Building Next Generation Data Center Facility in ASEAN

White Paper

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Soemantri Brodjonegoro II Building, 6th fl.
Directorate General of Electricity
Jl. HR. Rasuna Said Block X-2, Kav. 07-08
Jakarta 12950, Indonesia
Tel: (62-21) 527 9332 | Fax: (62-21) 527 9350 32
E-mail: communication@aseanenergy.org
www.aseanenergy.org

Forewords – ACE

One of the key drivers of economic growth in the ASEAN region is digital transformation, which keeps growing and evolving to cater to consumers' and businesses' demands. Digital services embark on a rapid journey, thus creating a surge in data center operations. Data center markets are developing in the ASEAN region, creating a promising future for investors. Even so, the emergence of data centers has not been without its indispensable effects. Data center contributes to a large increase in energy consumption–from server operations to cooling systems that need to be kept powered on constantly.

Data center is a critical piece of infrastructure, yet it is also necessary to remember that energy consumption will continue to increase during, and with the sight of, the burgeoning demand for data. Larger consumption means higher energy costs, and businesses are finding ways to cut the cost burden, even through limiting operational hours. To overcome this problem, it is essential to improve system efficiency and look for alternative cleaner energy in furtherance of data center operations. With a goal of transitioning to a low-carbon economy, ASEAN countries need to balance environmental protection while still attracting global players for countries' economic growth.

Practicing the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II 2021-2025 in the Programme Area of Energy Efficiency & Conservation, data center transformation will hopefully move towards green practices for a sustainable future in the ASEAN region. The collaborative work and approach are depicted in this White Paper on Building Next Generation Data Center Facility in ASEAN. The study explores the trends of data centers in ASEAN and worldwide. It expounds on technologies and methods that ASEAN countries could adopt as a means to reach their ambitious targets for energy efficiency.

With a large and continuous rise of online services, countries in the ASEAN region seem beneficial for data center markets. However, challenges to achieving sustainable data centers still arise, and serious commitment is needed to create a data center that meets low-carbon requirements. This White Paper reflects on challenges in data center installations and operations, as well as a comprehensive discussion on the matter of technology trends and ways to address energy consumption, cost savings, and environmental responsibility. Moreover, it provides policy recommendations for data center markets, both mature and emerging markets, for the development of data centers. We expect this article will come as a good reference for the energy technology sector, providing innovative products and solutions, along with recommendations for policymakers.

Dr. Nuki Agya Utama
Executive Director
ASEAN Centre for Energy

Forewords – Huawei

With the rapid development of the intelligent world and the booming digital economy, computing power and data have become key production factors, and the global data volume has increased sharply. According to the Intelligent World 2030 report, it is expected that by 2030, general computing power will increase by 10 times, and artificial intelligence (AI) computing power will grow by 500 times. The explosive growth of data volume and computing power drives the development of high-density and large-scale data centers (DCs), opening up new space for DC development. It is estimated that the global data center investment will increase from the current USD 35 billion to USD 54.3 billion by 2027. AI requirements and industry digital transformation requirements in the ASEAN region drive the development of large-scale cloud and intelligent computing centers and multi-network edge DCs. ASEAN governments have also issued AI strategies and digital transformation policies.

Currently, there are two definite trends in the development of the ASEAN data center industry, that are intelligent and sustainable. However, there are many challenges accompanying these trends. Firstly, the massive deployment of DCs has higher requirements on power capacity, renewable energy ratio, and power grid stability. ASEAN governments are advised to adopt active energy policies to encourage DC development. New DCs continuously use emerging technologies to reduce power usage effectiveness (PUE). The power consumption of existing DCs remains high, thus the reconstruction requirement of a low-efficiency system is also strong. Secondly, the power density of AI data centers will gradually increase from 8-12 kW/cabinet to 20-40 kW/cabinet. It poses new requirements for power supply and cooling infrastructure. Large language models and graphics processing units are also rapidly iterated. Therefore, faster rollout and more flexible capacity expansion capabilities should be considered in the DC design phase. Thirdly, AI DC systems' complexity is increasing, with many edge DC outlets but a lack of professional operation & maintenance (O&M) personnel and standards in the region. DCs should be transformed towards intelligent O&M. Fourthly, the AI DC infrastructure fault is serious, which requires higher power grid and infrastructure reliability. Hence, the redundant architecture and technology that balance the cost and reliability should be applied.

In the face of these trends and challenges, Huawei Digital Power will continue to increase investment in digital and power electronics technologies, as well as develop solutions for large-, medium-, and small-sized DCs, and critical power systems. We help customers and partners build sustainable and intelligent DCs from design, and construction to O&M. After long-term efforts, Huawei has completed more than 1000 DC projects with partners, with more than 14 GW capacity for multiple industries. Our future DC concept is GSSR - green, simplified, smart, and reliable.

In this White Paper, Huawei Digital Power and the ASEAN Centre for Energy jointly provide insights into the status quo and trends of DCs in the region, introduce major challenges and corresponding innovative technology applications, and propose policy and standard recommendations for mature and developing markets. We hope it helps the ASEAN DC industry achieve future-oriented long-term sustainable development.

Steve Kim
President
Huawei Data Center Facility and Critical Power Business APAC

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Authors: This report was prepared by experts from ACE and Huawei. In ACE, the main authors of the report are Rio Jon Piter Silitonga, Rika Safrina, Vu Trong Duc Anh, Marc Benjamin Kusno, and Zahra Aninda Pradiva. In Huawei, the main authors of the report are Wang Junfei, Li Baoyu, He Songyan, Zhao Junpeng, Luo Long, Yang Wu, Zhang Nengjie, Wu Dabiao, and Zeng Zhili.

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This collaborative effort reflects the dedication of a diverse group of organizations, and their valuable contributions are truly appreciated.

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Executive Summary

The ASEAN region is experiencing a significant acceleration in digital transformation to boost economic growth, driven by escalating demands from consumers and businesses. Central to this transformation are data centers, which are essential for managing and processing large volumes of data in many sectors. As digital services and artificial intelligence require massive computing power, there is a corresponding increase in the need for a robust data center facility. However, this expansion brings a rising energy demand, primarily fueled by continuous server operations and the extensive cooling systems required to maintain optimal equipment conditions. This report, published by the ASEAN Center for Energy in collaboration with Huawei, explores the current landscape, challenges, solutions, and forward-looking strategies for building next-generation data center facilities within ASEAN. It underscores the urgent need for more reliable, faster deployment and intelligent practices that align with broader environmental goals and sustainable economic growth, as guided by the ASEAN Plan of Action for Energy Cooperation.

The White Paper advocates integrating innovative technologies and practices in data center design, development, and operation and maintenance (O&M). This encompasses cutting-edge technologies in construction, electrical, mechanical, and management systems. Key innovations include the adoption of prefabricated architecture, modular data centers, advanced power supply systems, and cooling solutions, as well as smart management systems. These emerging technologies can significantly raise the availability rate, shorten deployment time, enhance green energy usage and energy efficiency, and simplify O&M.

In exploring the diverse landscape of mature and emerging markets within ASEAN's data center industry, the White Paper also identifies several key policy recommendations to address the associated challenges and opportunities. For example, it is recommended that governments release tax incentive policies to promote the data center market investment. Simplified processes for land, electricity, water, and submarine cables are advised during the project application stage. In addition, establishing robust regulatory frameworks and standards is deemed paramount to ensure consistency and compliance across all market segments. Especially for mature markets, incentivizing innovation is highlighted as a critical driver for progress, encouraging stakeholders to embrace cutting-edge technologies and sustainable practices.

The successful implementation of these strategies will require cooperation and commitment across governments, industry stakeholders, and technology providers. It is an opportunity for ASEAN to lead by example in lower carbon digital infrastructure development, promoting not only regional growth but also contributing to global efforts in reducing the environmental footprint of the digital age. The future of ASEAN's digital economy depends on the strategic transformation of its data centers into next-generation facilities that are reliable, simplified, smart, scalable, and above all, sustainable.

Abbreviations

A	ADB	Asian Development Bank
	AI	Artificial Intelligence
	AMS	ASEAN Member State
	APAEC	ASEAN Plan of Action for Energy Cooperation
	ASEAN	Association of Southeast Asian Nation
B	BMS	Battery Management System
C	CAPEX	Capital Expenditure
	CCPA	California Consumer Privacy Act
	CoC	Code of Conduct
D	DC-CFA	Data Center - Call for Application
	DEFA	Digital Economy Framework Agreement
	DX	Direct Expansion
E	EGDI	E-Government Development Index
	ENIAC	Electronic Numerical Integrator and Computer
	EPI	Enterprise Products Integration
	ESS	Energy Storage System
	EU	European Union
G	GDP	Gross Domestic Product
	GDPR	General Data Protection Regulation
	GITA	Green Investment Tax Allowance
	GITE	Green Income Tax Exemption
	GPP	Green Public Procurement
H	HPC	High-Performance Computing
	HVAC	Heating, Ventilation, and Air Conditioning
I	IaaS	Infrastructure as a Service
	IMDA	Infocomm Media Development Authority
	IoT	Internet of Things
	IRR	Internal Rate of Return
	IT	Information Technology
J	JRC	Joint Research Center
K	kVA	kiloVolt-Ampere
	kW	Kilowatt
L	Li-Ion	Lithium-Ion

M	MCMC	Malaysian Communications and Multimedia Commission
	MDC	Modular Data Center
	ms	Millisecond
	MW	Megawatt
O	O&M	Operation and Maintenance
	OPEX	Operating Expense
P	PDP	Programmed Data Processor
	PMDC	Prefabricated Modular Data Center
	PPP	Public Private Partnership
	PUE	Power Usage Effectiveness
Q	QR	Quick Response
R	RE	Renewable Energy
	ROI	Return on Investment
S	SPCN	Space, Power, Cooling Capacity, and Network
T	TIA	Telecommunication Industry Association
	TWh	Terawatt-hour
U	UPS	Uninterruptible Power Supply
	US	United States
V	VAX	Virtual Address eXtension
W	W	Watt
	WUE	Water Usage Effectiveness

Chapter 1.

Introduction on Data Center in ASEAN

Chapter 1. Introduction on Data Center in ASEAN

1.1. Data Center Definition

A data center is, by definition, a centralized facility where computing and networking equipment is concentrated to collect, store, process, and distribute large volumes of data. It provides a robust, secure environment for an organization's information technology (IT) operations, enabling the processing and storage of critical and proprietary information. These facilities typically house servers for running applications and databases, storage systems such as hard drives and solid-state drives for data retention, and network infrastructure like switches, routers, and firewalls to manage data flow and connectivity.

Additionally, data centers are equipped with power subsystems, including backup generators and uninterruptible power supplies (UPS), to ensure uninterrupted operations even during power outages. Cooling systems are also crucial to mitigate the heat generated by high-density computing equipment, maintaining an optimal operating environment. Physical security measures, including biometric access controls and video surveillance, are implemented to safeguard against unauthorized access or breaches.

