a grid design to dynamically adjust the air supply volume of each rack, and floored with a special thermal insulation floor to improve the cold air efficiency and effectively reduce the data center's PUE.



Chapter 5

Modularization: building data centers with modular blocks, removing water pipes to use air directly

Modularization can accelerate the construction and improve flexibility while ensuring project quality and thus has become a recognized development direction for data center. At present, the water-side free cooling architecture commonly used in China data centers is a major obstacle to modularization, while the indirect evaporative cooling architecture has obvious advantages in this respect. There are two main routes of modularization within the IT room, which are suitable for different business needs.

Modularization is the trend of data center evolution, reflecting the transformation from traditional engineering construction to factory prefabricated products and on-site modular assembly so as to meet the fast expansion needs of the Internet and cloud computing giants. At the same time, following the concept of standardization and reusability, a new ecology has been formed, and the construction and operating expense of the data center can be further reduced.

The construction of traditional data centers relies heavily on on-site construction, and the speed is usually slow, and the requirements for the technical level of construction workers are also high. Compared with the on-site conditions of the data center, the factory has more complete and professional processing facilities, and has obvious advantages in terms of the consistency and efficiency of complex operations (such as cutting and welding). If more processing work can be completed at the factory, so that standardized prefabricated modules are formed, and transported to the data center for on-site assembly, then, the deployment speed will be greatly accelerated, and the construction quality can be guaranteed.



It is hard to guarantee the quality and progress of on-site construction

By accelerating the construction speed of data center in response to rapidly evolving business needs, it is not only good for self-built or customized data centers, but also brings significant benefits to co-location data centers, and this method of building on demand can also prevent investment from depreciation: in terms of time, supposing that a data center will support four generations of servers in its life cycle, it takes about two years to build one in the traditional way, which means that the time for about one generation of servers has passed. In other words, data centers that should have supported four generations of servers may only support three generations of servers. From the current technological development of servers, the power consumption of almost every generation of servers is rising, therefore, after three generations of servers, the data center may be difficult to meet the requirements of the next-generation servers for supporting facilities, or its effective IT capacity will drop.



/ Building: improving parallelism and pursuit of acceleration

The modularization of data center is reflected at all levels. From the perspective of building, it is very difficult to achieve modular construction in traditional multi-storey concrete-poured buildings, and the large columns in the computer room will also affect the layout of the racks. If the building is too high, it can also pose even greater challenges to the piping design of the water system. However, in the core area of the city, if it is not reconstructed based on the old factory building, three or more-storey data center may sometimes be needed due to the requirement such as floor area ratio.



Phase I project of the Alibaba Cloud Zhangbei Data Center under construction in early of June, 2015
(Source: Qu Haifeng)

By using a large number of steel structures and prefabricated modules, it helps Alibaba Cloud shorten the construction period of the Phase I Project of the Zhangbei Data Center by 45 days. In April and June of 2015, the No.1 Campus and No.2 Campus were commenced in succession and were completed only within four and a half months, which means saving a quarter of the time, making it possible to complete

the construction of the main structure of the building before the cold and long winter in Zhangbei. In September, 2016, the two campuses were put into operation. The No.1 Campus also undertook part of the 2016 “Singles’ Day” shopping festival, contributing to the transaction of RMB120.7 billion on that day. If the building construction speed has not been significantly improved, the time window will be missed and the delivery may be postponed to 2017.



The Phases II and III of the No.1 Campus in Alibaba Cloud Zhangbei Data Center are designed by Alibaba itself. The upper picture shows the state on August 10 (Phase II). The lower picture shows the effect drawing on October 29 (Phase III highlighted).

In 2018, the team of China Digital Journey witnessed the construction speed of Alibaba Cloud Zhangbei Data Center. On August 10, when we visited Zhangbei, the Phase II of the No.1 campus was just delivered, and the land next to it (should be Phase III) was still an open space. On October 29, namely, after only 80 days, the Phase III was formally capped, just as the official news said that “the node construction is completed on schedule within 98 days”.

The modular approach helps to change the construction way of the data center from “serial” to “parallel”, thus speeding up the construction, for example, the measures taken including simplifying civil construction, performing modular manufacturing of electromechanical equipment in the factory simultaneously, transporting them to the site for assembly, and trying to make civil construction and electromechanical work be carried out in parallel as much as possible, in order to achieve rapid delivery. From the perspective

of the cost structure of the entire data center, the proportion of civil construction investment is not large, one magnitude lower than that of electromechanical facility part, but has a very long construction period. The modular design idea decouples the electromechanical part with the civil works, and the two are carried out at the same time to reduce the cross-construction and thus achieve the purpose of shortening the construction period.



/ Cooling: from water-side free cooling to indirect evaporative cooling

Because of the presence of various complex pipelines and valves, water systems are not as easy in modularization as electromechanical equipment. For a multi-storey data center located in the core area of the city, it is a typical practice to place the cooling tower on the roof of the building, while chillers, plate heat exchangers and other equipment in the cooling station on the ground floor or underground. They are connected by the cooling water pipeline, while chilled-water pipeline connects the cooling station to the computer rooms on various floors. Both the chilled-water storage tank and the (cooling) water storage tank can be arranged indoors or outdoors. In the Tencent Tianjin Data Center and the ChinData Wangjing Data Center, the reservoir is arranged underground, as an integral part of the main structure of the building. In the case where the power distribution room and the chiller room (cooling station) are on the same floor, isolation measures should be taken to avoid accidents such as water pipe bursting of cooling station spreading to the power distribution room.



Interior of the cooling station in Alibaba Cloud Zhangbei Data Center (Phase I): the left side of the aisle is the water storage tank and the water chilling units of the chilled water system, and the right side is the plate heat exchangers and the cooling water pipes (leading to the cooling tower on the roof). Of course, the most attractive part is the various colors of the water pipes

Due to the presence of complex water systems, include various large pipelines, the cooling station has higher storey height. In a multi-storey (three-storey and above) data center, it is usually the floor with the highest storey height. For example, the ChinData Wangjing Data Center is a four-storey overall-poured building in descending plate structure with two floors above ground and two underground, and B2 of the underground station is 7.2m high, which is higher than any other floor.



In the Phases I Project of the No.1 Campus in Alibaba Cloud Zhangbei Data Center, the white cooling station named as "Tianchi" connects to the two-storey computer room building through overhead water pipes. The plot at upper right across the road is that for the Phases II and III Project (not yet commenced in 2016)

In areas where land supply is relatively adequate, cooling stations and (IT) computer rooms can be placed horizontally rather than vertically (below it). In the Phase I Project of Alibaba Cloud Zhangbei Data Center and the China Mobile (Zhongwei, Ningxia) Data Center, the cooling stations are relatively independent buildings, and the height is basically equivalently the two-storey computer room building.

In terms of the modularization of the water system, Google has reached a higher level, which can be referred as an industry model. However, China data centers do not have to follow Google's footsteps because fresh air cooling, direct evaporative cooling and indirect evaporative cooling are more suitable for modular construction.

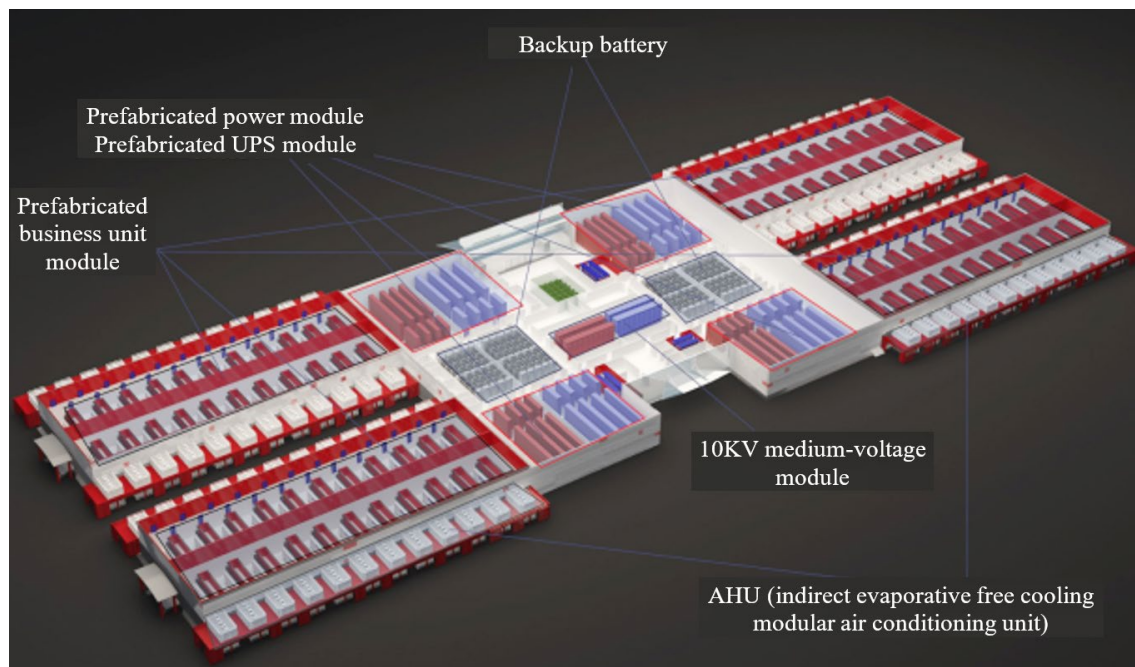
Just as people mainly dissipate heat through the skin of the body surface, the heat exchange between direct/indirect evaporative cooling and external air is mainly through the surface (side and top) of the building, with the difference being one inside and one outside: namely, the heat exchange of fresh air and direct evaporative cooling takes place inside the computer room building, while that of the indirect evaporative cooling is through the equipment installed outside the building.



The indirect evaporative cooling module returns air through the ceiling from the upper part, exchanges heat with the outdoor cold air, and then sends air from the lower part back to the computer room. Therefore, it is very reasonable to put such module on the side of a large flat data center

Indirect evaporative cooling technology has a natural advantage in terms of modularization. For example, It takes 7 months for the Phase I Project of ByteDance Huailai Data Center from construction to operations, thanks to the perfect combination between the indirect evaporative cooling equipment and the large flat prefabricated frame structure. It is reported that the No.2 Campus in JD Cloud East China (Suqian) Data Center (Phase II Project), which will be delivered in 2019, and Tencent and Baidu's new self-built or customized data centers will be in indirect evaporative cooling architecture with comprehensive modular design so as to speed up their construction.

The large flat prefabricated frame structure makes ByteDance Huailai Data Center the first large-scale distributed fully-prefabricated data center in China. The indirect evaporative cooling modules are located on both sides of the computer room module, and one module corresponds to one cold aisle in computer room compartment. The power module is also prefabricated as a whole, assembled outside the data center, and then go directly into the power room between the computer room modules by mechanical means. As for the data center with the power room arranged on the ground floor, and large openings reserved, the power module can also be prefabricated, with the Alibaba Cloud Zhangbei Data Center - No.1 Campus - Phase I Project as an example.



Architecture diagram for Phase I Project of ByteDance Huailai Data Center, which is the first China large-scale distributed fully-prefabricated data center in large flat prefabricated frame structure.

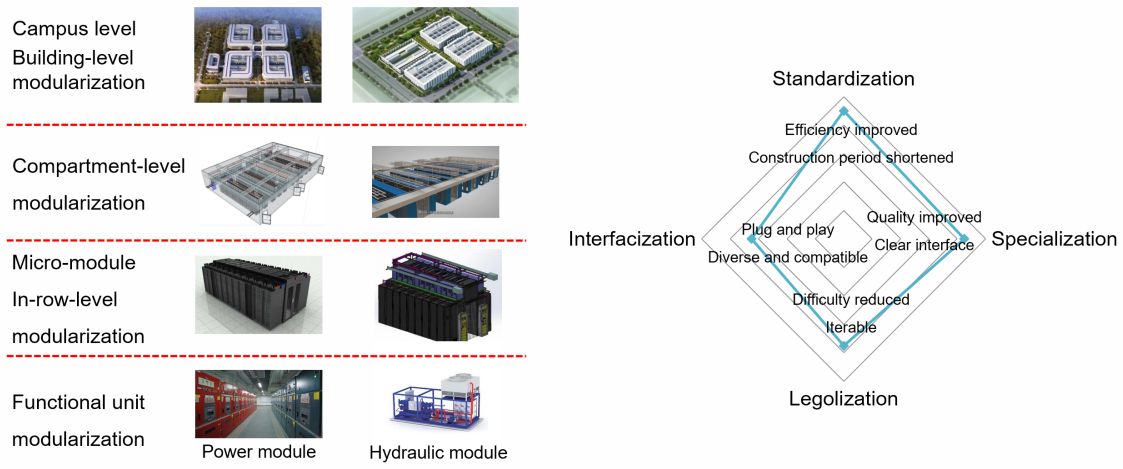


Overall power module of the ByteDance Huailai Data Center, with the dual paths colored with red and blue respectively



/ From micro-module to full modularization

One type of the modularization inside the computer room is the micro-module data center integrated with power supply and air-conditioning terminal, which not only reduces the dependence on the data center infrastructure (facility, including building and supporting equipment such as power supply and cooling equipment namely “air, fire, water and electricity”), but also speeds up the delivery through the on-site modular assembly, represented by Tencent Modular Data Center (TMDC) and the warehouse-type micro-module of Huawei. Tencent takes micro-module (MDC) as the smallest deployment unit that integrates the power supply and cooling functions originally in the data center infrastructure, which separates IT construction from civil construction, simplifies the computer room construction, delivers the relevant power distribution and cooling equipment along with the IT racks, and reduces the deployment granularity; moreover, factory prefabrication and on-site assembly also improve the deployment efficiency.



Levels and elements of modularization: this section focuses on micro-module and in-row-level modularization, as well as compartment-level modularization (Source: Several Trends in Data Center Development presented by Zhang Tuo, Vice President of Hangzhou Cloud Tripod, China Data Center Committee Summit 2018)

Both TMDC and warehouse-type micro-module technologies of Huawei adopt the design of cold aisle containment, integrated power distribution and precision in-row air conditioner, but in terms of the level of decoupling from the data center infrastructure, both have their own focuses: TMDC also integrates battery cabinets, so the battery compartment is eliminated in the data center; while the warehouse-type micro-module of Huawei also use hot aisle containment, and integrates the gas fire-fighting system, making it an independent fire compartment.

Such design makes the large bay on F2 of the Huawei Cloud Langfang Data Center only as a site for the placement of micro-module units (for keeping out wind and rain) to a large extent, and thus a more interesting evolution is derived:



The most conspicuous feature of the first-generation warehouse-type micro-modules of Huawei is the design of single set cold and hot aisle containment

The Phase I Project adopts the first-generation warehouse-type micro-module in combined cabinet structure, with single set cold/hot aisle containment, while the Phases II and III Projects adopt the second-generation warehouse-type micro-modules in the frame-type structure, in which the two modules are combined into a 3-aisle two-in-one module (both modules have its own cold aisles, and the adjacent part in the middle is got through to form a common hot aisle).

The frame-type structure of the second-generation warehouse-type micro-module decouples the rack from the micro-module, supports the use of the customers' own racks and meets the standards of Internet companies such as Tencent and Baidu; it can also allow the installation of various standard or non-standard racks, and the deployment of standard server racks, network rack, and Scorpio Rack and adapt to ICT equipment of various specifications.



The second-generation warehouse-type micro-modules deployed in the Huawei Cloud Langfang Data Center: two modules form a whole; a label of "Gas-loaded and no entry" affixed on the three doors indicates that there is a gas fire-fighting system, and the middle door corresponds to the hot aisle

Supporting racks of various specifications means that the power consumption of a single rack is variable, such as 4kW, 5kW, 7.5kW, and 10kW, up to 25kW/rack; IT micro-module can be converted to power micro-module or network micro-module, and adapt to a variety of scenarios; based on the characteristics of the frame-type structure, the micro-module can expand the power density and upgrade the reliability level. This modular division of labor can not only speed up deployment, but also separate civil construction from IT and supporting facilities, as well as adapt to more environments.