Data centers come in various forms, catering to different needs (Figure 1.1). Below are data center types based on purpose type.

- Enterprise data centers are owned and operated by the company itself and are tailored to its specific requirements in different industries.
- Cloud data centers offer cloud services for the enterprise or end user. This service is hosted on the cloud and can be public, private, or a hybrid of both.
- Colocation data centers offer the IT infrastructure to the enterprise. Typically, the customer owns the IT equipment and the facility provides power and cooling. Customers retain control over the design and usage of their equipment, but daily management of the data center and facility is overseen by the multi-tenant colocation provider.
- High-Performance Computing (HPC) data centers use supercomputers and computer clusters to solve advanced computation problems. Artificial intelligence (AI), machine learning, scientific research, image rendering, and weather forecasting are the main applications of HPC.

Figure 1.1. Cloud Data Center

Data centers come in a variety of shapes and sizes which can be located onsite or in a large facility offsite. The data center for a small business or branch may only occupy a room that is 500 square feet, while some of the largest data centers may occupy an entire building over 1 million square feet. Selecting the appropriate size data center will depend upon many factors including current and future requirements, budget, redundancy rating, and location.

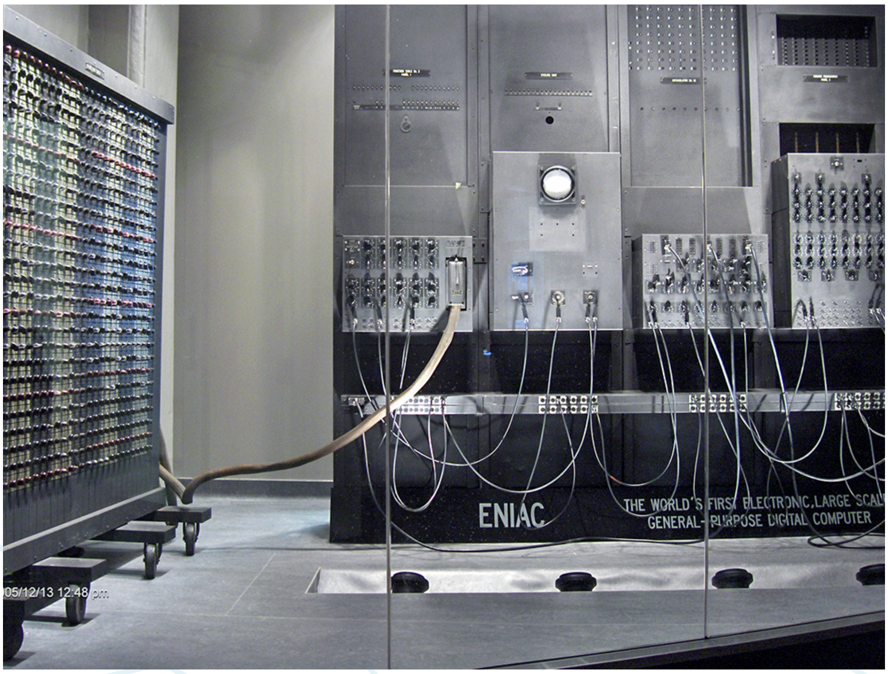
1.2. Historical Development of Data Center

The historical development of data centers is a journey that mirrors the evolution of computing technology and can be chronicled through several distinct eras, each marked by significant technological advancements and shifts in how data is processed and managed. The design of data center infrastructure has advanced throughout the period as well.

1.2.1. Computer Era (1940s – 1990s)

The genesis of the data center can be traced back to the 1940s with the advent of the Electronic Numerical Integrator and Computer (ENIAC) at the University of Pennsylvania (Figure 1.2). This pioneering effort marked the construction of the first facility that could be considered a data center, designed to house a machine that was the progenitor to all future mainframe computers. These early behemoths were not just room-sized but required complex environmental control to operate effectively. The IBM 700 series, introduced in the 1950s, represented the archetype of computing machines during this time, necessitating dedicated spaces with raised floors for cable management, along with precise temperature and humidity controls to ensure operational stability [1].

Figure 1.2. ENIAC at the University of Pennsylvania



Source: University of Pennsylvania [2]

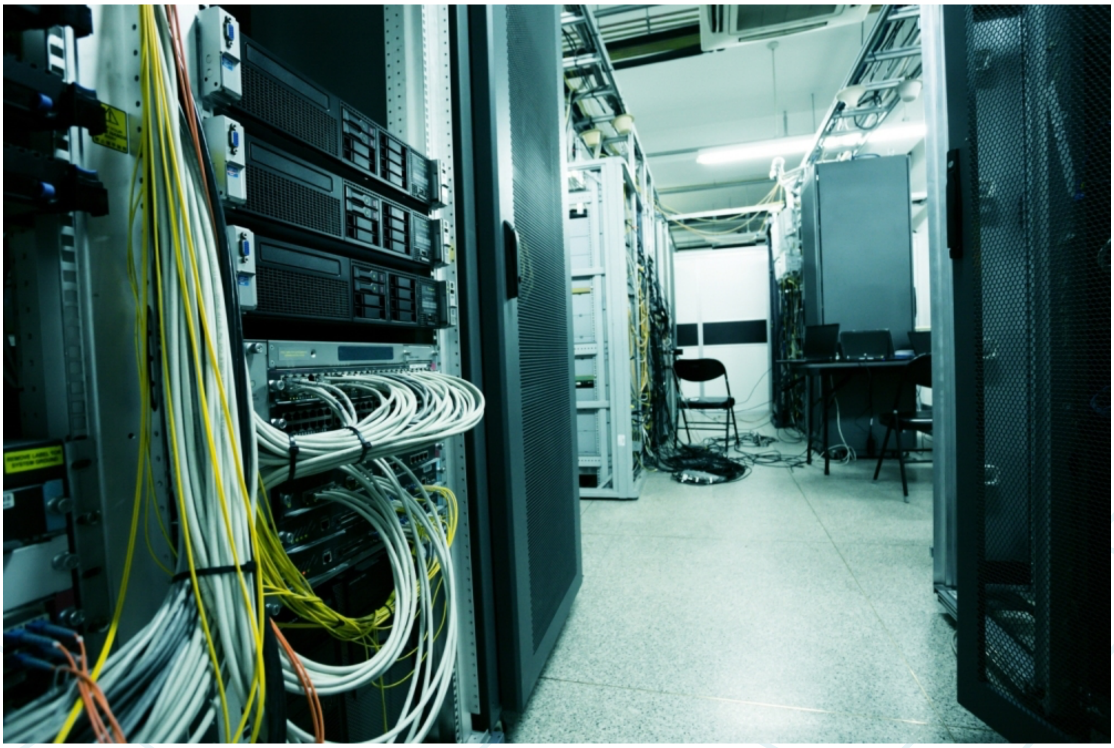
As technology progressed, the 1960s and 1980s heralded the age of the minicomputer [3]. These machines, exemplified by Digital Equipment Corporation's PDP and VAX series, were substantially smaller and more affordable than their mainframe predecessors. This democratization of computing power led to a proliferation of on-premises computer rooms across various organizations [4]. The design of these spaces became more standardized, with the introduction of server racks and enhanced cable management systems, allowing for a broader distribution of computing capabilities throughout an organization [3].

1.2.2. The Internet Era (1990s – 2010s)

The 1990s saw a paradigm shift, with the client-server model coming to the fore, spurred by the rapid expansion of the internet and the accompanying demand for more robust and scalable data centers (Figure 1.3) [1]. In-house data centers grew in size and capability, hosting an array of servers to not only manage internal data and operations but also provide vital internet connectivity [4]. The era also marked the rise of colocation data centers, where third-party providers offered space and resources for rent, enabling businesses to outsource their data center needs without the capital expenditure (CAPEX) of constructing and maintaining their facilities [1].

The early 2000s also saw a significant shift in data center technology with the introduction of virtualization. Virtualization technologies, such as VMware ESX, which was launched in 2001, revolutionized the way data centers operated. By allowing multiple virtual machines to run on a single physical server, virtualization enabled more efficient utilization of hardware resources and the consolidation of applications onto fewer physical servers. This development laid the foundation for the future of data center infrastructure [5].

Figure 1.3. Data Center in the Internet Era



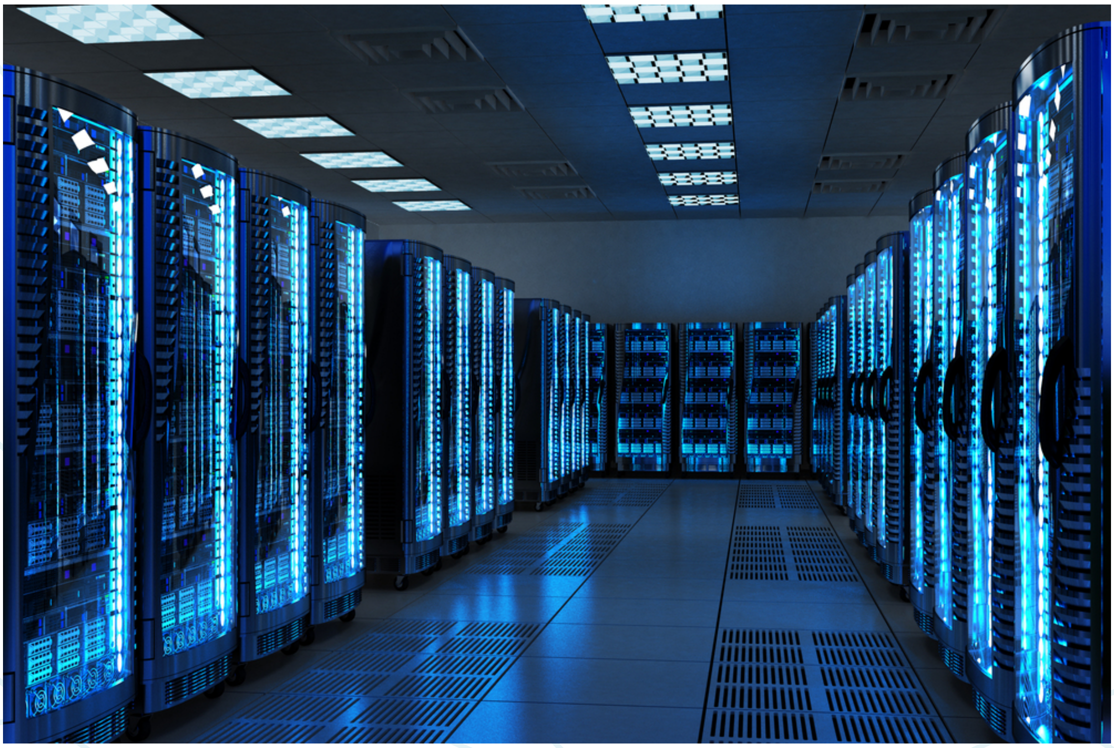
1.2.3. Cloud Era (2010s – 2020s)

The launch of the cloud computing platform marked a major milestone in the evolution of data centers. There was also the introduction of Infrastructure as a Service (IaaS), allowing businesses to rent virtual servers and storage from cloud providers. This development paved the way for the widespread adoption of cloud computing, as it provided organizations with a more flexible and cost-effective alternative to building and maintaining their own on-premises data centers. Cloud computing enabled businesses to scale their IT infrastructure on demand, paying only for their consumed resources [6].

1.2.4. Intelligent Computing Era (2020s – nowadays)

The 2020s and beyond have seen data centers evolve to meet modern businesses' growing demands. The rise of big data, large language model, GPT, the Internet of Things (IoT), and the increasing need for real-time data processing has driven the requirement for larger, more efficient, and scalable data centers [7]. These modern facilities are designed to handle massive amounts of data and provide the computing power necessary to support complex applications and analytics (Figure 1.4).

Figure 1.4. Data Center in the Intelligent Computing Era



1.3. Data Center Status in ASEAN

The Association of Southeast Asian Nations (ASEAN) is an emerging region (Figure 1.5), consisting of 10 ASEAN Member States (AMS). Data centers in ASEAN have evolved since the early 2000s with Singapore leading as the regional hub. Up to now, AMS have a total of 1.5 GW data centers under operation, over 500 MW data centers under construction, and nearly 2 GW under planning (Figure 1.6).

Figure 1.5. Map of ASEAN Member States

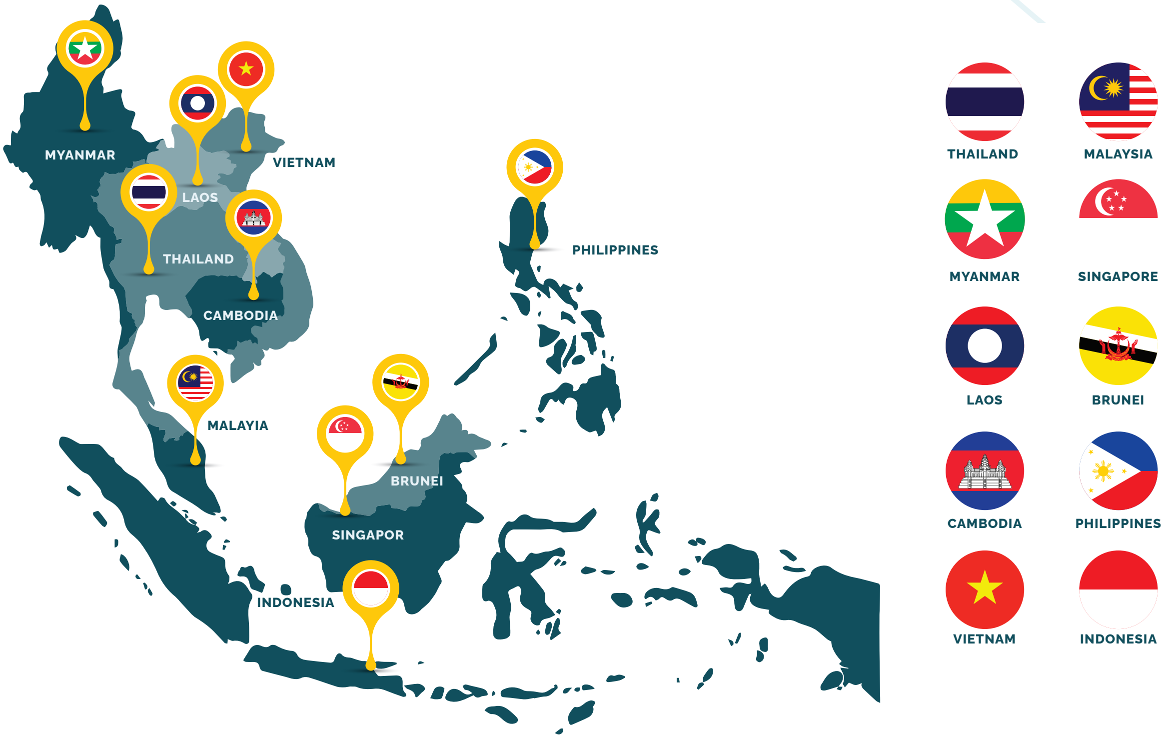
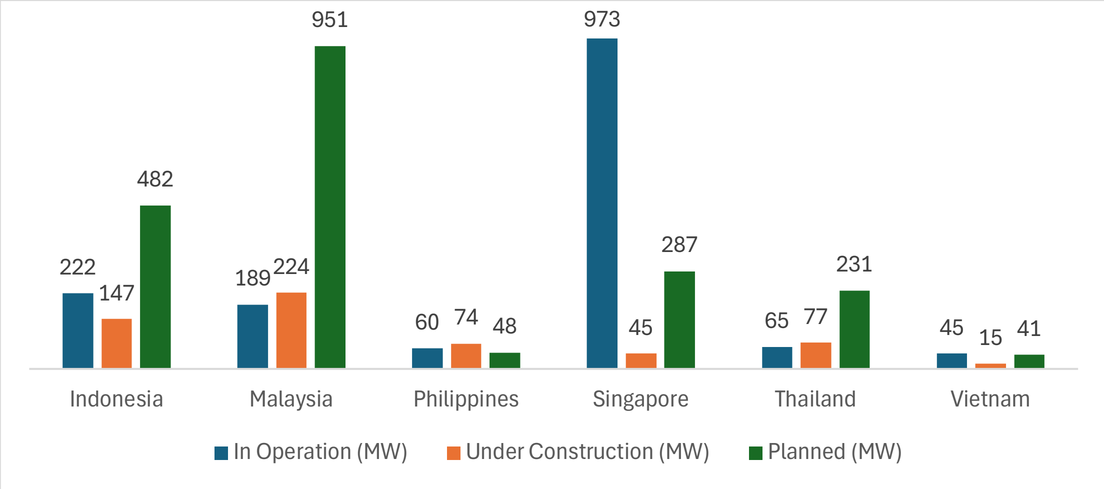


Figure 1.6. Data Center Capacity in Selected ASEAN Countries



Data Source: Asia Pacific Data Center Update H22023, Cushman&Wakefiled [8]

Singapore is one of the earliest countries in ASEAN to develop data centers and has attracted major global players to establish their data centers. Singapore's prominent role as a regional hub for data centers in Southeast Asia has significantly influenced the market dynamics in neighboring countries. The strategic geographic position and extensive subsea cable networks have established it as a key connectivity hub. Its reliable power supply, low risk of natural disasters, and favorable business environment solidify its status as a prime location for data center operations.

The stringent data protection regulations and intellectual property laws in Singapore attract multinational companies to host their data there. An established ecosystem of data center operators, cloud providers, and related services adds to the country's appeal as a data center hub.

However, Singapore faces challenges such as land scarcity, high power costs, and environmental concerns, which have led to a temporary moratorium on new data center development in 2019. Although Singapore lifted the moratorium in 2022 [9], carefully selected new development in a pilot 80 MW Data Center – Call for Application (DC-CFA) that met certain conditions, such as energy efficiency and sustainability requirements [10]. However, it results in the data center operators and cloud providers seeking alternative locations in the region [11].

Malaysia has seen significant investments from data center operators and cloud providers looking for alternative locations close to Singapore. Major developments are underway in areas like Cyberjaya, Johor, and the Iskandar region in southern Malaysia near the Singapore border. These locations offer proximity to Singapore, enabling low-latency connectivity while providing more space for data center expansion [12].

Indonesia, with its large population and rapidly growing digital economy, is also emerging as an attractive data center destination. Jakarta and surrounding areas have witnessed entry by major players building large hyperscale campuses. The country's increasing internet penetration, e-commerce growth, and digital transformation initiatives drive the demand for data center services [12].

Thailand is another promising data center market in Southeast Asia, across Bangkok, Chonburi, and other cities. It has a large and growing internet user base that consumes online content and services. The country has launched the Digital Thailand initiative and the Eastern Economic Corridor project to boost the digital economy and infrastructure.

Demand for data center services is also rising in the Philippines. This demand derives from the business process outsourcing sector, which accounts for at least 7% of the country's GDP.

Vietnam is one of the fastest-growing data center markets in Southeast Asia, across Hanoi, Ho Chi Minh City, Da Nang, and other cities. Vietnam has a young and tech-savvy population that drives the demand for digital services such as e-commerce, gaming, and social media. The country also has a low-cost advantage that attracts foreign investors and operators.

1.4. The Importance of Data Center in ASEAN

1.4.1. Boosting Economic Growth

Across Southeast Asia, a digital revolution is transforming the region's economies rapidly. As of 2022, ASEAN has 460 million Internet users, with 100 million joining in the last three years alone [13]. It is estimated that the region's digital ecosystem could grow from USD 300 billion to nearly USD 1 trillion by the year 2030 [14]. The region's digital economy is expected to contribute significantly to its GDP, with the gross value added of Southeast Asian countries' digital economy making up 45% of the region's GDP in 2022. By 2027, the digital economy is forecast to contribute approximately 56% to the region's GDP, with digital payments playing a significant role with a contribution of 61.5% [15].

The ASEAN Digital Economy Framework Agreement (DEFA), which is currently being negotiated, exemplifies a significant effort by AMS to build a unified and strong digital economy in the region. This initiative focuses on multiple key areas such as enhancing digital trade, facilitating cross-border e-commerce, and adopting digital payments. It places a strong emphasis on leveraging AI technologies. This transformation represents not just a shift, but a crucial pillar for the economic and social integration of ASEAN [16].

Parallel to this regional initiative, individual Southeast Asian countries are actively integrating AI and enhancing data protection. Malaysia, for instance, is advancing its AI agenda through public-centric initiatives such as the "AI for Rakyat" and Smart City programs, supported by tax incentives aimed at accelerating technological adoption. Indonesia is witnessing substantial growth in its AI sector, guided by its ambitious AI Strategy and reinforced by its inaugural data protection law, which aligns with EU standards. Singapore remains at the forefront with its updated National AI Strategy and substantial investments in AI research. In Thailand, the focus is on exploiting AI in the private sector, complemented by tax incentives to bolster data center operations. Meanwhile, Cambodia and Vietnam are enhancing their legal frameworks to ensure stringent data protection and attract foreign investments in their digital infrastructures. These national efforts collectively demonstrate a strong regional dedication to utilizing advanced AI technologies while ensuring data privacy and security, resonating with the broader goals of the DEFA.

As ten countries converge on the digital plane, this transformation is reshaping and influencing many sectors both directly and indirectly, from bustling e-commerce marketplaces to streamlined e-governmental services and is acting as a catalyst for the bloc's integration. At the center of this transformation are data centers, the "powerhouse" for digital life. Yet, as they expand across the region to meet soaring demand, the urgency for energy-efficient operations has never been more critical as data centers' intense energy consumption presents a monumental challenge for sustainable digital infrastructure for the region.