Needless to say the new data centers, the external conditions of the data centers reconstructed from a factory or warehouse may not fully meet the requirements for the data center, for example, the lack of thermal insulation measures may cause huge fluctuations in temperature and humidity, or the original water fire-fighting system may damage IT equipment. Warehouse-type micro-module of Huawei decouples IT and supports facilities from buildings, which can greatly reduce IT facilities' dependence on building conditions, and achieve the goal of saving transformation and construction costs and shortening the construction period.



Baidu's prefabricated module (referred to as "pre-module") belongs to in-row-level modularization, including array cabinet and hot aisle components; the deployment can be completed quickly by directly pushing the "North Pole" Rack server to the blue floor area and connecting the power and accessing the network. Baidu Cloud Computing (Yangquan) Center has adopted a large number of rack-scale server, thus pushing the modularization to the Rack level, which will be introduced in the next chapter

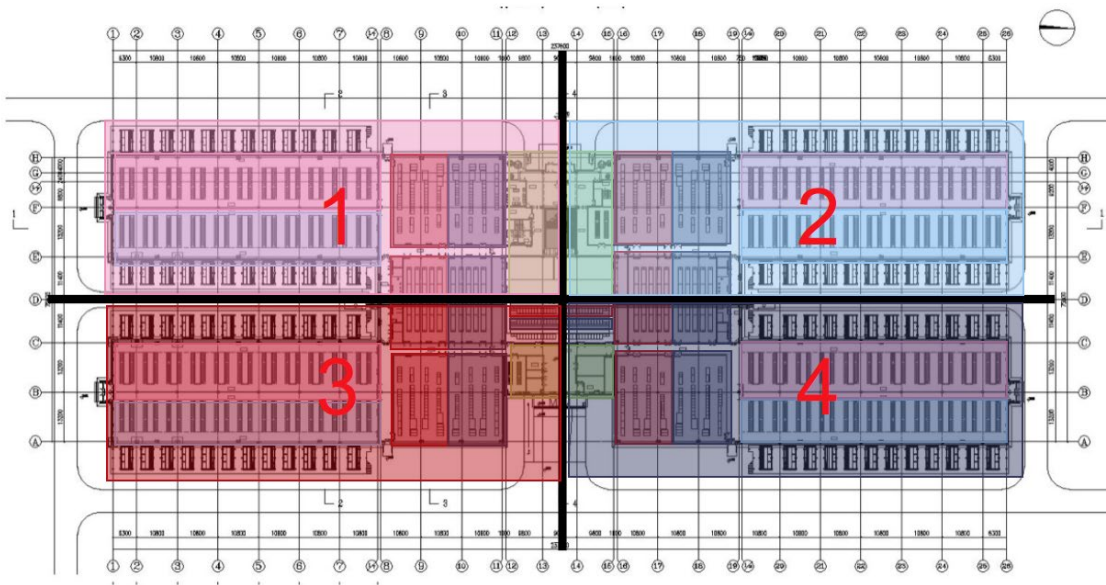
Another route for modularization inside the computer room is in-row-level modularization, in which the modularization of the air conditioner and the power distribution terminal of the data center are mainly combined with the computer room building (compartment). The racks are installed according to the planned layout instead of directly combining them as a whole relatively independent of the compartment, which is suitable for large-scale unified deployment. Several other hyperscale data centers visited in the 2018 China Digital Journey have different degrees of characteristics in this respect, and have also achieved relatively satisfactory results.



The ByteDance Huailai Data Center adopts the cable tray in the form of “gantry crane”, and lays different types of cables in layers (such as separation of two-source mains, power and control systems), and then enters the cable distribution frame installed in a way for short-depth rack at the IT rack’s upper part

Common to these two modular routes is the elimination of raised floors (in the computer room) and adopts hard floors directly, which simplifies the complexity of construction, operation and maintenance and improves the efficiency of deployment.

By either way, modularization can run through all levels from rack, IT module, computer room module, single building to the campus. In the micro-module genre, Tencent has a modular data center construction methodology code-named "Normandy", which can calculate proportions level by level, from the campus to the building, computer room unit, micro-module and rack, and then replicate and expand by micro-modules to form the computer room building, and even the entire campus.



The ByteDance Huailai Data Center also embodies a similar philosophy:

- The hot aisle containment among two rows of racks, 14 racks per row, one compartment of the computer room has 11 sets of such modules;
- Two computer room compartments form one business unit module, with 12 indirect evaporative cooling equipment on each side (corresponding to the number of cold aisles. The term “cold aisle” herein refers to the aisle in front of the rack rather than the entire interior of the computer room compartment), plus prefabricated power modules and prefabricated UPS modules (and their batteries);
- Four such business units plus a 10KV medium-voltage module form the 工 (“Gong”, a Chinese character) shaped layout Phase I Project;
- The Phase II Project is expanded to six business units, forming a 王 (“Wang”, a Chinese character)-shape layout.



Only more than a month after being visited during the 2018 China Digital Journey, the Phase II Project of the ByteDance Huailai Data Center was close to completion, and racks began to be deployed at the end of September. The indirect evaporative cooling module is also installed on the roof of the power module in the middle of six computer room modules. This is the most obvious iteration in the technical architecture.

This evolution has increased its effective IT capacity by 50%, and the partial design has a small iteration, but the overall design concept and construction principles are consistent, and the construction speed of the Phase II Project is further shortened to six and a half months.



Chapter 6

IT: collaborated efforts for potential exploration and overall improvement

The changes in the data center industry by large Internet companies began with the optimization of data center infrastructure and IT as a whole system. In order to help the data center reduce PUE, a high temperature server came forth; to adapt to the high power density brought by equipment such as GPUs, the power supply and cooling architectures of the data center are also facing changes... while the rack-scale server promotes the modularization of the IT side.

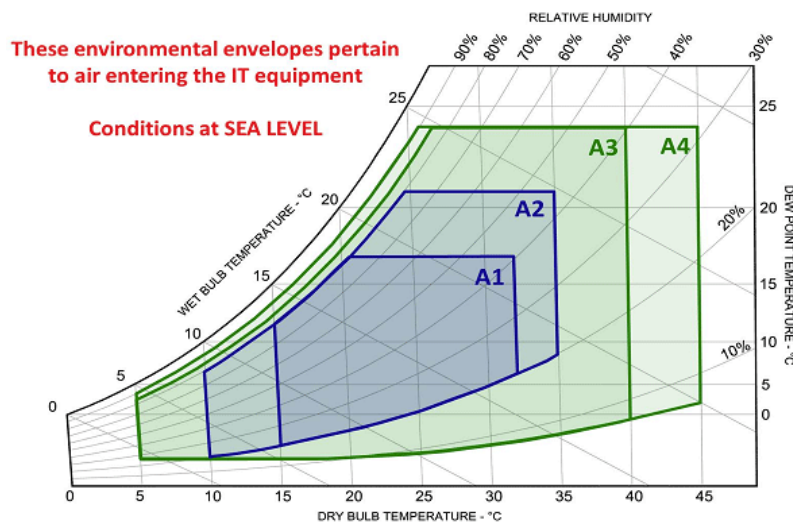
In the data center area, traditionally infrastructure (buildings and so-called "air, fire, water and electricity") is separate from IT, usually bounded by racks. Namely, inside of the racks belongs to IT (direct carrier of the business), while outside of the racks (usually including racks) belongs to the infrastructure. However, as large Internet companies move toward the ways of customized or self-built data centers, infrastructure and IT begin to be considered as a whole system, and the boundaries between them become blurred.

Similar to the previous infrastructure part, the IT part can also be discussed in terms of cooling, power supply, and modular deployment. This chapter mainly analyzes the connection between IT equipment (represented by servers) and the data center infrastructure.

/ The butterfly effect: raise inlet temperature and increasing efficiency

Energy efficiency comes first. PUE drops below 2, meaning that IT energy consumption has exceeded that of infrastructure. Especially after the universal use of natural cooling resources for "free cooling", IT energy consumption is an absolute big part in that of the data center. Improving the energy efficiency of servers can help save energy, but at the data center level, it is more important to consider IT and infrastructure as a whole to improve the overall energy efficiency of the data center and further reduce its PUE.

Compared with international giants, for the same water-side free cooling architecture, Google's data center has long reduced PUE to below 1.1 because its data centers are usually located in the regions with cold climates, and it even has a data center with seawater cooling introduced (Hamina, Finland) so that natural cooling resources are available throughout the year. While in Yangquan, Shanxi of China, where the geographical location is not so superior, it can only increase the temperature inside the computer room (cold aisle) as it is impossible to reduce the temperature outside the data center.



ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) proposed its thermal guidelines in 2011. The horizontal axis is the dry bulb temperature, the vertical axis is the dew point temperature, and the curve from lower left to upper right is the wet bulb temperature

This means that the increase in the inlet air temperature of the server requires the coordination of the server supplier in properly transforming the server to the so-called "high temperature server." Of course, high temperature operation is usually subject to limitation, and it is not possible to operate at very high temperatures throughout the year. For example, the Dell Fresh Air 1.0 specification is applicable to the specific Dell (EMC was not involved at that time) PowerEdge 11th and 12th generation servers, which can operate continuously at inlet air temperature of 35°C, and can operate at 40°C for 10% of the whole year, and under abnormal conditions of up to 45°C for 1% of the whole year; the maximum dew point is 26°C.



The Dell Fresh Air 2.0 specification is applicable to the specific Dell EMC PowerEdge 13th generation servers (with Intel Xeon E5 v3/v4 processors), which can operate continuously at inlet air temperature of 40°C, and can operate normally under abnormal conditions of 45°C for 1% of the whole year (about 90h); the maximum dew point is 29°C.

As the power consumption of core components such as CPUs increases, so does the high temperature resistance of the servers. Take Huawei 2U dual-slot server based on Xeon Scalable Processor (XSP) as an example:

- Maximum operating temperature of the Huawei FusionServer 2288 V5 supporting a maximum TDP (Thermal Design Power) of 125W CPU (such as 20-core @2.0GHz Xeon Gold 6138) is up to 40°C (complying with the ASHRAE Class A2 to A3 standard);
- Maximum operating temperature of the Huawei FusionServer 2288H V5 supporting a maximum TDP of 205W CPU (such as 28-core@2.5GHz flagship products of Xeon Platinum 8180) is up to 45°C (complying with the ASHRAE Class A2 to A4 standard).

It should be noted that under the same technical conditions, as the operating temperature increases, the constraints on the configurations of the servers are becoming more and more severe, especially the bulky

Huawei FusionServer 2288H V5
Technical White Paper

5 Product Specifications

Table 5-3 Operating temperature specifications

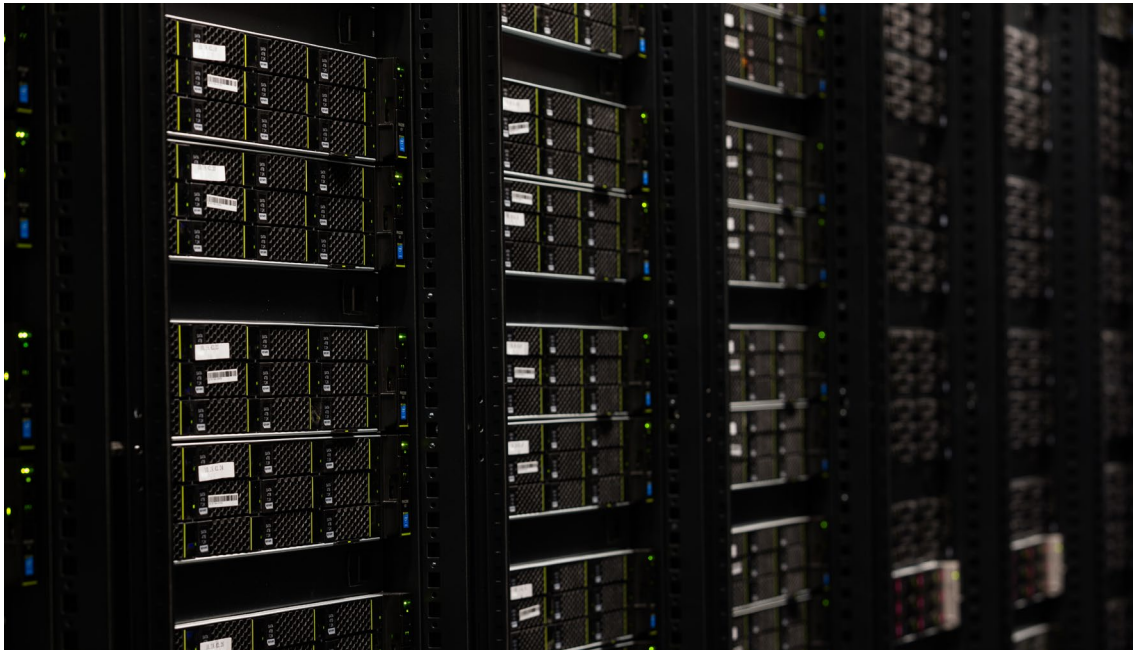
Model	Maximum Operating Temperature 30°C (86°F)	Maximum Operating Temperature 35°C (95°F) (ASHRAE CLASS A2 Compliant)	Maximum Operating Temperature 40°C (104°F) (ASHRAE CLASS A3 Compliant)	Maximum Operating Temperature 45°C (113°F) (ASHRAE CLASS A4 Compliant)
Server with twelve 3.5-inch drives (expander)	Supports all configurations.	Does not support P100 and M60 GPUs.	- Does not support PCIe SSD cards. - Does not support passive cooling GPUs. - Does not support rear drives. - Does not support built-in drives.	N/A
Server with twelve 3.5-inch drives (pass-through)	Supports all configurations.			
Server with 8 x 2.5-inch SAS/SATA + 12 x 2.5-inch NVMe drives	Supports all configurations.	Supports all configurations.	N/A	
Server with twenty-four 2.5-inch drives (pass-through)	Supports all configurations.	Does not support P100 and M60 GPUs.	- Does not support PCIe SSD cards. - Does not support passive cooling GPUs. - Does not support rear drives. - Does not support built-in drives.	

Model	Maximum Operating Temperature 30°C (86°F)	Maximum Operating Temperature 35°C (95°F) (ASHRAE CLASS A2 Compliant)	Maximum Operating Temperature 40°C (104°F) (ASHRAE CLASS A3 Compliant)	Maximum Operating Temperature 45°C (113°F) (ASHRAE CLASS A4 Compliant)
Server with eight 2.5-inch drives	Supports all configurations.	Does not support V100 GPUs.	- Does not support PCIe SSD cards. - Does not support passive cooling GPUs.	- Does not support PCIe SSD cards. - Does not support passive cooling GPUs. - Does not support rear drives. - Does not support standard IB and OPA cards. - Supports only Intel® Xeon® Platinum 8153, Gold 6152/6140/6126/5118/5215, Silver 4216/4215/4214, and other CPUs whose power is less than 105W.

The technical white paper for Huawei FusionServer 2288H V5 explains the preconditions for operating temperature in one and a half pages. This is an excerpt

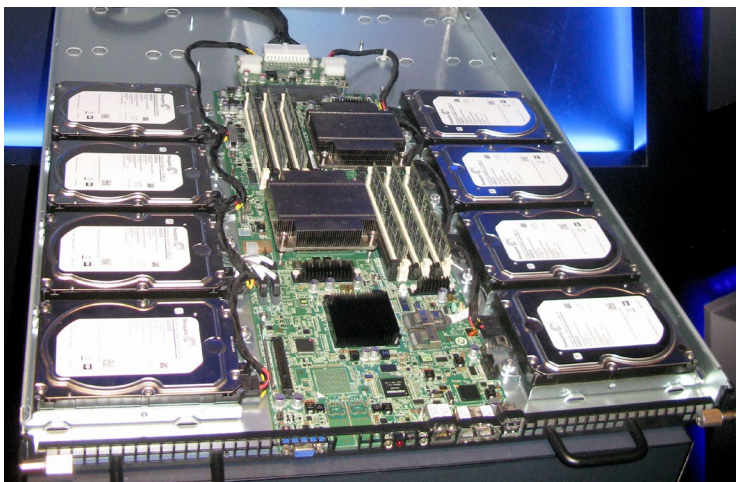
(airflow affected) components working in high heat (such as GPU). Therefore, when the power density of IT equipment such as servers reaches a certain level, various liquid cooling schemes become particularly attractive, which we will discuss in the next section.