1.4.2. Increasing Job Opportunities

The development of a data center requires a new set of skills covering interdisciplinary fields. Data centers have the potential to increase job employment in several ways:

- **Construction and Maintenance**: Building and maintaining data centers need a wide range of skills, from construction workers and electricians to HVAC (Heating, Ventilation, and Air Conditioning) technicians and IT specialists. The construction phase alone can create a significant number of jobs in the local area.
- **Operations and Management**: Data centers need personnel to manage day-to-day operations, including server maintenance, network management, and security monitoring. This includes roles such as system administrators, network engineers, and security analysts.
- **Support Services**: Data centers often require support services such as cleaning, catering, and security. These roles may be outsourced to local companies, providing additional employment opportunities in the area.
- **Software Development**: Many data centers develop their software for managing infrastructure, monitoring performance, and automating tasks. This can create jobs for software developers, testers, and project managers.
- **Data Science and Analytics**: As data centers accumulate vast amounts of data, there is a growing need for data scientists and analysts to extract insights, optimize performance, and improve efficiency.
- **Green Initiatives**: With increasing focus on sustainability, data centers may invest in renewable energy sources, energy-efficient cooling systems, and other green technologies. This can create jobs in RE, environmental engineering, and sustainable design.

- **Community Impact**: Data centers often attract other businesses to the area, such as technology startups or service providers. This can create a ripple effect of job creation throughout the local economy.

Overall, the presence of a data center can stimulate job growth directly through the employment opportunities it creates and indirectly through its impact on the local economy.

1.4.3. Ensuring Data Sovereignty

In the midst of this digital age transformation, data centers play a pivotal role, as they act as the foundational infrastructure, similar to the utility grids and transportation networks of the industrial age. These establishments are the epicenters of data storage, management, and distribution, enabling services integral to the functioning of e-commerce platforms, smart cities, and beyond. By facilitating secure and instantaneous access to data for commercial transactions and processing colossal data volumes, data centers ensure the seamless flow of information that powers modern life.

Data centers ensure data sovereignty by implementing various measures to protect and control data within the jurisdiction of the country or region. Here are some strategies they employ:

- **Geographical Location**: Data centers can establish their facilities within the geographical boundaries of the country or region to ensure that data physically resides within the jurisdiction. This helps comply with local regulations and laws regarding data sovereignty.
- **Data Encryption**: Encrypting data at rest and in transit helps ensure that even if data is accessed without authorization, it remains unreadable and unusable. Strong encryption techniques can safeguard data sovereignty by preventing unauthorized access or data breaches.
- **Access Controls**: Implementing strict access controls and authentication mechanisms ensures that only authorized individuals or entities can access the data. This includes role-based access controls, multi-factor authentication, and robust identity management systems.
- **Legal and Compliance Measures**: Data centers adhere to local laws and regulations related to data protection and privacy. This includes compliance with data protection laws, such as the General Data Protection Regulation (GDPR) in Europe or the California Consumer Privacy Act (CCPA) in the US. By following these regulations, data centers can ensure that data sovereignty requirements are met.
- **Data Residency Requirements**: Some countries have specific regulations requiring certain types of data to remain within the country's borders. Data centers can ensure compliance with these regulations by storing data locally and not transferring it across international borders.

- **Contractual Agreements**: Data centers may enter into contractual agreements with their clients or customers to specify how data will be stored, processed, and protected. These agreements often include clauses related to data sovereignty, ensuring that data remains under the control of the client or within the designated jurisdiction.
- **Transparency and Audits**: Data centers may undergo regular audits and assessments to ensure compliance with data sovereignty requirements. These audits provide transparency into the data handling practices of the data center and help verify that data sovereignty measures are effectively implemented.

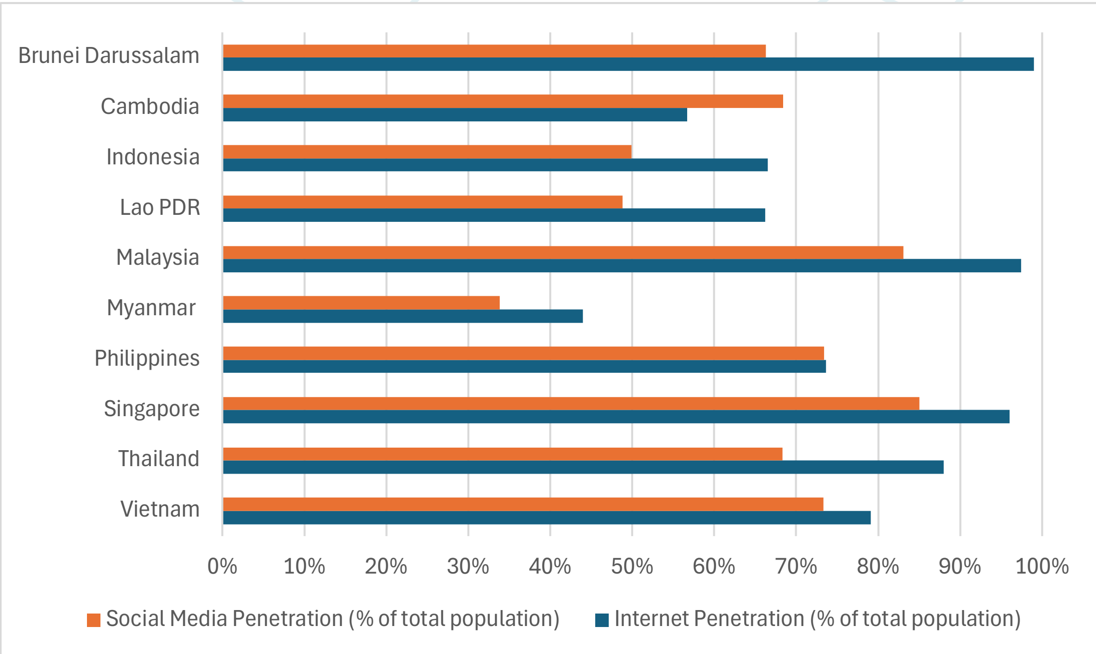
By employing these strategies, data centers can effectively ensure data sovereignty and maintain compliance with local regulations, thereby their clients and customers regarding the protection and control of their data.

1.5. What Drives and Supports Data Center Growth in ASEAN

1.5.1. Drive: Internet Penetration

The surge in internet penetration and social media usage has emerged as one of the primary catalysts for data center growth in the ASEAN region (Figure 1.7). This trend is most evident among the young, tech-savvy populations of several Southeast Asian countries.

Figure 1.7. Internet and Social Media Penetration in ASEAN Member States in Early 2024



Data Source: datareportal (2024)

In Indonesia, internet penetration has increased to 66.5% at the beginning of 2024 (Figure 1.7), with Generation Z (ages 12-27) accounting for 34.4% of internet usage [17]. Social media continues to thrive, with 167 million users in 2023, making Indonesia one of the leaders in the Asia-Pacific region for social media activity [18].

Malaysia maintains a strong digital presence with an unchanged internet penetration rate of 97.4% in 2024 (Figure 1.7), ranking it 10th globally. An impressive 91.7% of the population, equating to 30.25 million people, were active on social media in 2022 [19]. Malaysians favor platforms such as WhatsApp, Facebook, Instagram, YouTube, and the emerging TikTok.

Thailand is on a steady path of digital expansion, with its internet 88% penetration rate as of 2024 (Figure 1.7), and is expected to reach 84.49% by 2028 [20]. An overwhelming majority of Thais, 93.3%, were using Facebook, and 92.8% were on the Line messaging app as of early 2022 [21]. Thai youth show high engagement on platforms like TikTok and Instagram, signaling a diversification of social media use. The Philippines continues to lead globally in social media usage, with an average of over 4 hours daily on various platforms [22]. The social media presence grew to 82.4% of the population in 2022, with Facebook reigning as the most popular platform. Other platforms with significant user bases include Facebook Messenger, TikTok, Instagram, and Twitter [23].

In Vietnam, internet penetration was recorded at 79.1% in 2024 (Figure 1.7), with a high concentration of users among the urban and educated demographics [24]. Facebook dominates social media as a network and e-commerce platform [24]. Local messaging apps like Zalo have become the norm, overtaking traditional SMS in popularity and usage [24].

1.5.2. Drive: Digital Transformation in Different Sectors

The rapid growth of e-commerce and digital banking, along with the shift towards cashless payment systems, also necessitates expanding data center infrastructure in the ASEAN region to support these data-intensive applications. Southeast Asia's e-commerce market is experiencing a significant boom, projected to reach USD 211 billion by 2025 [25]. The pandemic has accelerated this trend, with online retail platforms like Shopee, Lazada, and Tokopedia witnessing soaring transaction volumes. Specifically, Indonesia is expected to be a major contributor, with a forecast of USD 95 billion in online retail sales by 2025 [26]. The increase in digital transactions and the resulting data generation require robust data center infrastructure for processing and storage.

Digital banking services are also rising as consumers increasingly engage with digital financial platforms. The volume of digital payments in the region surpassed USD 800 billion in 2022, and the number of active mobile wallet accounts in Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam is expected to grow significantly, reaching USD 440 million by 2025 [27] [28]. Government initiatives also promote cashless payments, exemplified by systems like Thailand's PromptPay and Singapore's drive for QR code payments.

Digital payment systems are rapidly replacing traditional cash-based transactions. Indonesia has become ASEAN's largest digital payments market, with a notable 40%

increase in transaction volume in 2020 [27]. The Philippines, traditionally reliant on cash, is seeing a high adoption rate of digital payments, with 97% of merchants accepting digital payment methods [27]. Data centers are critical in securely and efficiently processing increasingly digital payment transactions.

Fintech innovations, such as digital lending, buy now pay later schemes, and alternative credit scoring, are particularly relevant for the region's significant unbanked or underbanked population. These fintech services are data-driven and depend on the computational capabilities of data centers. As e-commerce, digital banking, and fintech continue to expand and evolve in the ASEAN region, the demand for reliable and secure data center infrastructure will continue to grow to support these data-intensive applications and ensure a seamless user experience for consumers and businesses.

In addition to the growth of e-commerce and digital banking, the digital transformation across various sectors, including government and healthcare, is significantly reshaping operations and services in the ASEAN region. Government digitalization efforts are evident with the increase in the E-Government Development Index (EGDI) scores. Countries like Singapore, ranked 12th globally, and Malaysia, ranked 53rd, show strong performance in online services and overall digital governance. Similarly, countries like Vietnam and Indonesia have made notable progress, with Vietnam advancing to rank 84th and Indonesia to rank 77th, reflecting improvements in online service provision and e-governance platforms. On the other hand, Cambodia and the Lao People’s Democratic Republic are actively pursuing digital transformations despite facing infrastructure and human capital challenges [29]. Similarly, the healthcare sector is undergoing significant digital transformation, with the ASEAN telemedicine market projected to grow at a compound annual growth rate of 28.9% from 2023 to 2030 [30]. This transformation aims to improve patient care and operational efficiency, relying heavily on data centers to support electronic health records, telemedicine services, and health information systems.

1.5.3. Drive: Technology Revolution

The emergence of advanced technologies is another factor driving the expansion of data centers in the ASEAN region. These technologies include AI, IoT, Edge Computing, and 5G Networks. AI applications such as machine learning, natural language processing, and computer vision are increasingly adopted across various industries. They require high-performance computing to process and analyze large datasets, thus fueling demand for advanced data center infrastructure.

The proliferation of IoT devices leads to vast real-time data generation. These connected devices range from consumer products like smart home appliances to industrial sensors. The data they generate needs to be processed efficiently, often in real-time, necessitating data centers with low-latency connectivity. Edge computing, which processes data closer to where it is generated instead of sending it back to centralized data centers, supports real-time applications such as autonomous vehicles, smart cities, and industrial automation by reducing latency. This shift requires the development of smaller, localized data centers distributed across the region.

The rollout of 5G is expected to intensify the data demands due to its higher speeds, lower latency, and increased device connectivity capacity. 5G enables a new wave of applications and services, requiring data centers to upgrade their infrastructure and adopt distributed architectures to manage the increased data traffic and localized processing needs. As these advanced technologies continue to evolve and gain traction in the ASEAN region, the demand for robust and strategically located data centers will only grow.

1.5.4. Support: Land Supply

Sufficient land supply and reasonable land price is paramount, since land accounts for roughly 10% of the total capital expenditures of a data center development. Land pricing has steadily risen for sites with plentiful power, fiber connectivity, proper zoning, water and sewage management. High intial land pricing can provide certain barriers of entry.land pricing across many ASEAN markets remains relatively elevated, which have seen growth with data center entrants increasingly making acquisitions in markets such as Batam, Ho Chi Minh City, and Jakarta.

1.5.5. Support: Electricity Supply

Electricity supply is a critical factor driving the growth of data centers, especially with the escalating power demands during expansion phases. Adequate power allocation remains a priority to support the rapid growth of high-computing demands. In Malaysia, Tenaga Nasional Berhad (TNB) has introduced an exclusive Green Lane Pathway and strategic offerings tailored for the country's data center market. This pathway expedites the supply of electricity, connecting data centers three times faster than the usual delivery time. This initiative reduces the implementation period from 36-48 months to just 12 months, and ensures high-voltage electricity supply is readily available within a shorter timeframe.

1.5.6. Support: Network Connectivity

Fiber density and quality are primary drivers for locating a data center, with fiber serving to connect the facility to others and the end user. More networks are always better with the diversity of fiber leading to lower latency and higher performance, even if certain networks connected to a particular data center may have bandwidth issues.

1.5.7. Support: Water Availability and Access

With cooling requirements rising, access to water is becoming increasingly critical for data centers across a variety of markets. Access to water can remain a key consideration given how quickly density requirements have been rising.

1.5.8. Support: Renewable Power Option

With carbon neutrality and net zero goals on the very near horizon, many hyperscale self-builds and larger-scale developments are being paired with new renewable energy infrastructure development. The region has vast potential of renewable energy, like solar and wind, that can be used to supply electricity to power up data center. By incorporating clean energy, AMS will not have to trade off the digital economic growth with the environmental sustainability.

Chapter 2.

Data Center Facility Challenges and PUE Insight in ASEAN

Chapter 2. Data Center Facility Challenges and PUE Insight in ASEAN

2.1. Challenges in ASEAN

With the increasing demand for cloud and intelligent computing, data centers are facing multiple challenges while developing rapidly.

1) Reliability and availability are still key challenges, and the influence of data center outages is getting worse in large-scale data centers

According to the Uptime Annual Outage Analysis report, more than half (55%) of operator respondents to the 2023 Uptime Institute data center survey report had an outage [31]. It has been a key challenge for data center operators to design and construct with higher reliability and availability.

Nowadays, with the popularity of smartphones, various mobile applications have become a necessity in people's lives. The stable running of data centers is closely related to people's daily lives, which means the outages of data centers might influence the national economy and people's livelihoods. That is why reliability and availability are the most fundamental features of a data center. Other features are meaningless without reliability and availability.

The redundant concept is an important method to improve reliability and availability, while the TIA 942 standard [32] is recommended to be adopted. For the battery system, which is the most vulnerable part of a UPS system, a separate battery room and water spray firefighting system should be implemented.

2) Traditional data center construction takes a long period and cannot meet the requirements for a fast service rollout, and is difficult to expand on-demand capacity

With the trend of digitalization and cloudification, the quick rollout of data center services has become a mandatory requirement. The earlier the data center goes online, the more obvious the benefits will be. Considering the impact of weather and design changes, the construction cycle faces multiple uncertainties. The construction period is long, while the return on investment (ROI) and internal rate of return (IRR) are low, affecting the profitability and business monetization capability of the data center. In addition, the computing power of Data centers in the AI era doubles yearly, and IT devices will be updated in three to five years. Traditional construction takes a long time, and new-generation technologies cannot be upgraded in a timely manner.

Traditional data centers are planned at a time, and the initial investment is large. The construction planning varies with many services, resulting in a waste of investment. When new services emerge, the capacity cannot be expanded quickly, resulting in missing business opportunities. In addition, due to insufficient elasticity, the computing power and power consumption per unit space keep increasing, and smooth capacity expansion cannot be achieved.

3) When data center power consumption is booming, sustainability will be a big challenge

Data centers are estimated to be responsible for up to 3% of global electricity consumption in 2023, while this proportion was only 2% in 2022 [33], [34]. In Singapore, data centers accounted for 7% of the total electricity consumption (3.4 TWh) in 2020 and is projected to reach 12% by 2030. AI computing is pushing power consumption to grow rapidly. With the development of the large language model, the scale of a data center and the power density of IT cabinets are also booming, which will put a lot of pressure on a data center.

A critical issue identified is the substantial energy consumption associated with the region's operation and maintenance of data centers. Given the tropical climate, these facilities often require constant cooling, significantly contributing to their energy usage. Without effective strategic interventions, the energy demands of these data centers are projected to increase sharply, presenting not only sustainability challenges but also significant economic burdens due to increased power consumption costs.

Besides, carbon neutrality has become a world consensus, which the data center industry should also take into account. To make a data center sustainable, there are many factors we need to consider, such as using more green power, building a battery energy storage system, lower PUE, lower Water Usage Effectiveness (WUE), as well as heat and water recycling [35].

4) Traditional data center lacks intelligent functions for operation and maintenance (O&M)

With the application of new technologies, the complexity of data centers is increasing. Traditional manual O&M methods make it difficult to ensure the reliability and efficiency of data centers. In addition, the O&M skills of data centers are high. According to market research, 61% of data centers lack qualified O&M personnel, and the O&M workforce is insufficient [36] [37]. Equipment room resources, such as electricity, cooling, and space, are unbalanced and fragmented, causing resource waste. The intelligence level of data centers needs to be improved.

Currently, there is no regional mandatory standard for ASEAN countries to follow regarding data center design, construction, and operations. The most commonly used recommended standards in the region are Uptime and TIA-942 [36]. This white paper hopes to analyze these challenges and propose appropriate solutions to address them.

2.2. Data Center PUE Insight in ASEAN

PUE is one of the most commonly used indicators for measuring the energy efficiency of a data center. It evaluates the energy performance of the data center by calculating the ratio of the energy used as a whole in contrast with the energy used by just the IT equipment alone. The closer the PUE number is to “1”, the more efficient the data center uses energy.

According to the ADB [38], PUE can be categorized as follows:

- PUE = 1: all power used to power IT equipment (theoretical)
- PUE = 1.2 - 1.6: optimized, feasible with appropriate measures
- PUE = 2: efficient, should be the first target
- PUE = 2.4: on average, more improvement is needed
- PUE > 3: inefficient, a lot of room for improvement

In ASEAN, there is no harmonized regional standard or regulation that governs the data center's PUE. Instead, individual countries have developed their own strategies and enforcement levels. Countries like Singapore and Malaysia have led by establishing technical guidelines or regulations governing data centers' PUE.

Singapore's data centers were responsible for approximately 7% (3.4 TWh) of the country's total electricity use in 2020 and is projected to reach 12% by 2030 [39]. In response to the significant energy consumption, the Singaporean government introduced a new energy efficiency standard in 2023 to improve energy use in data centers, focusing on operations in tropical climates. The Singapore government also mandated that PUE for new data centers should be 1.3 and below [39].

Singapore's Sustainability Standard for Data Centers in Tropical Settings

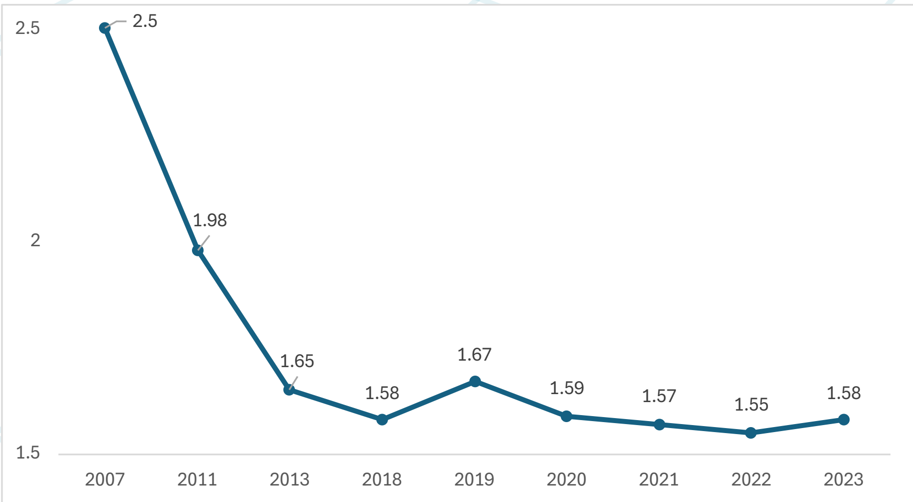
Singapore's Infocomm Media Development Authority (IMDA) launched a new sustainability standard for data centers in tropical climates in June 2023 [40]. *This standard aims to reduce the energy use of data centers, which are key to the digital economy but need a lot of cooling. The main idea is to raise the operating temperatures of data centers to 26 degrees Celsius or higher, instead of keeping them around 22 degrees Celsius or lower. This can save 2% to 5% energy for every 1-degree Celsius increase in temperature. The standard came from guidelines by a working group that studied how to run data centers in warmer settings. Early tests have been positive. For example, Digital Realty, a data center operator in Singapore, cut down 2% to 3% of total energy use by increasing temperatures by 2 degrees Celsius in two data halls. Also, the Government Technology Agency started trying higher temperatures in a government data center. IMDA's initiative is part of bigger sustainability plans. It is working with the Building and Construction Authority to update the Green Mark scheme for data centers, encouraging more data centers to follow this standard. The new standard can help lower the environmental impact of data centers in Singapore and inspire other ASEAN countries with similar tropical climates.*

In Malaysia, to guide energy efficiency efforts within this expanding sector, the "Specification for Green Data Centers" was established. The Malaysian Communications and Multimedia Commission (MCMC) recommends a PUE target of 1.9 or lower for data centers in the country [41].