Baidu Cloud Computing (Yangquan) Center realizes the using of natural cooling resources for 96% of the year by increasing the inlet air temperature of the servers, and the total time of relying solely on chiller cooling is only over 300 hours, about two weeks. Near noon on September 11, 2018, the team of the China Digital Journey visited the Yangquan Data Center and felt that it was slightly cooler in Yangquan than Beijing. The large monitoring screen showed a temperature of about 15°C, and the instantaneous data of the Module Buildings 1~4 were as follows: cold aisle temperature was between 23~28°C, and the hot aisle temperature was between 33~40°C.



It is learned that when cooling resources is switched at the times when spring turns into summer and autumn turns into winter in the Yangquan data center, the cold aisle temperature can reach 31°C. There is also an experimental total high temperature computer room in Yangquan, where the cold aisle temperature can reach 35~40°C, thus achieving free cooling throughout the year, which is a more extreme case of using CapEx for OpEx.

Another case of Baidu Cloud Computing Center in Yangquan is the OCU aforementioned, which replaces airconditioner fan with server fan, and could be considered as a kind of collaborated effort.

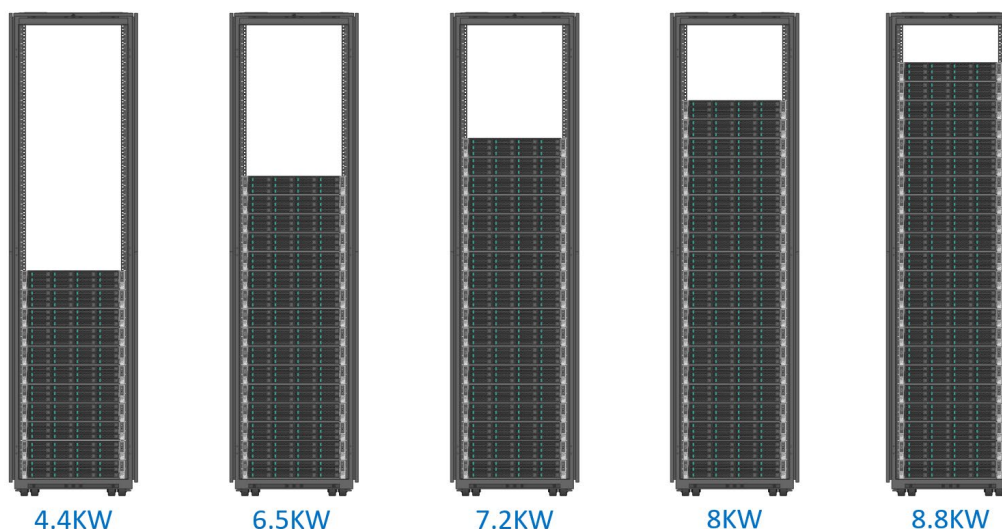


High temperature corrosion resistant server nodes for Baidu "North Pole" Rack



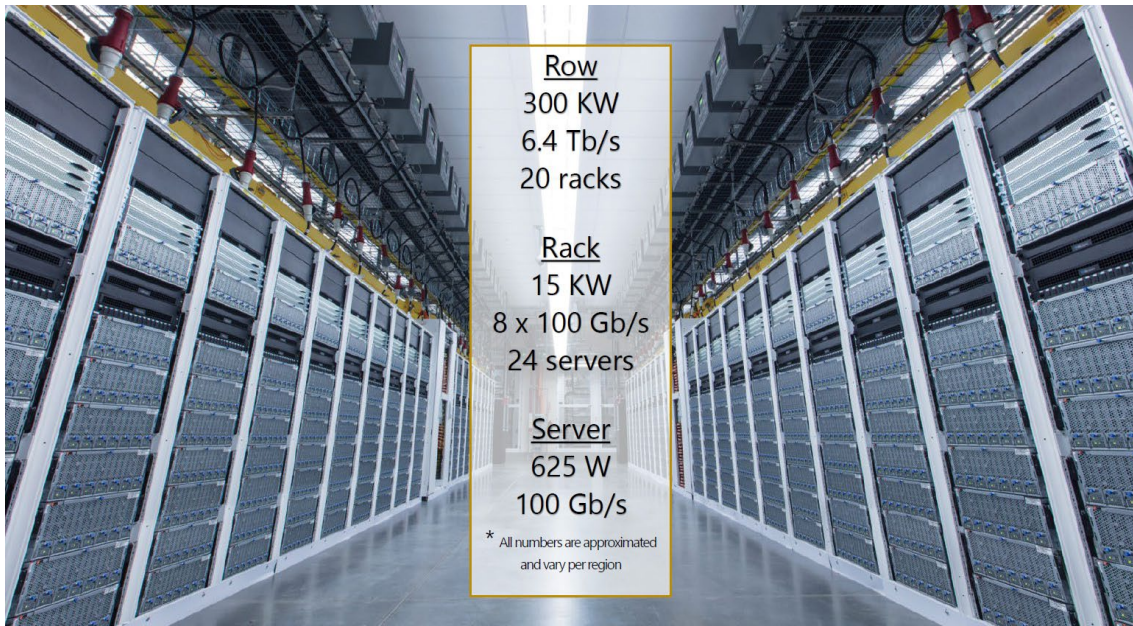
/ More work needs to be done on power supply, liquid cooling with both hopes and challenges

On power supply, hyperscale data centers need more power density, so as to fill in the racks and maximize the utilization of the space. In this journey, Tencent Tianjin Data Center with the longest history, single rack power ranges from 6.5kw (Building No. 3 and 4) to 8kw (Building No.1). The single rack power of Huawei Cloud Langfang data center reaches to 8kw, with ByteDance Huailai 7.2 kw, Baidu Cloud Yangquan data center 8.8 kw. The power density of all the data centers is significantly higher than the 4.4 kw of the telecom operators. More precisely, it is 1.5 or 2 fold power density of the telecom operators' data centers.



Calculated by using a reference model of a 2U computing & storage equalization server with a power of 400W, if the single rack power supply capacity reaches 8.8kW, 42U rack will be unable to accommodate the servers - the switches are not counted (48U rack is selected in the picture)

On the whole, the hyperscale data centers built by China Internet and cloud computing companies have an average power of more than 7 kilowatts (kW) per rack, but rarely exceed 10kW. There is still a gap between such power level and that of the high performance computing (HPC). However, considering the large size of the data center, such a power level has reached the highest level in China and is quite sufficient for the mainstream 2U computing & storage equalization server.



Microsoft introduces that its Azure Data Center (possibly the one in Dublin, Ireland) has a single rack power of up to 15kW and accommodates 24 units * 625kW servers (not configuration shown in the background picture. Source: Open Compute Project)

With the gradual popularization of AI application, the high-power components such as GPU have begun to be widely adopted, and the power consumption of CPU, FPGA, and various ASICs has become higher and higher, posing a double challenge to the power supply and cooling capacities of data centers.

The team of the China Digital Journey has seen the application of GPU servers in Baidu and ByteDance Toutiao data centers. Baidu Cloud Computing (Yangquan) Center runs two generations of Baidu's self-developed GPU servers (without CPU, these servers are used together with regular servers). As for X-Man 1.0, 16 GPUs of PCIe version, together with matching server nodes, are placed in a 4U space, thus a



X-Man 1.0 exhibited at the Baidu Create 2018

single North Pole 2.0 Rack server in Baidu Cloud Computing (Yangquan) Center reaches the upper limit of 8.8kW for single rack power by only accommodating two such systems, and the rack still has nearly two-thirds of the space unused, but can no longer accommodate other IT equipment.

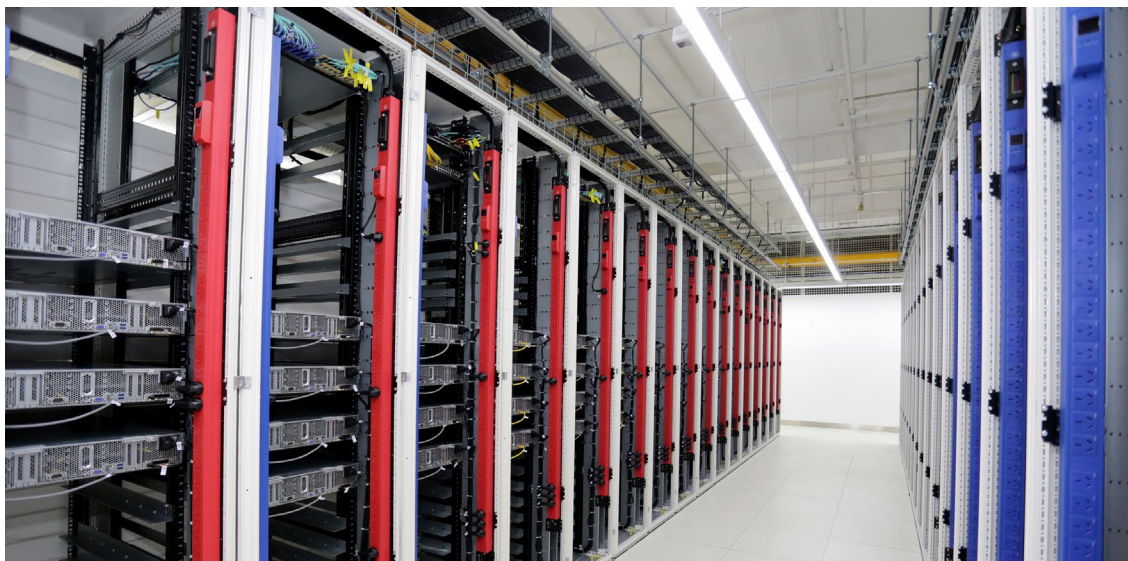
At the same time as the power density is increased, the cooling capacity is also facing the challenge. Some computer rooms in Baidu Cloud Computing (Yangquan) Center are provided with water-cooling back door for cooling, but those containing servers are still air-cooled.



In addition to the four kinds of air-conditioning terminal (CRAH, OCU, AHU and IDEC) technologies, Baidu Cloud Computing (Yangquan) Center also supports water-cooling back door, as well as the cold plate liquid cooling scheme described below

ByteDance Huailai Data Center also has similar situations. Some racks are equipped with ultra-high-density GPU servers, namely, a 2U rack accommodates 8 GPU servers of SXM2 version with higher power (compared to that of the servers of PCIe version) and the dual-slot Xeon scalable processors, with the power of up to 3kW. ByteDance controls the single server operating power within 1.8kW, so that one rack can accommodate 4 GPU servers of such version, with a total power of 7.2kW. In this case, only 8U rack space is occupied by the servers in total, and only a quarter of the rack space is used by the servers and the switch, but the rack can no longer accommodate other equipment, showing a sharp contrast to the 2U computing & storage equalization server scenario described above.

Baidu X-Man 2.0 is also equipped with 8 GPU servers of SXM2 version, with the cooling mode upgraded to cold plate (liquid cooling) to ensure the cooling of the GPU servers when running at full speed. With the cold plate liquid cooling mode, tall heat sinks are not needed and all the core components of X-Man 2.0 can be installed in a 2U rack server, but Baidu still adopts a 4U rack server for a simple reason: although the equipment density in the rack is increased, the power supply capacity of the rack cannot be kept up, there will still be a lot of unused space, and it is meaningless to simply pursue the improvement of density.

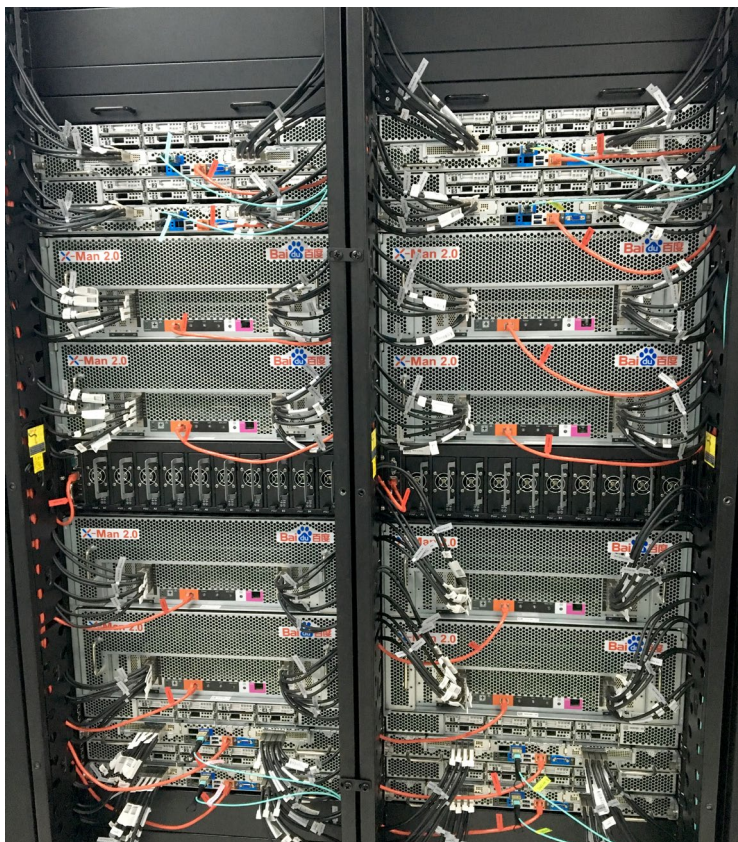


Baidu Cloud Computing (Yangquan) Center's North Pole 2.0 Rack server can accommodate four sets of X-Man 2.0 and the supporting servers, and the number of its GPUs in a single rack is the same as that of X-Man 1.0, while the power is increased to about 11kW, which has already reached a very high level among the China Internet and cloud computing data centers.



4U X-Man 2.0; in fact, a 2U server is sufficient

The Alibaba Cloud Zhangbei Data Center - Phase II Project is provided with a medium-scale immersion liquid cooling system. The data center design needs to be adjusted accordingly regardless of the water-cooling back door, cold plate liquid cooling or immersion liquid cooling.



A Baidu North Pole 2.0 Rack server can accommodate 4 sets of X-Man 2.0

/ **Rack Scale Design: small-scale centralization and large-scale distribution**

Rack-scale server is an example of modular deployment of IT, such as the Baidu North Pole Rack server mentioned above. The rack-scale server is an integration of the rack and the server (usually including the ToR) installed on the rack, which is assembled, tested and configured in the factory, and then is transported and pushed to the reserved position in the computer room, saving the process of on-site unpacking, testing and racking set by set in the data center. With the rack-scale server, the granularity of server deployment is increased from one to dozens of sets, and the delivery speed is also greatly improved.

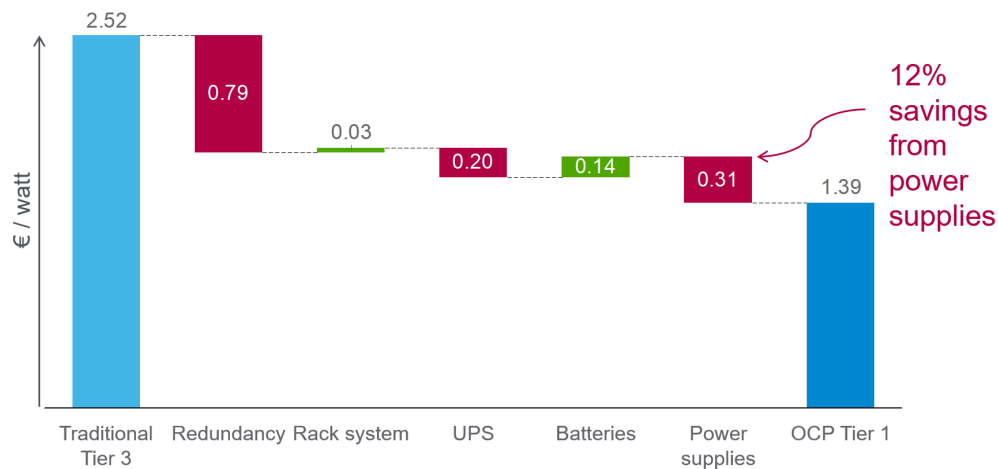
According to the data provided by Baidu, using the North Pole Rack server, the single-day delivery speed can be up to 5,000 nodes for single computer room and 10,000 nodes for double computer rooms (or two-



The spacious and bright server unloading and unpacking area is the goodwill of a data center for business

way deployment), which is more than ten times that of the traditional delivery method.

The daily delivery of 5,000 or 10,000 servers is still an extreme situation. However, according to the annual purchase of hundreds of thousands of servers of the top Internet and cloud computing companies in China, it is common that a single data center has a monthly delivery of 50,000 servers. The significantly improved delivery efficiency is of evident value to the hyperscale data centers that require rapid business deployment.



Like the Scorpio rack-scale server, the Open Rack of Open Compute Project (OCP) also pools the server power supply unit (PSU). According to the estimates made by Schneider Electric, this can save 12% of the cost (Source: Open Compute Project, 2016)

After years of development, the rack-scale server design is more than a delivery method but has developed into a kind of products. Taking the Baidu Cloud Rack (North Pole) server as an example, it integrates the power supply, cooling (server fans) and management functions in accordance with the specifications for Project Scorpio rack-scale server, reducing the number of server power supply units (PSU) and fans and achieving higher power supply and cooling efficiency.



The hot aisle (containment) of computer room in Baidu Cloud Computing (Yangquan) Center, on both sides of which the back fan walls are built for the centralized cooling of North Pole 2.0 Rack servers

Following the specifications for Scorpio 2.x rack-scale server, the North Pole 2.0 Rack server has the internal width being expanded from the traditional rack of 19 inches to 21 inches, a node depth of 850mm as well as greater internal space, and thus has higher density. Taking the Scorpio 2.x computing & storage equalization node as an example, it can accommodate a dual-slot Xeon mainboard and 12 * 3.5-inch disk slots in a 1U space, which is comparable to a traditional 2U storage server. At this point, the North Pole 2.0 Rack server of Baidu Cloud Computing (Yangquan) Center can accommodate 35 compute nodes, reaching a power density of 8.8kW. In case of a regular 2U server, it will need a 70U space, and even the 56U rack cannot accommodate it.



At Baidu Cloud Computing (Yangquan) Center, most of the North Pole 2.0 Rack servers are configured with 34 or 35 * 1U full-width nodes

Scorpio 2.x rack-scale server has a very prominent advantage, which is its storage capacity. Its cold storage model can accommodate 18 hard disks in a 1U space, fully occupy a 46U rack due to low power, and can provide a storage capacity of 720 3.5-inch hard disks by 40 cold storage nodes. Both Baidu and Alibaba have a relatively large purchase of this kind of servers.



The JBOD node (only storage, used together with server head node) of Scorpio 2.5 provides 20 3.5-inch disk bays in a 1U space, and 1U can provide a bare capacity of 280TB according to its configuration with Seagate Exos X14 helium-sealed hard disk drives

The deployment of the rack-scale server also puts higher requirements on the infrastructure of data centers, and the site elements such as ground bearing capacity, elevator, and aisle design must meet the transportation and installation conditions of the racks. For example, a fully loaded cold storage rack weighs more than 1.2 tons, and the freight elevator of Baidu Cloud Computing (Yangquan) Center, with a loading capacity of up to 4 tons, can deliver two such racks at the same time. In addition, since the rack and nodes should be treated as a whole and cannot be laid down or tilted during transportation, the doors of elevator, computer room, etc. must be high enough, and the transport ramps everywhere shall be as gentle as possible.



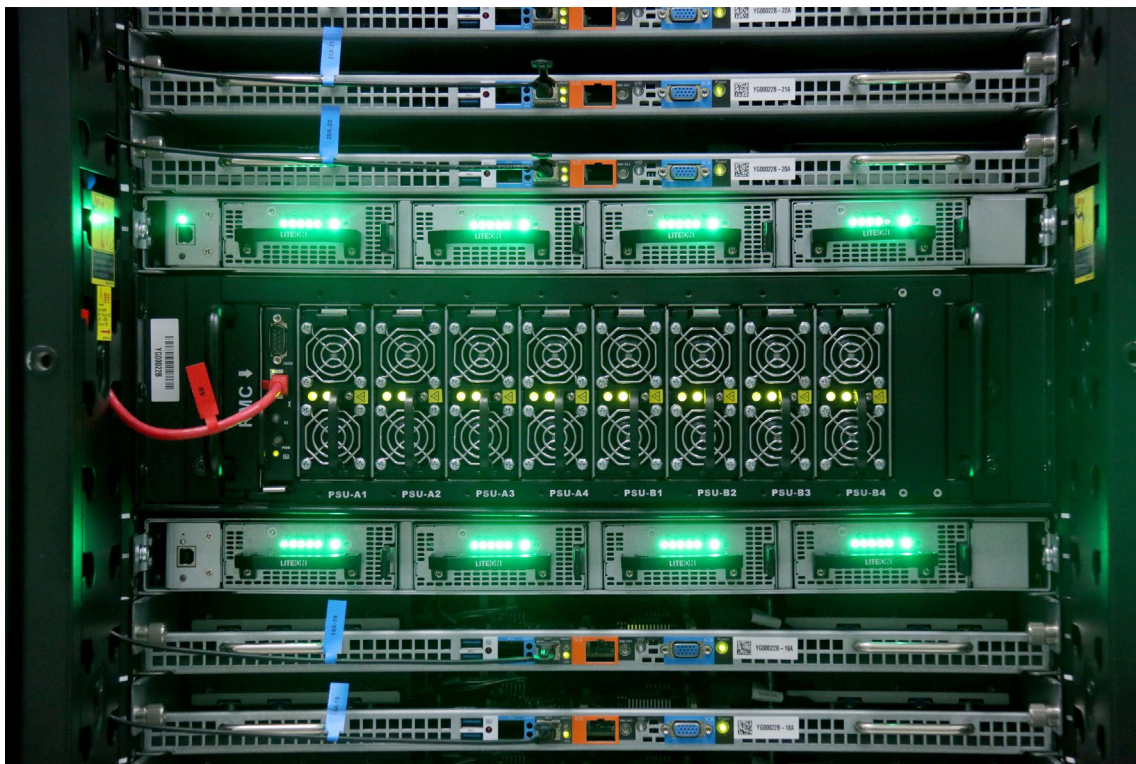
The BBU node defined by the Scorpio 2.5 specifications consists of four battery modules, total with an output power of 1.1kW. This node is provided with the 18650 lithium-ion battery cell which is known to the public due to Tesla, and two such nodes supply power for 8.8kW IT load for 15min continuously, which is the same as the power supply time of the lead-acid battery used for the traditional UPS or HVDC solution. However, it has obvious advantages in terms of power density and is space-saving

Baidu Cloud Computing (Yangquan) Center has the highest deployment rate of rack-scale servers in China, with Baidu North Pole 2.0 Rack servers accounting for nearly 96%. Compared with the Scorpio

2.0 specifications, Scorpio 2.5 has a new feature that the battery backup system (BBS) of up to 2U can be installed in the rack. This kind of North Pole 2.0 Rack server equipped with in-built rack-level lithium-ion battery has been successfully launched at the Baidu Cloud Computing (Yangquan) Center, further optimizing the power supply architecture of the data center. The configuration of UPS and traditional lead-acid batteries is abandoned at the same time as the power distribution system is completely modularized, realizing the integration of electromechanical and IT equipment, with a power supply efficiency of up to 99.5% (two mains of electricity, with losses mainly from floated charging of lithium-ion battery).

With the battery room being canceled, up to 25% of the infrastructure area can be saved, so that more computer room space can be provided. In combination with the increase of the rack density and the comprehensive application of various means, the total installed capacity of servers at Baidu Cloud Computing (Yangquan) Center has been increased from 120,000 servers at the initial design to 160,000 servers up to now. The actual installed capacity has exceeded 110,000 servers during the 2018 China Digital Journey.

Transferring the battery (and UPS function) from the infrastructure side to the IT side is another manifestation of the integration of data centers.

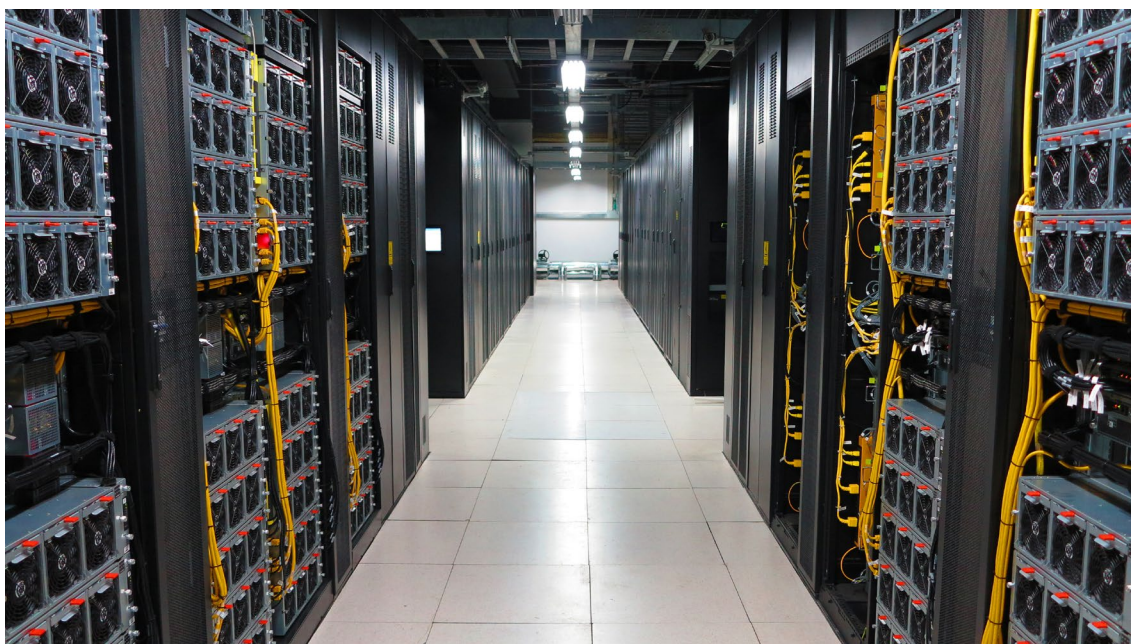


The lithium-ion battery backup unit (BBU) built in the North Pole 2.0 Rack server will occupy a rack space of 1U respectively above and below the power supply frame. However, in practice, the server nodes are not fully occupied due to the limitation of the total power of the rack (except for the cold storage rack), so the additional 2U power backup unit improves the space utilization of the rack

Tencent, together with Baidu and Alibaba, jointly launched the Scorpio Project, and the time when it deploys rack-scale servers was also relatively early. Several micro-modules in one compartment of the Building 3 in

Tianjin Data Center have adopted rack-scale servers, which were from Dell and Huawei respectively. From the appearance, the fans at the rear of the two types of rack servers had quite different specifications, and should be considered as products of the Scorpio 1.0 era - starting from Scorpio 2.0, the specifications of the shared parts such as the fan wall and the power supply frame were unified.

It is learned that JD Cloud East China Data Center has also begun to deploy (Scorpio) rack-scale servers to further improve energy efficiency.



In a computer room of Building 3 in Tencent Tianjin Data Center, which was just put into operation in 2014, two micro-modules nearby adopted rack-scale servers. In the picture, there are 6 Dells rack-scale servers (4 on the left and 2 on the right) and two Huawei ones; the latter are at the right side adjacent to Dell ones while no rear fans can be seen from this angle



Chapter 7

Green and environment friendly: wind power, solar power, energy storage and water saving

The most popular technologies in the data centers on environmental protection include the use of renewable energy and the protection of water resources. Wind power and solar power are two well-known renewable energy sources, which require data center constructors and operators to overcome their limitations. In terms of water saving, the air-side free cooling architecture also has obvious advantages.

The 2018 China Digital Journey- Data Center Tour in Northern China also focused on the environmental protection of large data centers, mainly reflected in the use of green (clean) energy and the protection of water resources.

Data centers far away from the core areas of cities not only can make better use of natural cooling resources, but also the natural energy. In the data center field, the concept of “renewable energy” is often used in the European and American markets, while the term of “clean energy” is generally used in the China market. By definition, clean energy, that is, green energy, refers to energy that does not emit pollutants and can be directly used for production and life, including nuclear energy and “renewable energy”, wherein the nuclear power plants can only cause minor environmental pollution when no accident occurs, but the raw materials such as uranium consumed for generating nuclear energy are non-renewable.

Energy sources such as wind power (wind electricity), solar power and hydropower (hydroelectricity) are referred to as "renewable energy" since their raw materials are renewable.

Renewable energy is energy that is collected from renewable resources, which can be naturally replenished on human timescale, such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. (Wikipedia entry: renewable energy)



The wind power plants spread all over the No.1 and No.2 Campus of the Alibaba Cloud Zhangbei Data Center from a distant view



/ Renewable energy in American and European data centers

The large-scale data center owners in Europe, America and some other developed countries have been at the forefront of using renewable energy and formed a trend, which can provide excellent ideas and examples for China large-scale data center builders:

- In 2015, Google promised to order a renewable energy output of 781 megawatts (MW), of which 625MW was generated by wind turbines, thus becoming the first company to buy so large a quantity of wind energy sources;
- In 2016, Google, Facebook, Amazon and Microsoft joined the Renewable Energy Buyers Alliance (REBA) which aims to help corporations order 60GW (gigawatts, 1 billion watts) of additional renewable energy into the U.S power grid by 2025;
- At the end of 2016, Microsoft announced the signing of two Power Purchase Agreements (PPA) for a total of 237MW to provide clean energy for its “zero-emissions data center” in the Cheyenne Region, Wyoming;
- In 2016, Amazon announced the establishment of its largest wind power plant in western Texas, which hosts more than 100 wind turbines and can generate 1 million MWh (1,000kW/h) of wind power per year, thus providing a total of 2.6 million MWh of electricity per year together with its previous four wind and solar power plants;
- In 2017, Google signed a 12-year PPA with Tellnes wind farm in Norway to buy 100 percent of the latter's output, namely, 160MW of wind power (Tellnes capacity) from 50 sets of wind turbine generators, bringing the total capacity of its renewable power purchases in Europe to 500MW;
- In 2017, Apple signed a 200MW PPA with a wind farm in Oregon;
- In 2018, Facebook signed a 15-year PPA with Luxcara in Norway, and the three wind farms of Luxcara are projected to provide 294MW of wind power to the two data centers of Facebook in Sweden;
- In 2018, Microsoft signed a 315MW solar PPA in Virginia, which is an important milestone because Microsoft has realized its commitment made in 2016 of powering its data centers with energy that is at least 50% wind, hydro and solar by 2018;
- In 2018, Google and Apple announced almost at the same time that they had purchased 100% renewable energy to “match” its consumption of electricity in 2017. Meanwhile, Google announced that it had signed several renewable energy PPAs totaling 3GW ; Apple claimed that it had 25 operational renewable energy projects around the world, totaling 626MW of generation capacity, with 286MW of solar PV generation coming online in 2017. It also had 15 more projects in construction. Once built, 1.4GW of clean renewable energy generation would be generated.