At the individual level, many data centers can be classified as "optimized," with PUEs ranging from 1.1 to 1.6. These data centers are operated by various players, such as global tech giants, local telcos, data center operators, and hyperscale.

In recent years, the global average PUE has shown a discernible trend. Since the first poll in 2007 by the Uptime Institute, the industry-average annualized PUE fell sharply from 2.5 to 1.98 in 2011, and then to 1.65 in 2014. By 2022, the average annual PUE of 1.55 was consistent with readings over the past few years — demonstrating no significant movement since 2018, as shown in Figure 2.1. This stagnation does not indicate an end to technical innovation in data centers. Instead, it reflects the tapering off of "low hanging fruit" easy gains in energy performance from better air-flow management, optimized environmental controls, and some upgrades to electrical systems in legacy facilities. Further efficiency gains in many existing facilities would require major refurbishments that are costly and potentially disruptive to their operation — if such a retrofit is feasible. With this global situation as a context, the PUE values in the ASEAN region present a stark contrast. At the national and regional levels, data center efficiencies in the ASEAN region still have room for improvement.

Figure 2.1. Average PUE Globally



Data Source: Statista [42]

Although an average PUE for the ASEAN region is not available yet, an estimation can be made. According to the Uptime Institute, the average PUE of the Asia-Pacific region in 2020 was 1.69 [43]. This average, however, may not reflect the actual situation in the ASEAN countries, as some of the large economies in the region have much lower PUE values. China, for example, had an average PUE of 1.49 [44], and Australia of 1.48 [45], both well below the regional average. Japan [46] and India [47], on the other hand, had an average PUE of 1.7, close to the Asia-Pacific average. Thus, we can infer that the ASEAN countries, not included in these data, may have a higher average PUE than the Asia-Pacific average of 1.69, which is already higher than the global average.

One possible factor that could explain the high PUE values in the ASEAN region is the tropical climate, which requires more cooling power. However, this alone cannot account for the gap between the ASEAN region and other regions, such as Europe and North America, which had much lower average PUE values of 1.46 and 1.53, respectively, in 2020. These regions have managed to achieve lower PUE values through better design and efficiency standards, and by applying innovative technologies to their data centers. Therefore, there is a need for improvement in the ASEAN region to enhance the region's data center efficiency, taking lessons from global trends and challenges. Despite the significant gaps between the energy efficiency of data centers in the ASEAN region and international benchmarks, there are successful case studies from around the world that can serve as models for improvement in the region.

The EU Code of Conduct on Data Center Energy Efficiency

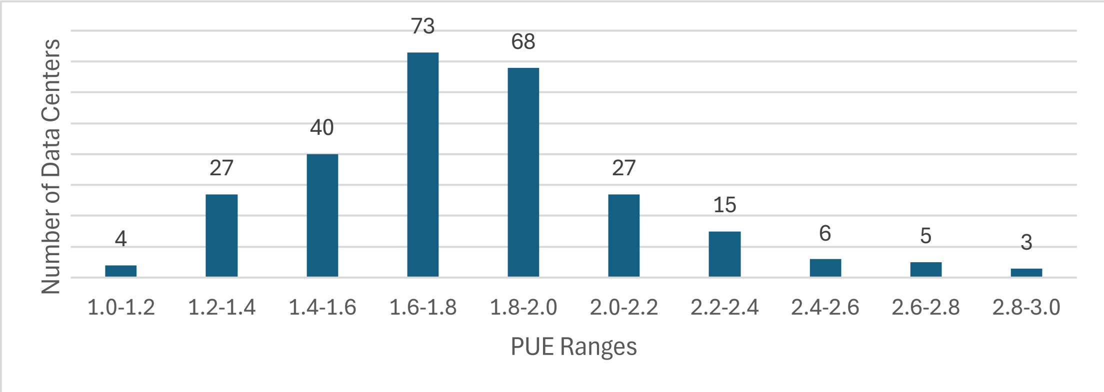
One of the case studies of successful international standards is the EU Code of Conduct on Data Center Energy Efficiency. This is a voluntary program managed by the Joint Research Center (JRC) of the European Commission, which targets data center owners and operators, as well as the supply chain and service providers. The program aims to inform and stimulate data center operators and owners to reduce energy consumption cost-effectively without hampering the critical function of data centers. The program has been successful since its start in 2008 [48].

The EU Code of Conduct on Data Center Energy Efficiency covers two main areas: IT Load and Facilities Load. The IT Load involves the amount of energy drawn by IT-related hardware. This includes servers, storage devices, and networking equipment. On the other hand, the Facilities Load is defined as the energy used by the supporting infrastructure. This covers elements like cooling systems, power distribution units, and lighting [48].

As for the participants in the program, there are two categories: participants and endorsers. The owners and operators of data centers can register as participants. Other stakeholders, such as vendors, consultants, and associations within the industry, can sign up as endorsers. As participants, they are expected to adhere to the Code's intent and put into practice its recommended best practices. Additionally, they are required to submit a report on their energy performance data every year. Endorsers are expected to promote the Code to their clients and support them in achieving its goals. Some well-known brands that have participated in the EU Code of Conduct on Data Center Energy Efficiency include Microsoft Corporation, Hewlett-Packard, Fujitsu Services, and IBM. Participants benefit from cost savings in implementing energy efficiency measures, as well as public recognition for their efforts to reduce energy consumption, which can enhance their reputation and attract new customers. In addition, participants are eligible for annual awards, which provide further recognition and can serve as a marketing tool for participants [48].

According to a 2018 report by the JRC of the European Commission, across the EU, 370 data centers have requested to join the EU Code of Conduct since the start of the program in 2008, and 329 have been approved as participants. In addition, there are 249 endorsers in the program. The majority of the participant data centers have achieved a PUE below 1.80, as shown in Figure 2.2.

Figure 2.2. Number of Data Centers per PUE Range of the EU Code of Conduct on Data Center Energy Efficiency



Data Source: Avgerinou, M., Bertoldi, P. and Castellazzi, L. (2017) [49]

Chapter 3.

Next Generation Data Center

Chapter 3. Next Generation Data Center

3.1. Concept of Next Generation Data Center

With surging demand for data center construction, information technology evolution, and low-carbon requirements, the data center industry is undergoing profound changes, and its development will enter a new era. What is a "next-generation data center facility" that meets the requirements of the new era? ASEAN governments have worked with data center industry leaders, and technology experts to extensively discuss industry and technology trends and reach many important consensuses, summarizing the four characteristics as Reliable, Simplified, Sustainable, and Smart.

1. Reliable: Reliable operation is the cornerstone of a data center. Through modular redundant architecture and AI active prevention, we can guarantee the safety and reliability of data centers at all levels, from components, equipment, and systems.
2. Simplified: In response to the increasing scale and complexity of data centers, the architecture and key subsystems are minimalist through hardware convergence.
3. Sustainable: Innovative measures are undertaken to build energy-efficient and low-carbon data centers benefiting society.
4. Smart: Responding to the O&M challenges of massive data centers and enabling facility autonomous driving with the help of digital and AI technologies.

3.2. Innovative Product and Solution

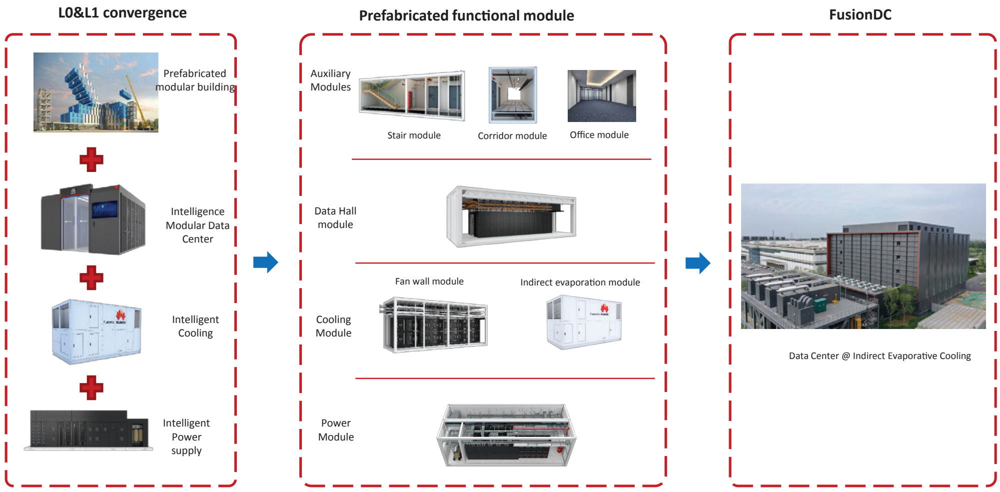
To achieve the features of the next-generation data center, the industry needs innovative products and solutions, which will be explored in this section.

3.2.1. Innovative Construction Technology

3.2.1.1. Prefabricated Modular Data Center (PMDC) to Shorten the Delivery Time

For green field large data center scenario, the PMDC is recommended. It integrates the civil engineering (L0) and mechanical and electrical engineering (L1) of the data center and uses the modular design for functional areas (Figure 3.1). The structural system, power supply and distribution system, HVAC system, management system, fire extinguishing system, lighting system, lightning protection and grounding system, and integrated cabling subsystems are pre-integrated with modules that are prefabricated and pre-commissioned in the factory. Large-scale civil engineering is not required onsite. In this way, the data center can be quickly constructed and deployed. PMDC has the following advantages: quick construction, flexible deployment, and high delivery quality. When PMDC is used, the construction period of a large data center (1000 cabinets), which usually takes more than 18 to 24 months, could be shortened to about 10 months (excluding the design period). In addition, with PMDC's flexibility, the construction can be carried out in stages and batches based on business and investment requirements to reduce investment risks. The PMDC adopts highly integrated assembly technology, which greatly reduces the consumption of water, electricity, and waste during construction. PMDC also utilizes the end-to-end integrated delivery mode to ensure the consistency of the entire system, reduces the influence caused by design changes and onsite construction, and provides better PUE and performance than the traditional mode. Compared with the traditional civil engineering mode, the carbon emission of the data center life cycle is significantly reduced.

Figure 3.1. Prefabricated Modular Data Center Solution



While the prefabricated all-in-one data center is designed for outdoor edge data center construction. It supports 6 to 8 cabinets of IT equipment (Figure 3.2). It pre-integrates the power supply and distribution system, cooling system, cabinet system, management system, and fire extinguishing system of a small-scale data center into a standard 40-foot or 20-foot container module, which means one container is one data center, and no building is required onsite. It enables quick data center delivery by prefabrication, pre-commissioning, and simplified onsite installation.