However, the “100% renewable energy” claimed by Google and Apple is not really a complete use of renewable energy. Due to the limitations of renewable energy (such as wind power and solar PV power)

itself or external conditions, some data centers and offices use renewable energy, while the non-renewable energy consumed is “neutralized” by purchasing PPA, which is what Google calls “Matching”. This can be seen in the Clicking Clean 2017 issued by Greenpeace (Greenpeace.org), but even so, it is also valuable. What deserves special attention is that Baidu, Alibaba and Tencent are also mentioned in this report:

	Final Grade	 Clean Energy Index	 Natural Gas	 Coal	 Nuclear	Energy Transparency	Renewable Energy Commitment & Siting Policy	Energy Efficiency & Mitigation	Renewable Procurement	Advocacy
 Adobe	B	23%	37%	23%	11%	B	A	B	B	A
 Alibaba.com	D	24%	3%	67%	3%	F	F	C	F	D
 amazon.com web services	C	17%	24%	30%	26%	F	D	C	C	B
 Apple	A	83%	4%	5%	5%	A	A	A	A	B
 Baidu 百度	F	24%	3%	67%	3%	F	F	D	F	F
 Facebook	A	67%	7%	15%	9%	A	A	A	A	B
 Google	A	56%	14%	15%	10%	B	A	A	A	A
 HP	C	50%	17%	27%	5%	D	B	C	B	C
 IBM	C	29%	29%	27%	15%	C	B	C	C	F
 Microsoft	B	32%	23%	31%	10%	B	B	C	B	B
 NAVER	C	2%	19%	39%	31%	B	B	B	D	D
 ORACLE	D	8%	26%	36%	25%	D	D	F	D	F
 Salesforce	B	43%	12%	16%	15%	B	A	C	B	B
 SAMSUNG 삼성SDS	D	11%	19%	29%	31%	C	D	C	D	C
 Tencent 腾讯	F	24%	3%	67%	3%	F	F	D	F	F

Company scorecard in the Clicking Clean 2017 issued by Greenpeace (Greenpeace.org), from which we can see that coal, natural gas and nuclear are all deduction items. Chinese companies such as BAT (Baidu, Alibaba and Tencent) have started late and are limited by national conditions, so they are not high in the use of renewable energy, resulting in a lower rating, but Alibaba is still rated as Grade D (Amazon as Grade C)



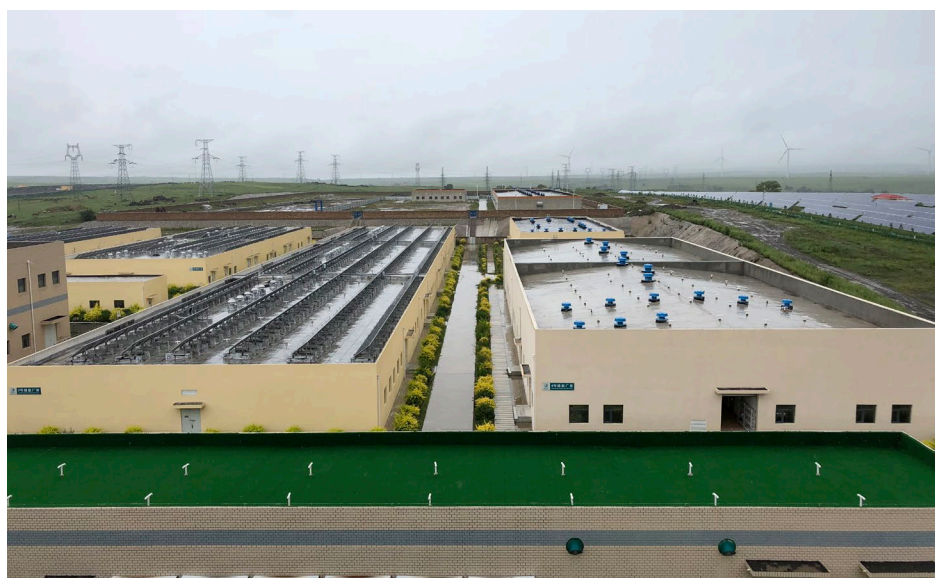
Wind power, solar power and energy storage

During the 2018 China Digital Journey - Data Center Tour in Northern China, our investigation of clean energy focused on wind power and solar power, both of which are “renewable energy”. These two kinds of renewable energy mentioned above have one common feature: “depending on the weather”: wind energy and solar energy are easily affected by the weather, and are characterized by volatility, intermittence, and randomness. It is a problem faced by the whole world to find a way of achieving continuous and stable power output. In particular, solar energy is greatly affected by cloudy weather, rain and snow and not available at night, causing great troubles for the utilization and grid connection of PV power.

Energy storage can effectively alleviate or overcome the instability shortcomings of wind power and PV power to a certain extent. For example, in 2011, Zhangbei constructed the Wind/Solar/Energy Storage and Transmission Demonstration Project, which integrated the functions of wind and PV power generation, energy storage and intelligent power transmission, among which,

- Wind power demonstration segment adopts the most typical six types of wind turbines in China, including the 5MW permanent magnet direct-drive wind turbine, with axle core 100m above the ground, blades of 62m long and a total weight of 743t, which is called as the largest one on the land;
- PV power demonstration segment adopts more than ten kinds of PV modules and tracking methods, with an installed capacity of 100MW (including 88MW for demonstration area, and 12MW for test area); technical and economic comparison has been carried out from multiple perspectives and all aspects;
- In terms of energy storage, the planned capacity is 70MW, with nearly 30MW deployed, which adopts multiple battery technologies, including lead acid, all-vanadium redox flow, lithium titanate and lithium iron phosphate, as well as cascade-utilized battery and super capacitors. It has been an exploration and practice of many technologies such as integrated application and coordinated control using more than 300,000 batteries for the first time. The project is known as a large-scale chemical energy storage power station with the most kinds of technologies adopted in the world. The scale of the cascade-utilized battery is up to 9MW, which realizes a deep reapplication of the batteries decommissioning from electric vehicles on the engineering system cascade platform and is also an application exploration about combine the electric vehicle and energy storage industries, for which relevant technical specifications are formed.

Part view of the energy storage plants in the National Wind/Solar/Energy Storage and Transmission Demonstration Project on a rainy day. In this weather, the PV panels installed on the plant roof and on the surrounding site cannot generate electricity, and the energy storage equipment can play its role in such an occasion. In addition, wind turbines in the distance were also unaffected by rainy days



Wind power and PV power are inseparable from natural conditions, and should be rationally utilized according to local conditions. As of our visit, Zhangbei has built wind power of 2,430,000kW and PV power of 580,000kW, of which the PV power capacity is all combined to the grid, while 150,000kW of wind power not. According to the data provided by Alibaba Cloud, the average wind speed in Zhangbei is 6m/s through the year, namely, the wind energy resource is sufficient, and the wind power installed capacity can reach 5,000,000kW or more (in the future). Thanks to the use of wind energy, solar energy and other green energy and lower PUE (within 1.25, as low as 1.13), Alibaba Cloud Zhangbei Winter Olympic Cloud Data Center can reduce the carbon emission by 59,000t per year, equivalent to saving electricity of 64 million kWh by taking the carbon emission factor as 0.9288, i.e., that in the North China Power Grid in 2014, and equivalent to the quantity of carbon dioxide absorbed by 3.32 million trees per year by taking an average of 50g of carbon dioxide absorbed per tree per day.

The scale of wind power in Zhangbei is several times that of PV power, which is mainly because that:

1. The lighting duration is limited. Zhangbei County is one of the counties with best sunshine conditions in Hebei Province, and has an average annual sunshine duration of 2,897.8 hours. Despite this, the lighting duration only accounts for one-third of the whole year;
2. PV power generation requires larger area. Although the size of the wind turbine is large, the land area directly occupied is not large, and the ground beneath can still be used for agriculture, animal husbandry (cultivated land, grassland) and the like.

The 5MW wind turbine of the Zhangbei Wind/Solar/Energy Storage and Transmission Demonstration Project has an output power larger than that of two high-power diesel generators, which can support the operation of tens of thousands of servers. Another two 3MW wind turbines have also been built nearby. The five source-grid-friendly wind farms (including a demonstration area and a test area, hosting the 5MW and 3MW wind turbines stated above) in Zhangbei region have an installed capacity of 500MW with a total of less than 180 wind turbines.



On the way from Ulanqab to Hohhot (Zhuozhi County in Ulanqab City, closer to Hohhot, altitude about 2,100m), there is a large wind farm with hundreds of wind turbines, but the pasture on the ground is barely affected

In contrast, PV power generation has a lower power density. The peak power per square meter of PV panels is between 200 and 300 watts. Tens of thousands of square meters of PV panels will be required in order to reach a megawatt output, resulting in a larger area of land occupied, which cannot be used for other purposes.



China's 10GW-level wind power bases are mainly distributed in the north and the eastern coast of China (Source: National Wind/Solar/Energy Storage and Transmission Demonstration Project)

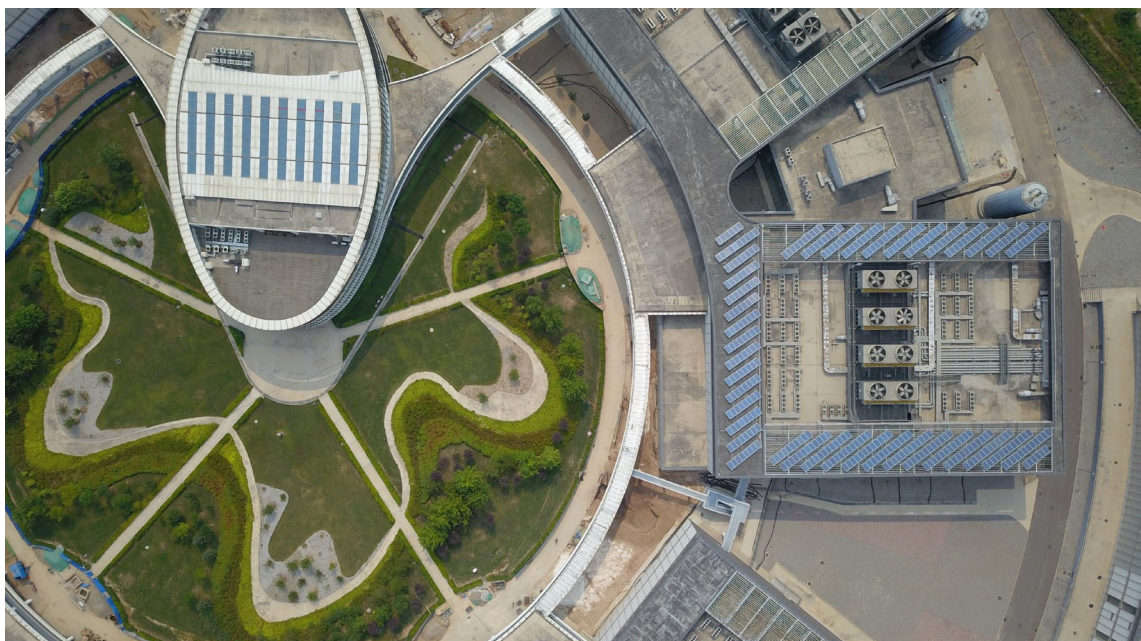
Of course, it does not mean that wind power must be superior to PV (power generation). Both of them have strong regional characteristics, and the key is to adapt to local conditions. For example, on the way to Hohhot in Inner Mongolia, wind farms are in the majority; along the roads from Huailai to Zhangbei and from Beijing to Yangquan, there are a lot of hills covered with PV panels; while the wasteland similar to the Gobi near the Zhongguancun Science and Technology Park - West Cloud Valley in Zhongwei City is covered with a large number of PV panels. In Huailai, the total installed capacity of PV power plants is also greater than that of wind power plants, because the land available for PV power is greater than that for wind power.



A PV power plant in Chahar Right Middle Banner region, Ulanqab City, Inner Mongolia, about 65km northwest of the urban area, altitude about 1,600m

One of the advantages of PV power is its distributed deployment, including its characteristic of DC output. In Baidu Cloud Computing (Yangquan) Center, nearly 400 PV panels were installed on the roof of Module Building 2 in 2015. Each PV panel has a peak output power of 250W, totaling about 100KW, which is directly connected to the data center power grid and is mainly supplied for operation of power system. Under the light conditions of the day we visited, the output power was about half of the peak.

In other words, about two PV panels can ensure the normal operation of one server in certain time of the day. Based on past experiences, distributed solar energy is tended to be used for the water heaters with energy storage function in the data center campus.



376 PV panels installed on the roof of the Module Building 2 in Baidu Cloud Computing (Yangquan) Center. Form the picture, we can see that other module buildings also have same space reserved (for installation of PV panels)

In the Baidu Cloud Computing (Yangquan) Center, the green energy mainly comes from the (large) power grid, with wind power as the principal. Clean energy contribution has reached 16% (26 million kWh) of the total power used by the Baidu Cloud Computing (Yangquan) Center in 2017, and is expected to increase to 23% (55 million kWh) in 2018, reducing carbon emissions by about 26,000t for the whole year, equivalent to the quantity of carbon dioxide absorbed by 1.42 million trees per year.



A PV power plant in the Zhongguancun Science and Technology Park - West Cloud Valley (altitude about 1,300m) in Zhongwei City, Ningxia Hui Autonomous Region; the data center and reserved land are in the distance

The stability of solar power generation is not unsolvable. During our visit in Zhangbei, we made a special trip to Huaqiang TeraSolar Zhangjiakou solar thermal power station project and comprehensive clean energy development project. Solar thermal power generation collects direct solar light through various physical methods to heat the working medium to generate high-temperature high-pressure steam for driving the steam turbine to generate electricity. Taking the Huaqiang TeraSolar Project as an example, the condensers have a lighting area of about 400,000m², including 200,000m² for north and south mirror fields respectively, of which the former has been basically completed and adopts the Fresnel-like secondary reflection heat collection system with east-west axis inclined, with its completely independent intellectual property rights owned by Beijing TeraSolar Photothermal Technologies Co., Ltd., has an installed capacity of 15MWe, and is equipped with concrete thermal energy storage (TES) with a heat storage capacity of 720MWh; the latter is under construction and will adopt tower concentrator system. Another innovation at the north mirror field is the adoption of direct steam generation (DSG) technology system.

Another innovation at the north mirror field is the adoption of direct steam generation (DSG) technology system. Compared with synthetic oil and molten salt, the water/steam used for heat transfers fluid, removes the oil-water heat exchangers, simplifies plant configuration and reduces investment. The use of water is more eco-friendly, not only cheaper than oil and molten salt, but also non-toxic and non-flammable and less corrosive. Water is directly evaporated and super-heated in the solar field, which brings challenges to the implementation of solar collector tubes and related systems as well.



The South Mirror Field under construction and the North Mirror Field in the distance (the white cube shaped building is the thermal energy storage tower of the North Mirror Field) (at an altitude of about 1,500m)

Compared with photovoltaic (PV) power generation, concentrated solar power (CSP) generation has two main advantages:

First, it is well compatible with the power grid. CSP generation has a commonality with thermal power and nuclear power generation, which is, "boiling water" in different ways and using the heat to generate high-temperature and high-pressure steam to drive steam turbines to generate electricity. It converts thermal energy to electrical energy to directly output alternating current, which is unlike photovoltaic power generation requiring inverter. Due to relatively mature and highly stable power transmission technology, CSP is more convenient to interface with the power grid and is of good quality;



Second, it is capable of energy storage and peak adjustment, realizing continuous power generation. Energy storage is a major problem in the development of renewable energy, and the efficiency and economy of thermal energy storage are significantly better than those of electricity storage. For example, the thermal energy storage tower of the Huaqiang TeraSolar Project absorbs high-temperature (over 400°C) high-pressure steam using a concrete thermal energy storage device, with a thermal energy storage duration of 14 hours and a capacity of 720MWh. The Phase I Project (North Mirror Field) has a planned installed capacity of 15MWe and a designed annual generating capacity of 75 million kWh, which means that the annual utilization hours reach up to 5,000h, equivalent to more than half a year.



The North Mirror Field looks spectacular if you watch it standing on the roof of the building next to thermal energy storage tower on the left. Each of the specular arrays is more than 1km wide visually. There can have over 6,000 photovoltaic panels additionally installed to fully utilize the space on the top of the only 8 rows of arrays

In addition, CSP generation also has the advantages of using relatively environment-friendly materials and no pollution in production and power generation, with no more detailed description herein. According to reports, after the completion of the project, compared with thermal power plants of the same generating capacity, it can save 25,000 tons of standard coal annually, with emission reduction of smoke of about 16.7 t/year, sulfur dioxide of about 60.8 t/year, nitrogen oxides of 155.6 t/year and carbon dioxide of 75,400 t/year, having significant benefits for environmental protection.

However, the overall progress of CSP generation in China is at a slower pace, and there are still many specific technical problems to be solved during implementation.



The North Mirror Field equipped with the Fresnel-like condensing mirror is called the "Sun Island", and the South Mirror Field equipped with the tower-type condensing system is called the "Conventional Island"

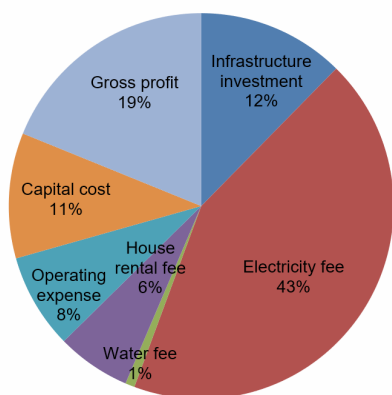


/ WUE and sewage recycling

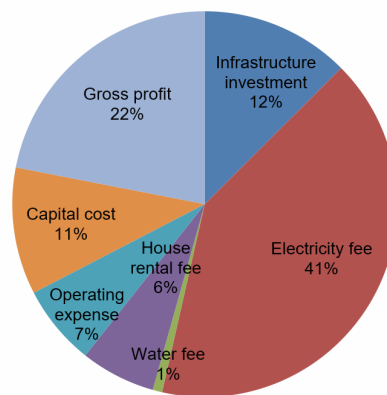
In terms of water saving, the main metric for data centers is water use efficiency (WUE). Since a large-scale data center with cooling water system as the cooling resources has huge water consumption just like it has huge electricity consumption, WUE is also one of the top priorities of data centers since it is related to the protection of water resources, although the water fee is not high in the expenses of a data center.

WUE is a metric created by the Green Grid in 2010 to help data centers measure the amount of water used in facilities needed for cooling and for other buildings. It is similar to the PUE measurement, that is, WUE is the ratio of the total water consumption of the data center to the power consumption of the IT equipment, in unit of L/KWh.

In 2015, Facebook consumed 221 million gallons (about 0.837 million tons) of water, 70% of which was consumed in its data center. In the same year, the first water restriction order was issued in California due to continued drought. According to data from 451 Research, California is the state with the largest number of data centers in the United States, exceeding 800 in total. It is estimated that the water consumed in these data centers each year is enough to fill 158,000 Olympic standard swimming pools, reaching 104.28 billion gallons (nearly 400 million tons), accounting for 0.7% of water consumption in California.



Before operational optimization



After operational optimization

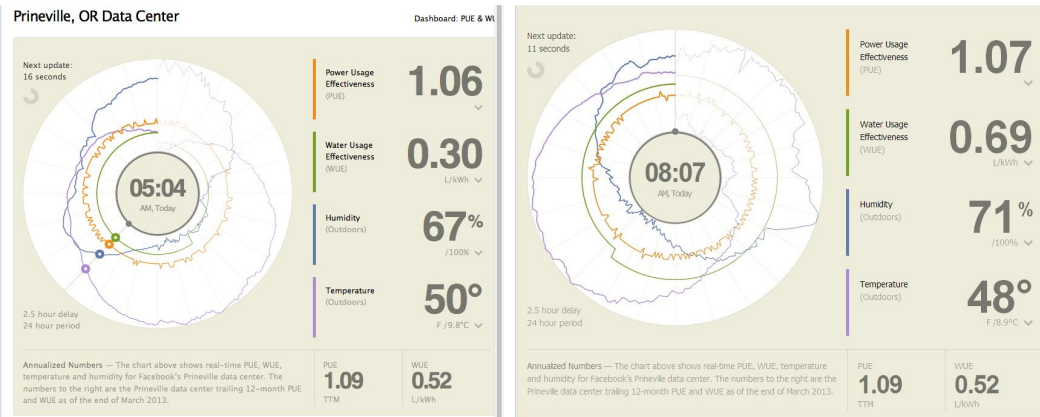
Electricity fee is the bulk of operating expense for a data center. By operational optimization, we can reduce it by one or two percentage points. But water fee only accounts for one percentage point, so there is very limited room for such cost saving. The main driving force for water saving in data centers is the factors such as environmental and social responsibilities (Source: Several Trends in Data Center Development presented by Zhang Tuo, Vice President of Hangzhou Cloud Tripod, China Data Center Committee Summit 2018)

Apple Inc. is the biggest water user in Prineville, Oregon, with its first data center consuming 27 million gallons (about 100,000 tons) of water in 2016 which accounted for 4.5% of the annual output of water in the area. With its second data center in use, city officials did not reveal how much water Apple used in 2017, but suggested it might be close to 10% of Prineville's total water output. According to local media reports in Oregon in December 2018, Apple has committed to investing USD8.7 million to help Prineville build an underground water storage facility to meet the needs of its two data centers.

The first data center of Facebook was built in Prineville, not far from those of Apple. In early August in 2012, Facebook became the first data center operator to disclose its WUE metric, and for its Phase I Project in Prineville, the WUE metric was 0.22 in the second quarter, which was excellent.

In areas such as Zhangbei, where water is scarce, finding a suitable source of water was once one of the jobs of the Alibaba Data Center team.

The water consumption of cooling resources in the data center includes water consumption due to evaporation, running, sewage disposal and humidity adjustment. The water consumption due to



PUE and WUE metrics (updated every minute) of the Facebook's Prineville data center at different moments, from which we can see that the annual average data of WUE reaches 0.52 and the local temperature conditions are good (Source: The Internet)

evaporation has a lot to do with the climatic conditions and routes of cooling technology in the location of the data center. If the air temperature and humidity are suitable, cooling resources (such as fresh air cooling) can be used directly, with less or no evaporation, and thus the water consumption will naturally be greatly reduced. For example, the indirect evaporative cooling technology is used in the ByteDance Huailai Data Center, and the center is only required to run for 3,000 to 5,000h (1/3~1/2 of the time) under the evaporative cooling wet condition, which can save more than 70% of water, with WUE ≤ 0.31 .

The WUE metric is used far less common than the PUE metric due to latter long history, and its wide range of variation. The air-side free cooling project has obvious advantages in terms of the WUE metric. However, in terms of the water-side free cooling, the Alibaba Cloud Qiandao Lake Data Center using deep lake water for cooling has published a design annual average WUE of 0.197, with the large evaporative



Cooling tower in operation

facility - cooling tower becoming an auxiliary one since the cooling resources is acquired mainly from the deep lake water.

Sewage disposal is the price that is required to pay to maintain the normal operation of the cooling system. Taking the water system as an example, the cooling tower dissipates heat through water evaporation, leaving impurities such as calcium and magnesium ions to precipitate within the cooling tower and the pipelines. The long accumulation of such impurities will cause the water's hardness and conductivity to rise, and its constitution to be more complex, so it is necessary to carry out sewage disposal correspondingly. The daily disposal volume can reach several hundred or even thousands of tons. Baidu Cloud Computing (Yangquan) Center recycles the sewage by collecting and then neutralizing it with acid and alkali, and diluting the calcium and magnesium ions within the sewage. After the campus is fully put into operation, the annual water saving volume will reach 480,000 tons, equivalent to the annual water consumption of more than 4,000 households.





Chapter 8

Site selection and campus: from agriculturalization or industrialization to informatization

Site selection largely determines the style of a data center. Hyperscale data centers in 4th and 5th tier cities are more “flat”, and have better aesthetic sense on its outlook design, colors, logos and symbols. At the same time, the data centers built-up in these areas have greater influence.

Site selection is a prerequisite for data center construction. In the previous chapters, we have explained the logic behind the site selection of several data centers from multiple perspectives.

For the 10 data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China, one of our most prominent feelings is: they have experienced development from industrialization to informationization, and from agriculturalization to informationization.

Site selection largely determines the style of a data center. In the urban area, the data centers are mainly the newly-built multi-storey buildings or reconstructed factory buildings and warehouses, such as Tencent Tianjin Data Center and Huawei Cloud Langfang Data Center, where technical routes are very similar: water-side free cooling + micro-modules, wherein the water-side free cooling is used by most of the data centers in urban core areas because this technology is basically no requirement for air quality; the cold aisle containment is the mainstream, and the air supply under the elevated floor and the micro-module coexist, which can be customized as required by customers.

A data center reconstructed from factory building more directly reflects the characteristics of process “from industrialization to informationization”. Because of environmental protection and other issues, large factories have been withdrawn from the core areas of the cities, leaving more adequate power supply and larger rooms, which are suitable to be transformed into data centers.



The sketch design of Huawei Cloud Langfang Data Center is more realistic. It is difficult to build another such “luxury” data center campus in the core area of a city and the surrounding area, although the data center only occupies a part of this campus



/ Data center and industry layout

The survey data released by CAICT show that the number of racks in Beijing, Shanghai and Guangzhou has decreased from 42% to 37% of domestic total, which tends to be more reasonable. Among the data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China, a higher proportion of them are far away from the core area of the city, and half of them are located in areas where the agriculture/animal husbandry is dominant and the industrial base is weak. In addition to the climatic advantages, these data centers have sufficient land supply and do not have to share the electricity with residents or other factories. They even have a second-mover advantage in green energy.

However, due to the weakness of industrial base, these places often have weak power infrastructure. If there is no substation or insufficient capacity in the area where the data center is located, the construction speed will be affected. Currently, one campus has not been put into operation or built because the substation is not in place, respectively in two data center clusters where three-point layout is originally planned.

Another characteristic of process “from agriculturalization to informatization” is that the interaction between data centers and the local economy is often more intense than that during the process “from industrialization to informatization”.

Huailai County is close to Beijing, but its traffic is not as convenient as that in Langfang City. The county is also subject to the restrictions since Guanting Lake is Beijing's water source base, thus no industry investment attraction has been truly developed, while with the grape industry and traditional agriculture as the core, the county has a proportion of agricultural production value as high as 75%, and its wine industry is the first major user of electricity. After completion of the ByteDance Data Center, it is expected that the output value of the information industry in 2019 will double the total output value of the county and account for up to 46% of the total output value. As the hyperscale data centers of ByteDance and Tencent emerge, the ranking of first major user of electricity will inevitably go to informatization.

As a national-level poverty-stricken county, Zhangbei is very underdeveloped in its industry, and there was no thermal power plant before. After vigorously building wind power and solar power generation, there is very high proportion of green energy in the power grid, which is equivalent to directly entering the green energy era. The Alibaba Cloud Zhangbei Data Center naturally benefits from above.

The impact on the local economy can be seen from a small detail: around the No.2 Campus, two new roads have been built in the south and north, named after the constructors respectively.

The entry of the data center will also help the green energy to be consumed locally, without having to be transmitted to the core area of the city at a long distance, or resulting in a large amount of abandonment of electricity and failure of transmission due to no access to the power grid for various reasons. However, to locally consume energy sources such as wind and solar energy that are not stable enough, there is still a big challenge in the economical efficiency of energy storage, although the data center uses various energy storage methods conducive to “shifting peak load” to optimize energy use costs.

According to reports from Xinhuanet and China Business News and other media: State Grid Jibei Electric



Power Company, together with the Global Energy Interconnection Research Institute, China EPRI of NARI Group and other units, cooperates with Alibaba Group and Elion Resources Group to build the world's first flexible substation-based AC/DC distribution network - Zhangbei Flexible Sub station and AC/DC Distribution Network Demonstration Project was officially put into commercial use on December 26, 2018.

This demonstration project was commenced in October 2017, with a 10kV photovoltaic DC booster station and a 10kV flexible substation built. It is connected to 2.5MW PV of the Elion's Photovoltaic Plant for Poverty Alleviation in Desheng Village, Zhangbei County to generate power, realizing DC boosting and grid-connection of MW-level photovoltaic power generation to provide three kinds of clean energy power supply modes of 750VDC, 240VDC and 380VAC for Alibaba Group's Xiao'ertai Data Center (No.2 Campus).

In January 2018, the project was completed and realized electrified grid-connection; in August, it passed 168h of trial operation. After nearly 11 months of trial operation, the demonstration project experienced the heavy load test during the "Singles' Day Shopping Festival" and "Double Twelve" periods to successfully meet the dual needs of new energy consumption for grid-connection in Zhangbei area and the smooth operation of the Alibaba Data Center.

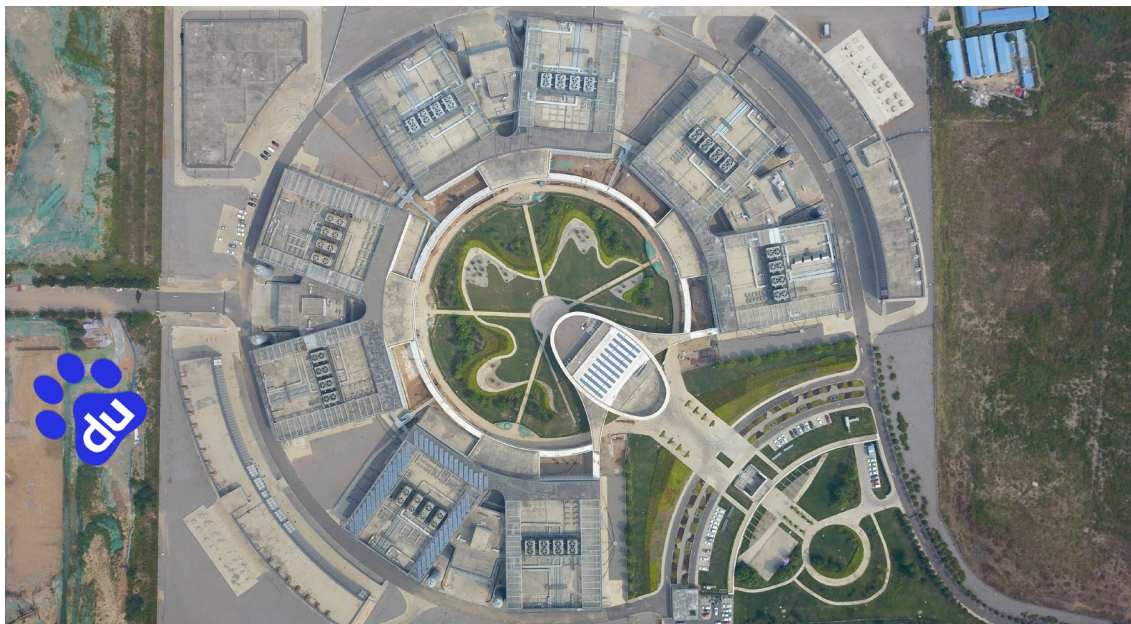
The AC/DC distribution grid based on the flexible substation solves the problem of localized consumption of distributed photovoltaic power plants, realizes the high-voltage DC grid-connection of photovoltaic power of megawatt capacity in the mode of DC boosting without the use of the inverter, to transmit the photovoltaic power to the data center, which is just in line with Alibaba's high-voltage DC power supply architecture, and even the balance can be connected to the power grid.

Due to the omission of the transformation link, about 2% of consumption is reduced, and the annual revenue of the Elion Desheng Photovoltaic Power Plant for Poverty Alleviation is increased by more than RMB70,000. From January to November 2018, the new energy abandonment rate of State Grid Jibei Electric Power Company was decreased by 2.1 percentage points year-on-year to 4.8%. The new energy abandonment rate of the whole grid has dropped for six consecutive years.



/ People-oriented campus design

With sufficient land supply, these data centers have more room for stylish design. For example, Baidu Yangquan Data Center has been designed as a combination of 8 modular buildings in pairs, which are placed in the shape of the bear's paw in Baidu Logo; both the Phases I and II of the ByteDance Huailai Data Center are large flats, and the No.1 Campus of the JD Cloud East China Data Center is also a single-storey building. However, with the commencement of the follow-up project, it will not be easy to obtain new land for use, and in order to meet the local government's requirement for the floor area ratio, the Phase III of the ByteDance Huailai Data Center has been changed into a multi-storey (equivalent to three-storey) building. No.2 Campus in Suqian will also be a two-storey building. Both use indirect evaporative cooling technology, and in fact, such advantage can be better taken in single-storey (flat) buildings.



Birdview at Baidu Cloud Computing (Yangquan) Center, you can see that its style design is original: 8 modular buildings in pairs, whose main structures just form the bear's paw in Baidu Logo, which can also be viewed as a lit bulb. Unfortunately, the overall color scheme is too low-key because the 8 module buildings are not painted blue, and there is only one sign that cannot be considered big at the entrance of the campus by the main road (beyond the left part of the picture)

The data center is the "residence" or "office space" of the servers, which is still very different from the human residence or office space. The original intention of the floor area ratio is to make more use of the land. For the data center, it is mainly to place more servers in the same land area, which can be achieved by increasing the number of servers in a single rack. For example, in the same land area, 8.8kW of power supply capacity per rack in a single-storey building is equivalent to 4.4kW per rack in the two-storey data center, and in fact a single-storey building has more obvious advantages in construction and maintenance than a two-storey one.