The prefabricated all-in-one data center is fully prefabricated in the factory. On-site deployment of data centers only requires simple water and electricity connection work. Customers do not need to construct buildings for the data center, which is time-consuming and requires the installation of complex electromechanical devices onsite. Therefore, deployment time is shortened by about 50%. Besides, the prefabricated all-in-one data center can be installed on the ground, rooftop, or steel platform, which helps customers avoid troubles in siting.

Figure 3.2. Appearance (top) and Layout (bottom) of All-in-One Data Center

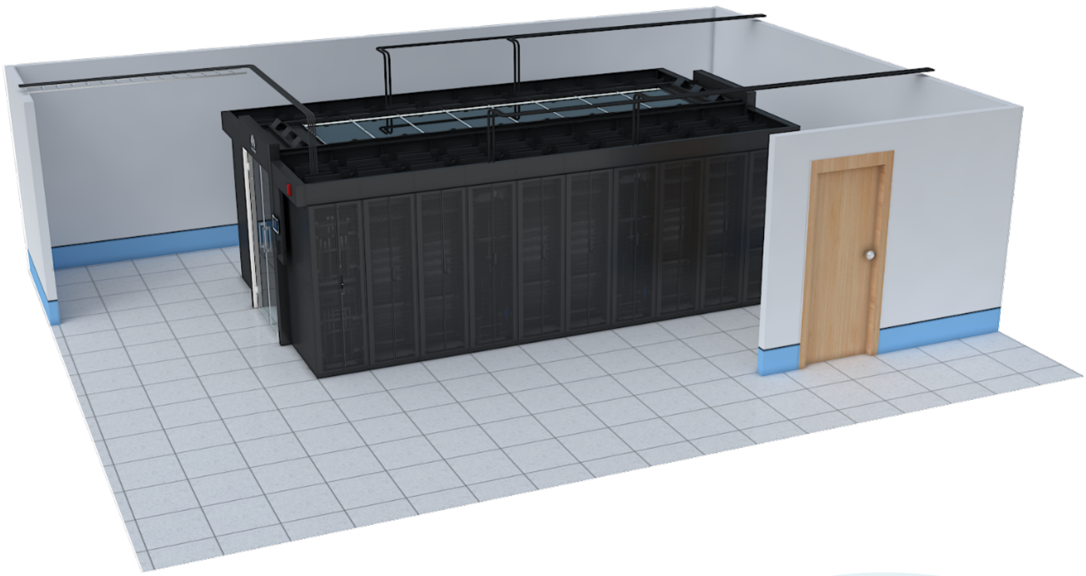
The prefabricated all-in-one data center implements visualized management, remotely monitoring the overall running and fault status. Intelligent algorithms help cooling products run in the optimal state.

In addition, the container module, which integrates customer service devices, has excellent structural performance, such as a 25-year lifespan, GR-63-CORE Zone 3 shockproof performance, 12-level wind resistance capability, and IP65 tightness level of dustproof and waterproof. It supports the long-term stable running of the data center in harsh outdoor environments. Therefore, the prefabricated all-in-one data center is the best solution for customers to quickly build edge data centers without buildings.

3.2.1.2. Modular Data Center (MDC) Solution to Build Qualified Data Center Quality

For the scenario of in-room medium and small data centers, the MDC solution is strongly recommended. It adopts the modular design and integrates the power supply and distribution, temperature control, cabinet, aisle, cabling, and monitoring systems into one module (Figure 3.3). Integrated designs, such as local cooling, cold and hot isolated aisle containment, high-efficiency UPS, and intelligently optimized temperature control system, improve data center energy efficiency and implement intelligent O&M management.

Figure 3.3. Appearance of Modular Data Center



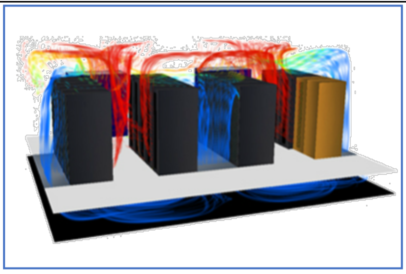
Although the MDC solution has been developed for about ten years, it has become the mainstream construction mode of small and medium data centers and is recognized for its high reliability and availability. With the increasing convergence of innovative applications of digital, communications, and AI technologies, MDCs are moving towards intelligence and full-lifecycle digitalization.

For customers who are interested in MDC solution, the MDC Standard published by EPI is recommended, which illustrates clear requirements for each function unit [50]:

- MDC Ratings
- Structural Subsystem
- Environmental Conditions
- Electrical Subsystem
- Mechanical Subsystem
- Cabling Subsystem
- Security Subsystem (if provided)
- Fire Safety Subsystem (if provided)
- Monitoring Subsystem (if provided)
- Administration Requirements

The standard also recommends the adoption of an integrated UPS (with a built-in Power Distribution Unit) to save space, and the battery should be housed in a separate room to enhance safety. The comparison between MDC and traditional data centers can be seen in Table 3.1.

Table 3.1. Comparison Between the Modular Data Center and the Traditional Data Center Solutions

Item	Modular Data Center	Traditional Data Center
		
Design	Low environmental requirements, no need for professional building	Need professional building
Deployment	7~10 days	30 days
PUE	Precision cooling PUE：1.2~1.5	In-room cooling PUE≥2.0
Power density per rack	5~30kW	≤7kW
Expansion	Flexible expansion, lower Initial investment	Flexible capacity expansion is not supported

Note: A small- and medium-sized equipment room with a maximum of 100 cabinets is used as an example.

To sum up, the micro-MDC solution deeply integrates the physical space of the equipment room and the prefabrication of core components, hence, greatly improving the reliability and user experience. It is the preferred solution for small- and medium-sized data centers to implement quick delivery, on-demand deployment, and energy savings.

3.2.2. Electrical Technology

3.2.2.1. Integrated Power Supply System to Save Space for IT Infrastructure

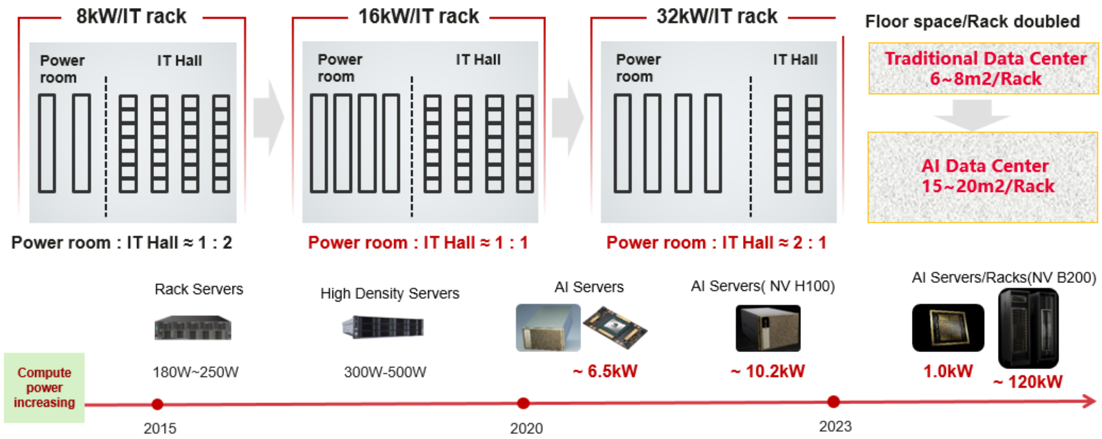
An integrated power supply system is an advanced innovative technical solution which can save land occupation for the power supply and distribution system, optimize energy efficiency, shorten the deployment time, and improve the engineering quality in large data centers. This technology, also called PowerPod, is a new generation of power supply and distribution products, which is integrated, safe, and reliable. PowerPod could be classified into indoor and outdoor based on application scenarios.

Outdoor PowerPod

The outdoor PowerPod can be used in many types of data center, including colocation data center, cloud, large-scale enterprise, and HPC. It improves the overall reliability of the power supply system via modular and predictive maintenance. The system could be equipped with AI function to predict the loosen of screws and the healthy state of the air circuit breakers. It also could predict the life time of the fan and direct current capacitor of UPS. These AI functions could help O&M engineers to realize predictive maintenance of the system to optimize the reliability.

As the IT power density going up, the power and battery room takes up much more spaces of the data center than before. If no innovation is implemented, the proportion of the power room to IT space is shown in the Figure 3.4. The proportion will increase to 2:1 with the power density of 32kW/IT rack, so moving the power room and battery room out of the data center building is becoming a preferred choice of AI data center operators.

Figure 3.4. Increasing Proportion of the Power Room to IT Space in Data Center



The outdoor Powerpod is an integrated solution for quickly constructing a low-voltage power supply system outside a data center building (Figure 3.5). Outdoor PowerPod is prefabricated in the factory, transported to the site as a whole, and can be put into operation after simple installation process (positioning, hoisting, fixing, connecting, and wiring). The outdoor PowerPod has low-voltage switchgear, UPS, feeder, busway, lithium iron phosphate (LFP) battery, cooling system, fire extinguishing system, lighting, access control and monitoring systems in a standard container (Figure 3.6).

Figure 3.5. Schematic Diagram of Outdoor PowerPod

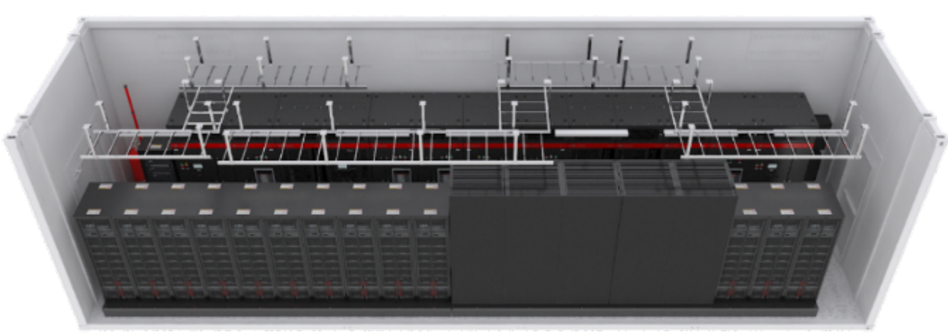
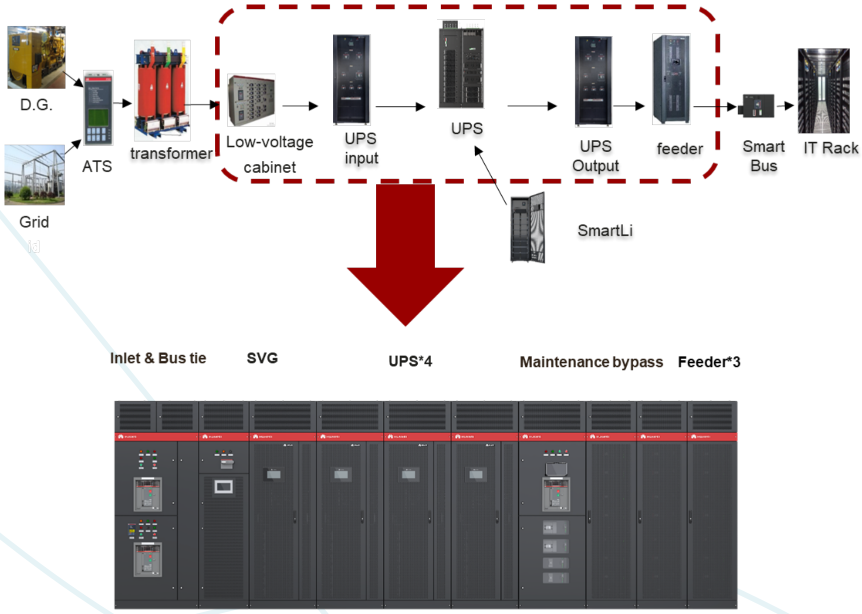