Design diagram of ByteDance Huailai Data Center: the red and gray 工("Gong", a Chinese character)- and 王("Wang", a Chinese character)-shaped large flat buildings on the right are the Phases I and II respectively. The higher building to the left of Phase II is Phase III, where in contrast to Phase II, the indirect evaporative cooling module on the side is for the cooling of the power module on the first floor, while the computer room on the second floor is higher and can be considered as two storeys (height of the entire building is three storeys), which is cooled by the indirect evaporative cooling module on the roof (like the cooling tower in the water system)

A data center in the core area of the city is relatively low-key in terms of color matching, logo and styling. A specially constructed data center building complies with the principle that form is subordinate to functions, for example the computer room building shall have minimum number of windows, only the so-called ECC or the comprehensive office building that is mainly used for "holding people" is more attractive in terms of styling and color matching, such as Building 2 of Tencent Tianjin Data Center and the ECC of Baidu Cloud Computing (Yangquan) Center connecting the modular buildings. The data center transformed from the factory building and warehouse should be as close as possible to the original structure of the building. Even if there are a bit too many windows, the design of Huawei's warehouse-type micro-module with cold and hot aisles containment can be adopted to reduce the dependence on the original body of the building.

Several data centers built in underdeveloped regions are just the opposite:

The exterior wall of the building complex in the Alibaba Cloud Zhangbei Data Center reflects the bright "Ali

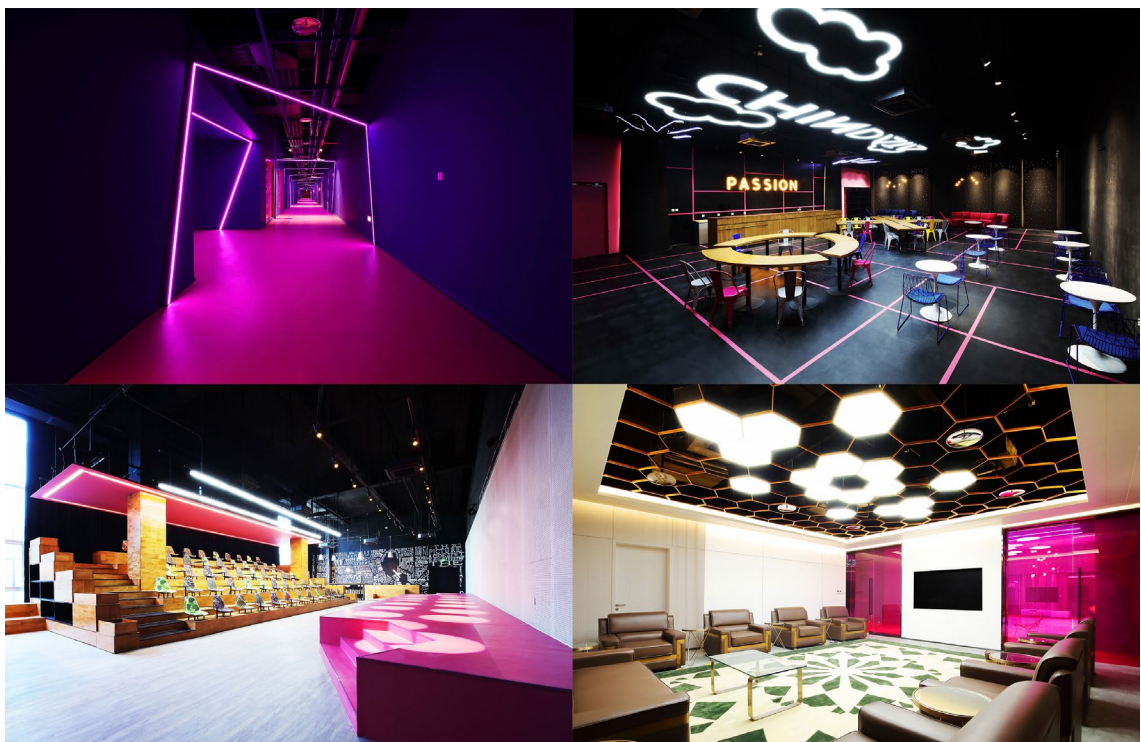


Orange" theme to varying degrees: the comprehensive building in the middle of the No.1 Campus - Phase II Project has been designed into an irregular disc shape, with the side wall completely painted orange and the white Alibaba logo attached right to the entrance, which are very eye-catching in terms of the color matching, styling and sign.

In the JD Cloud East China Data Center (No.1 Campus), there is a large blue area on the side wall of all the four modules with the red JD logo attached. In the comprehensive service area in the center, there is an ECC in the start-button shape. More flashy ideas may be reflected in the No.2 Campus.

In the ByteDance Huailai Data Center, the exterior wall is painted in red, white and gray as the color in "Toutiao" (TopBuzz), with a lot of pink used in the interiors (including racks), while it evolves into a Las Vegas nightclub style (the data center is in uninterrupted operation for 24h a day, just like the sleepless Las Vegas City) in the Phase II, with the additional meeting rooms of a small theater style and other supporting facilities fully serving people.

For these data centers in the 4th and 5th tier cities, bright colors, beautiful shapes, and eye-catching signs help to boost the morale of the staff and the image of the company.





Chapter 9

Operation and maintenance: strengthening operation and external output

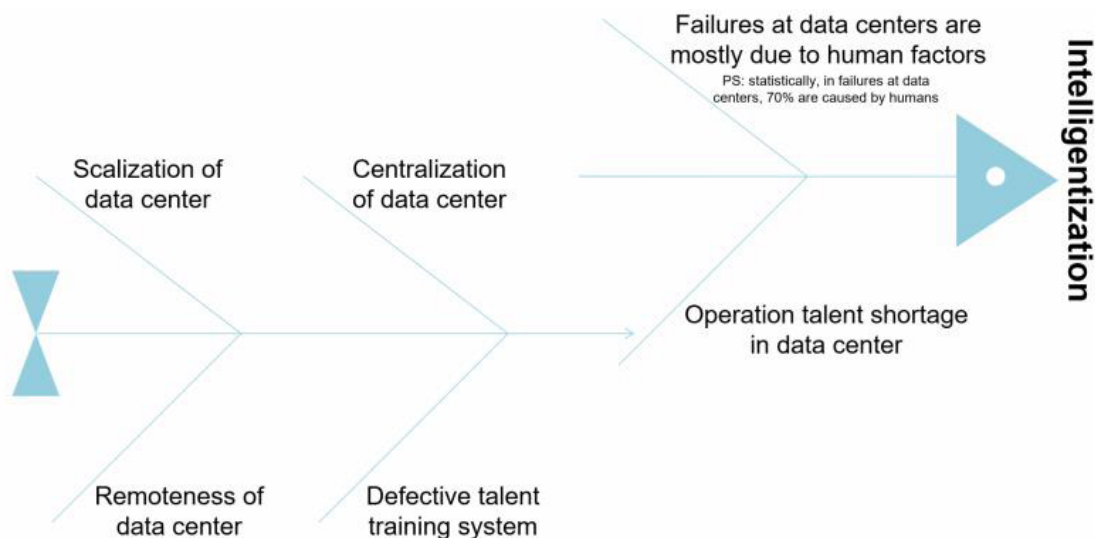
The scale-up, centralization and remoteness of a data center have brought tremendous pressure on its operation and maintenance, so the automatic and intelligent operation based on digitalization and standardization is an inevitable solution. The data centers of telecom operators, the Internet companies, and cloud computing providers are all using IT technology to improve the operation of their infrastructure.

The operation and maintenance of a data center is mainly carried out by humans but not only humans.

Bigger data centers are built in remoter areas, posing a great challenge to their operation and maintenance.

On the one hand, the rapid growth of business corresponds to the rapid increase in the number of servers. Take Toutiao (TopBuzz) for example, the number of servers has increased from 20,000 or 30,000 to 170,000 in a year and a half, and it is impossible to handle the extra operation and maintenance just by hiring more staff. In fact, in a large Internet company, one employee can manage thousands of servers, such as in the Tencent Tianjin Data Center, where one employee manages the operation and maintenance of 10,000 servers on average.

On the other hand, it is difficult to recruit highly-qualified operation and maintenance personnel in places far away from the core cities. If data centers in Beijing-Tianjin region can still manage to outsource work, it will be much difficult in the remote areas of the west. For example, in China Mobile Ningxia (Zhongwei) Data Center, those staff who are from Yinchuan have to drive nearly 200km home on weekends.



This picture concludes the challenges and solutions very vividly for modern data center operation and maintenance (source: Several Trends in Data Center Development presented by Zhang Tuo, Vice President of Hangzhou Cloud Tripod, China Data Center Committee Summit 2018)

The solution mainly lies in better leveraging of the services and IT, both with automation as the core, reducing the dependence on humans since the failures in data centers are mostly caused by human.

Still, we will introduce the role models from the telecom operators, the Internet and cloud computing respectively from the data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China.



/ Service and cooperation

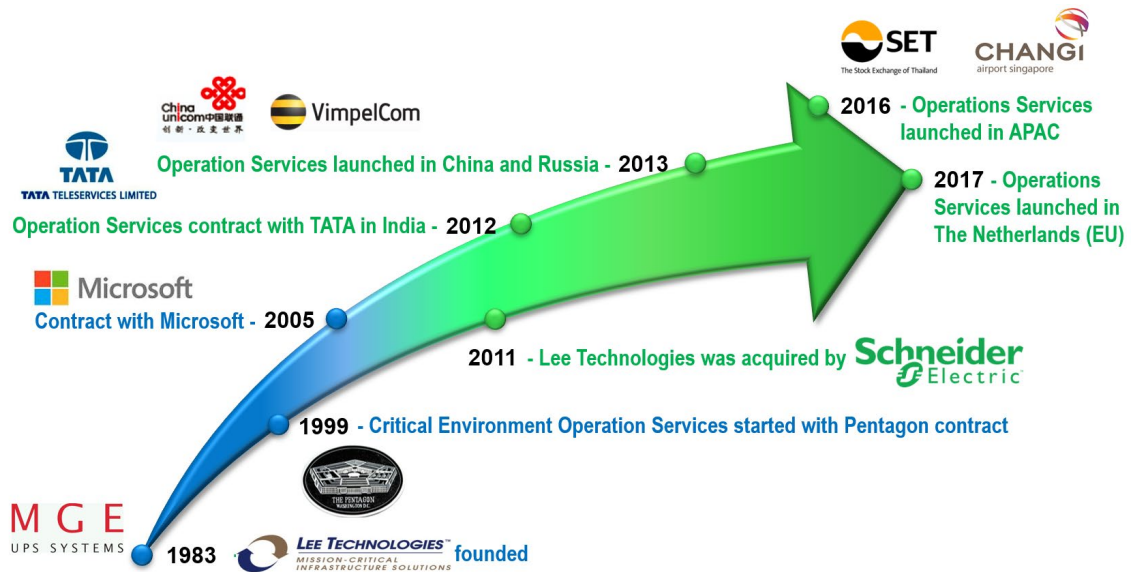
The telecom operator's data center can purchase the agent service of operation and maintenance from the equipment supplier, the typical case of which is the cooperation between China Unicom Hohhot Cloud Data Center and Schneider Electric.



As a contractor to build the ByteDance Huailai Data Center, ChinData has highly recognized Schneider Electric's Okken series of power distribution equipment; while China Unicom Hohhot Cloud Data Center has not only fully adopted Schneider Electric's power distribution equipment, but also cooperated with it in the system of operation and maintenance

As the world's fifth largest data center operator (sorted out by 451 Research in 2017 according to the companies' annual reports), China Unicom covers a wide range of customers including those from the Internet, government, education, finance and other industries, mainly providing IDC infrastructure and peripheral services. Schneider Electric has a history of the operation and maintenance of data center infrastructure dating back to the 1980s, and Lee Technologies was founded in the same term and was acquired by Schneider Electric in 2011. It is said that Schneider Electric's operation and maintenance system and the famous Uptime M&O (Management & Operations) certification are both derived from Lee Technologies. These two concepts are almost the same, with the main difference in that the former, more inclined to implementation, will provide rationalized advices based on personnel deployment, architecture, process quality management and some technical aspects, and help the customer to realize the evolution of the entire operation and maintenance system on site.

Schneider Electric and China Unicom have been in cooperation in the operation and maintenance system for five years. China Unicom Cloud Data hopes that Schneider Electric can provide it with a professional operation and maintenance team, and help it to create a perfect and standardized operation and maintenance system conforming to the International standard, while it can focus on the core business. Each team does what they are good at.



Schneider Electric's development in infrastructure operation and maintenance of data center

Building an operation and maintenance service system can be roughly divided into three steps:

1. Build the architecture. China Unicom provides a framework of macro demand while Schneider Electric provides personalized services and sets up a customized team to ensure the operation and maintenance.
2. Prepare the standard. Combining the actual situation of China Unicom Cloud Data with its own management philosophy, Schneider Electric prepares a standard that meets the actual operation and maintenance needs of the data center.
3. Establish a platform. Establish a digital operation and maintenance platform to realize facility digitalization, process automation, maintenance prefabrication, standardization of operations and tele-mediation of services, and finally create a digital operation and maintenance platform as the benchmark in the industry. The advantage of digitization is that it can improve the overall operation and maintenance efficiency on the one hand, and can help the personnel in the operation and maintenance team to analyze the subsequent big data and propose corresponding transformation suggestions on the other.



/ Independent construction and research & development

The self-built or customized data centers of hyperscale Internet and cloud computing companies, characterized by complete control over infrastructure and IT equipment such as servers, can break the traditional barriers in the full lifecycle including the design, construction and operation & maintenance, achieving greater efficiency through integration.

One of the key points of automation is that IT acts on OT (Operation Technology). This combination is also called IOT, where IoT (Internet of Things) is applied. On the one hand, the data of various

electromechanical equipment are digitized and standardized so that they are easy to collect and more accurate. On the other hand, this type of integration is presented as IOT in operation and maintenance. We are sure that IoT is very important, but here is mainly about the integration of IT and OT. When OT is combined with the infrastructure in the data center field which it mainly acts on by means of IT of the same data center, it equals that the data center uses its own service target to serve (data center infrastructure) itself.



The Internet and cloud computing companies were the first to realize that they can't just regard the data center infrastructure as the carrier of IT equipment, but they can also use IT technology to optimize the operation and maintenance of data center infrastructure, realizing the intelligent operation of data center.

The prerequisite for intelligent operation is digitization and standardization. Until a few years ago, behind the highly convenient Internet service, the China data centers remained at a relatively primitive stage: "Hundreds of alerts on various monitoring devices in the computer room remain unhandled, and the operation and maintenance personnel hold the most primitive tools such as paper and pencils to conduct daily inspections and maintenance, professional engineers have to hold a pile of paper data and drawings to test the equipment..." In Binhai of Tianjin, with the first self-built data center as the platform, Tencent launched the construction of automated operation and maintenance capacity, and independently developed the data center infrastructure management platform, called Nebula.

During the process, Tencent first encountered hardware challenges: many data were reported falsely or failed to be reported due to the diversity of the acquisition hardware devices and the uneven quality of hardware devices; the protocol standards for reporting data were also different and they were specified by manufacturers, which caused a lot of unnecessary troubles for the reporting work. Through uniting the leading powers of the industry, Tencent promoted the development of a standardized protocol for data acquisition, i.e., the north-south protocol standard.



Many suppliers within the industry are also aware of the above problems, but large Internet companies have both huge data center infrastructure and strong software development capabilities, which can effectively promote the process of digitization and standardization. Digital inspections using tablets have been widely implemented in the Internet and cloud computing data centers visited during the 2018 China Digital Journey - Data Center Tour in Northern China.

Tencent's management practice of batteries is a good example of the multi-dimensional and large-scale management of equipment. With electrical and chemical properties, the battery is a large energy storage device. Any problem occurring to it may cause a fire and explosion, and the consequence is immeasurable. In the past, the analysis of the battery was limited to a single threshold value of device, that is, whether the temperature was too high. Based on a large amount of battery data, Tencent has concluded several core indicators of battery health management, including battery capacity, internal resistance of battery and battery temperature, which are to be quantified and formulated, and obtained the formula of battery health through the analysis of a large amount of data, through which the health of the battery is predicted.

腾讯数据中心 Tencent Data Center						
首页 数据 告警 工具						
天津数据备份中心东区3栋DC						
活动告警列表						
空间平面 逻辑平面 活动告警列表						
时间	告警内容	告警类型	等级	关联设备编号	关联设备名称	操作
2017-03-11 05:48:40	单体电池电压当前值为23.2, 高于阈值14.5V或低于12.5V	单体电池电压异常	L2	DC3-M304L-BAT-02-19	电池	关闭 转单 详情
2017-03-11 05:48:40	单体电池电压当前值为23.2, 高于阈值14.5V或低于12.5V	单体电池电压异常	L2	DC3-M304L-BAT-02-18	电池	关闭 转单 详情
2017-03-11 05:48:40	单体电池电压当前值为23.2, 高于阈值14.5V或低于12.5V	单体电池电压异常	L2	DC3-M304L-BAT-02-17	电池	关闭 转单 详情
2017-03-11 05:48:40	单体电池电压当前值为23.2, 高于阈值14.5V或低于12.5V	单体电池电压异常	L2	DC3-M304L-BAT-02-16	电池	关闭 转单 详情
2017-03-11 05:48:40	单体电池电压当前值为23.2, 高于阈值14.5V或低于12.5V	单体电池电压异常	L2	DC3-M304L-BAT-02-15	电池	关闭 转单 详情

On this basis, Tencent now performs real-time calculations on the 600GB of data about the battery generated every day, and conducts in-depth analysis of more than 100,000 batteries in its 77 data centers, implementing real-time health management of batteries. After the battery management service was launched, many hidden problems were discovered. More than one thousand batteries had operational hazard, so a special project was set up on site to follow up and rectify such issues. In addition, warnings about the batteries can be sent one month in advance, and the fault can be eliminated by the operation and maintenance action before their occurrence.

1 输入需要应用的设备编号 (多个设备请以逗号或分号或回车分隔) [查看详细设备编号信息](#)

设备编号: *

2 输入告警类型

告警类型: * 告警级别: *

3 输入表达式和频率

告警: * 当 分钟发生 次时产生告警

恢复:

4 输入通知角色及方式

通知角色: ☒ 腾讯空调专业工程师 ☐ 腾讯配电专业工程师 ☐ 腾讯自控专业工程师
☒ 总包空调专业工程师 ☐ 总包配电专业工程师 ☐ 总包自控专业工程师
☐ 空调现场工程师 ☐ 配电现场工程师 ☐ 自控现场工程师
☐ 现场运营主管 ☒ 数据中心经理 ☐ FOC

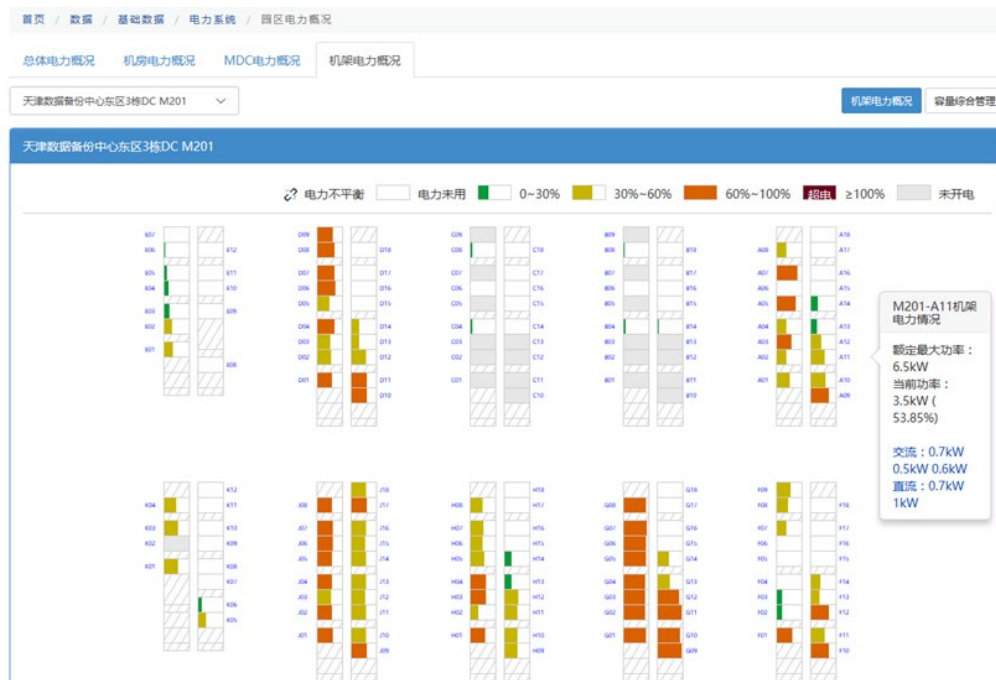
通知方式: ☒ RTX ☒ 短信 ☒ 微信 ☐ 邮件 ☐ 电话

5 输入需要使用的告警模板 [这是什么](#)

模板内容:

Furthermore, changes in the technical architecture will have a major impact on operation and maintenance. Known from Tencent's experience, 70% or 80% of the daily faults in the data center are related to the water system. If a air-side cooling architecture such as indirect evaporative cooling is used, there would be no pipeline, chiller or water pump in the entire computer room when the hardware is prepared, so that a large proportion of faults can be avoided. Moreover, the faults at the data center are also related to the construction quality and process on site. With productized and standardized solutions, a lot of assembly and commissioning work is carried out inside the factory, where there are better equipment and more experienced workers. Thus the equipment can be commissioned in the factory before being transported to the site for direct assembly so that many faults can be avoided.

Analysis of the information collected by various devices and sensors can not only reduce and prevent the occurrence of faults, but also be used to improve the energy efficiency of the data center. In May 2014, when the term "artificial intelligence" was not popular yet, Google announced the use of machine learning and neural network algorithms to "squeeze" the PUE potential of data center. A typical Google data center had a PUE of about 1.25 at the beginning of operation, and Google has lowered it to 1.12 through continuous operational optimization, until it is not possible to go down any further. Because when it is developed into a certain stage, due to the interaction between cooling and electrical systems and various complex feedback loops, it is difficult to accurately derive the efficiency of the data center using traditional engineering formulas. For example, a small rising in the temperature of the cold aisle will result in many changes, which are nonlinear, in the cooling system, wherein the power consumption of equipment such as chillers, cooling towers, heat exchangers, and water pumps will be unstable (increase or decrease). As a result, the cold aisle temperature may probably rise and the total power consumption increase (rather than decrease).

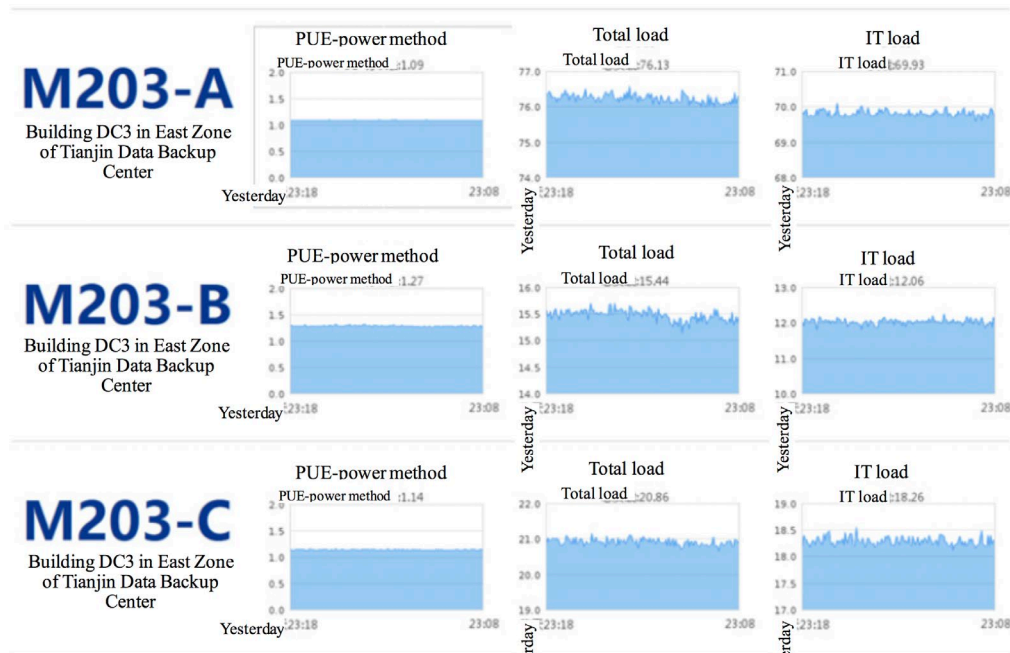


The machine learning method is to build a mathematical model based on a large amount of existing sensor data to understand the relationship between operational parameters and thus improve the overall learning efficiency; neural network is a kind of machine learning algorithm, which simulates the cognitive behavior of interaction between neurons. Google's BMS (Building Management System), PMS (Programmable Management System) and control system generate hundreds of millions of raw operational data every day, which are difficult for humans to understand, but suitable for mining by machines.

Google has deployed tens of thousands of data points using sensors to acquire infrastructure operational data and electricity usage information such as total server load, water pumps, cooling towers, water chilling units, dry coolers, wet bulb temperatures, outdoor humidity, wind speed, and wind direction, which are 19 variables to be used as elements for study by the neural network, and only one server is required for running the entire neural network system. Through PUE simulation by combination with historical data,

Google's data center team adopts a new set of operational parameters that can reduce PUE to be less than 1.1, and its predicted PUE accuracy of data center is between 0.4% and 0.5%. Considering that Google has millions of servers, reducing PUE by 0.02 (from 1.12 to 1.1) also has considerable energy-saving effect, and most importantly the input-output ratio is very good. As the actual operational data are accumulated continuously, the accuracy of the PUE model is expected to increase further over time.

Google's practice demonstrates that machine learning method can leverage existing sensor data to simulate data center energy efficiency optimization and thus achieve energy saving of 10% to 15%. Machine learning can tell the operation team how to optimize the energy efficiency of the data center, including how to simulate data center parameter configuration assessments, energy efficiency assessments, and identify optimization proposals.



It is said that Tencent is studying how to achieve similar optimization results in its data centers located in the south (with more unfavorable climatic conditions) with fewer variables.



/ Transformation and output

Huawei began the digital transformation of data center management from 2016, and provided the full-stack service including “monitoring, management, control, operation and service” through the development of SmartIT intelligent management platform featuring “construction standardization”, “operational visualization”, “operation and maintenance automation” and “self-service” to “utilize” maximally the existing tools, protecting existing IT investments.

- Operational visualization, oriented towards IT management and operation personnel, is to create an online digital world based on the physical world, and to refine it to the "capillary level", accumulating digital operating measurement system from the data center to applications and users and using it as the acting point to lift and pull operational capabilities;
- Operation and maintenance automation, oriented towards the operation and maintenance administrator, is to design standardized operation and maintenance scene and solidify the operation and maintenance administrator's expert experience according to the operation and maintenance targets, accumulating various operation and maintenance capabilities such as daily health examination and batch configuration, letting machines operate and maintain machines based on AIOps to free the administrators from the heavy daily work;
- Self-service, oriented towards IT users, is to carry out multi-cloud management of resources through multi-cloud management services, providing self-service for users, including computing, storage, network, deployment and other services. After online access, the users can get IT resources in minutes to deploy and release business applications.



In the Langfang Cloud Data Center, Huawei has applied AI technology to the daily management of the data center. With AI technology, Huawei processes the data of the hard disks and memories with the highest fault rate in servers and storage devices, and predicts the fault trends and occurrence time of the hard disks and memories in advance, having achieved the leap from preventive maintenance to predictive operation and maintenance; with iCooling technology, Huawei carries out intelligent collaboration of IT and cooling system, adjusting the operation of the cooling system to an optimal state, thus saving more than 5% of energy per year, that is close to RMB10 million of electricity fee.

After continuous practice and improvement, Tencent and Huawei successively output their data center operation technologies in 2018.



On the HUAWEI CONNECT 2018 in October, Huawei officially released the external output version based on SmartIT, i.e., the Intelligent Maintenance and Operation Center (I-MOC), which supports local deployment and cloud service mode. As a cross-hybrid IT unified operation and maintenance platform, it includes monitoring, management, control, operation and service systems, and is combined with Huawei's industry operation and maintenance services, RMS services, cloud DC operation and maintenance services, to provide customers of the business scenarios such as Smart City, Smart Campus and Safe City with an integrated and all-round operation & maintenance scheme, bringing a new experience of visual, intelligent, easy-to-use and open digital operation and maintenance.

On the basis of the Nebula platform for internal service, Tencent launched the Tencent intelligent maintenance platform (Tnebula) that has borne the Tencent data center team's years of exploration and practice in the data center automation operation. The Tnebula platform was first established commercially in Chongqing in November and will be gradually deployed in China Telecom in Chongqing, starting with the Shuitu data center.

The integrated customization and management of data center infrastructure (air, fire, water and electricity) and IT equipment, especially their own strong IT capabilities, enable the large Internet and cloud computing companies to further optimize the operation efficiency of their data centers. Research is conducted to predict changes in actual workloads and adjust data center operating parameters in order to further lower PUE, instead of relying on hardware-based energy efficiency improvements.

From outside to inside and from hardware to software, the transformation led by hyperscale data centers will have a profound impact on the IT industry and even the lives of all of us.

Afterword & Acknowledgment

From the beginning of March 2018 when the initial idea was inspired to the early autumn when travel was began, and until the completion of the investigation report, "2018 China Digital Journey - Data Center Tour in Northern China " finally came to an end.

Spanning more than 5,000km, from the North China to the Northwest China, and then to the East China, this "thousand-mile journey" has covered the 10 large data centers. First of all, we would like to thank Tencent (Tianjin), Huawei Cloud (Langfang) and ChinData (Beijing), ByteDance (Huailai), Alibaba Cloud (Zhangbei), Schneider Electric & China Unicom (Hohhot), China Mobile (Zhongwei & Langfang), JD Cloud (Suqian) and Baidu (Yangquan) for the 10 companies' strong support and cooperation.

Provisions should be arranged before an army is mobilized. We were a team of more than a dozen people with three or four cars, and our itinerary and expenses every day were under the charge of special personnel. The whole journey was jointly planned by Liu Ce and Wang Haifeng, who also were in charge of logistics.

Along the way, Guo Ping, Kang Xiang, Song Chen, Zhang Shuai, Qi Meng, Xie Shicheng and other media celebrities output wonderful articles, Lin Yu and Tang Ming made aerial photography tirelessly under the hot sun, Xu Yixun made sweet dubbing for the video and Zhao Zhipeng conducted the editing work day and night, all of which have enhanced the China Digital Journey. We would also like to thank our partners behind the scenes - the Time Filter, Zhan Heng, Jia Xibei and Zhang Fenglin.

We set off from Binhai of Tianjin on August 6th, and returned from Yangquan of Shanxi on September 11st. After a period of bustle and refinement, we started preparing the investigation report. The reason why we positioned it as an "investigation report" instead of the original "white paper", was that, in my opinion, since the data center industry is too large, it is very difficult to produce the main trends reflected in the data centers visited during the journey, so it is more accurate to position it as an investigation report for a research activity rather than an industry white paper.

Five years ago, Zeng Zhiqiang and I wrote a technical report titled Data Center 2013: Hardware Re-architecture & Software Defined, which was started with "Data Center", though there were actually very few content about the data center infrastructure. At this time, we position the report on the 2018 China Digital Journey - Data Center Tour in Northern China as a "data center brochure that is easy for IT people to understand", in the hope of making up for the shortcomings of that previous report.

What's longer than the journey is the time span for preparing the investigation report. In the process, in addition to strong support from technical experts from 10 data centers, we also benefited a lot from the guidance of Qu Haifeng, Han Yu, Wang Tiewang and Zhang Tuo, members of the China Data Center



Committee (CDCC). (Note: the sources of most quoted pictures and data have been indicated in the investigation report, while those whose sources are not indicated are mainly from E7Academy.)

Of course, our appreciation goes to Liangtianzai Design, who makes this investigation report “presentable”.

As China Digital Journey puts it, the “China Digital Journey” is a long journey, during which we have always been on the way, only stopping sometimes to pack up our baggage. A new beginning of the year of 2019 follows the end of the year of 2018.

Thank you for reading, and look forward to seeing you again!

Zhang Guangbin

Jan, 2019 in Beijing





All the best for 2019!



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