Figure 3.6. Schematic Diagram of PowerPod Power System



Outdoor PowerPod has the following advantages:

- **High efficiency:** The integrated design shortens the length of power supply and distribution links. With the high efficiency modular UPS and advanced ECO function (0ms transfer), the link efficiency reaches 97.8%. Compared with traditional solution, outdoor PowerPod could save USD 4.5 million within 10 years. (Assumption: data center size=20MW, load rate 50%, electricity charge at 0.12 USD/kWh, COP=3, traditional solution efficiency 94.8%)
- **Small footprint:** With compact design, innovative architechture design and innovative switchgear, PowerPod could help to reduce the footprint of the power supply and distribution system by 30-40%.
- **Fast deployment:** The power distribution cabinet, UPS, battery, and air conditioner are pre-integrated in the high-strength container. Test and joint commissioning of the PowerPod is implemented in the factory. Greatly reducing the on-site acceptance and commissioning time, the system could be put into operation after simple installation steps at site. If the data center adopts modular desgin, it could shorten the deployment time from 18~24 months to 10~12 months. One of the example of this implementation is in a colocation service provider in Johor, Malaysia, which was delivered within 10 months.
- **Intelligent:** The system monitors and manages the power supply and distribution system by link, learns the system running status in real time, and quickly locates and maintains faults. In addition, with AI function, the system provides the

warning function to implement proactive O&M and prevent faults before they happen.

- **Reliable：** Each PowerPod is physically isolated and a safe distance is reserved, ensuring security and reliability.

Below are the recommended configurations for the outdoor PowerPod:

- **Container**: Based on the environment characteristics, construction capability, standards, space utilization, transportation and hoisting convenience of ASEAN countries, the 40ft container are recommended. Stress analysis and earthquake resistance shall be fully conducted during design. The suggested distance between each outdoor PowerPOD is 2m, while the the distance between PowerPod and datahall is 3m.
- **Capacity**: In order to make full use of container space and cost considerations, it is recommended that the outdoor PowerPod adopts the following configuration to match the 2500 kVA and 2000 kVA transformer.

Table 3.2. Recommendation on Outdoor PowerPod Capacity

Transformer	IT only	IT+Mechanical
2500kVA	2.4MVA (4*600KVA UPS)	2.4MVA [3*600KVA UPS (IT)+1*600KVA UPS (MECH)]
2000kVA	1.8MVA (3*600KVA UPS)	1.8MVA [2*600KVA UPS (IT)+1*600KVA UPS (MECH)]

- **Firefighting system**: Different countries have different fire regulations. Fire protection design must comply with local laws and regulations. Gas firefighting system is recommended.
- **Cooling system**: The DX air cooling system and N+1 redundancy are recommended because it is simple, can be delivered quickly, and has no risk of water entering the power room. The PowerPod should be able to work normally under the highest temperature of the country's last 20 years record.
- **Power system**: Modular UPS and busway connection are advised to be adopted in the power system to realize high efficiency and easy maintenance. To improve the reliability of the power system, temperature sensors should be installed near the joint points between the horizontal main busbar and the vertical busbars, and the external cable terminals of the input and output breaker.
- **Batteries**: 10 minutes backup time for LFP batteries with high energy density and safety are recommended. Batteries and the UPS should be deployed in the same container. Cables between the UPS and batteries are pre-integrated in the factory to achieve quick delivery.
- **Management:** The monitoring screen could be mounted on the external surface of the PowerPod to realize simple management without entering the container.

The single line diagram, 3D device view, working status, and alarm information can be displayed in the monitoring screen of PowerPod.

Indoor PowerPod

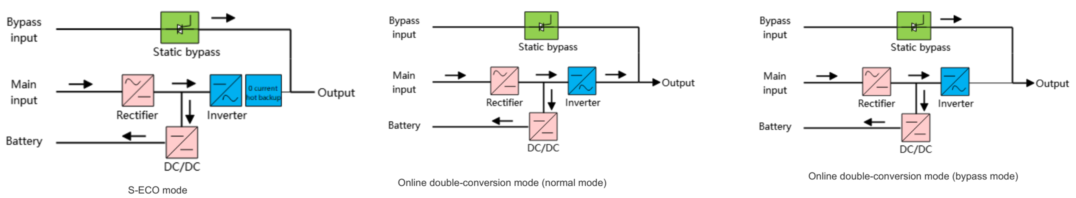
If the power room is located inside a data center building, then indoor PowerPod will be used. The indoor PowerPod includes low-voltage distribution cabinets, reactive power compensation, UPS and feeder cabinets, inter-cabinet copper bars, and monitoring systems. Different from outdoor PowerPod, the indoor one does not contain battery system, cooling system, fire extinguishing system, lighting system, and access control function. Similar to outdoor PowerPod, the advantage of indoor PowerPod could also be summarized as high efficiency, small footprint, fast deployment, high intelligence, and high reliability.

3.2.2.2. Advanced ECO Mode to Save the UPS Consumption

Uninterruptible power supply (UPS) is a device that uses power electronic technology to isolate and convert power. It can provide continuous and high-quality alternating current power supply for loads. Currently, UPS' efficiency in the industry has greatly improved. It is recommended that UPS with the claimed double conversion efficiency of more than 96% be used in new and reconstructed data centers. In the 2N architecture and redundancy design, which contains double the amount of equipment needed that runs separately, the load rate of a single UPS in a data center does not exceed 40% during normal operation. Generally, the UPS runs at a light load rate of 20% to 30% for a long time. Therefore, improving UPS efficiency at a low load rate is critical. In addition, the modular UPS uses module-level hibernation technology to improve efficiency further under light load. In addition, the modular UPS uses the fully redundant architecture and hot swapping of modules to rectify faults within five minutes, improving system availability.

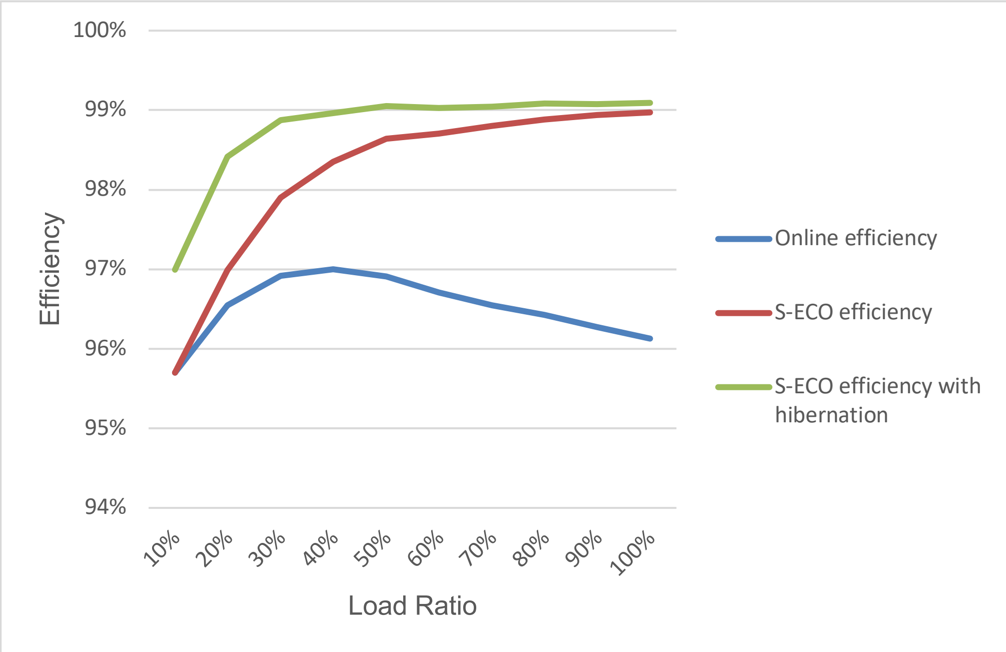
The UPS has three modes: mains, bypass, and battery (Figure 3.7). During traditional UPS operation, the UPS preferentially works in mains mode and switches to bypass mode in special working conditions such as overload. In this mode, the rectifiers and inverters of the UPS run with loads. Therefore, the system loss in the mains mode is relatively high.

Figure 3.7. UPS Operation Modes



To further improve the UPS operating efficiency, the industry proposed the concept of eco mode more than ten years ago. That is, the UPS runs in bypass mode first when the mains quality is good. When the mains quality exceeds the limit, the system automatically switches back to the mains mode. However, the traditional ECO function has about 10 ms interruption when the system switches back to the primary path. Therefore, the ECO function has no commercial value for data center users. While the S-ECO mode in the industry effectively solves this problem by implementing 0 ms transfer. In addition, the UPS can actively compensate for harmonics in the bypass mode. When harmonics exist in the load, the harmonic current of the load can be compensated to meet the harmonic requirements of the power grid. To sum up, this S-ECO mode combines 99% efficiency, harmonic compensation, and 0 ms transfer and is recommended for scenarios that require high energy efficiency.

Figure 3.8. High Performance UPS Efficiency Curve Under Different Operation Modes



Considering the different levels of the power quality of each country of ASEAN, it is recommended the grid power quality be compliant with the following requirements to let the UPS work in advanced ECO mode:

- Voltage range: nominal voltage±10%;
- Frequency range: 50Hz/60Hz±2%;
- The total harmonic distortion rate of the power grid voltage (THDv) is within 8%.

3.2.2.3. LFP Battery to Save Space and Prolong Lifetime

In the power supply system, the battery provides a power supply for loads before the mains are abnormal, and the diesel generator starts and runs at full load. Currently, lead-acid batteries and lithium-ion batteries are used in industry. Either adopting the PowerPod or UPS in a data center, a Li-ion battery is a good choice to save space and total cost of ownership. Lithium batteries have the advantages of long service life, high power density, small footprint, and low load-bearing requirements compared with lead-acid batteries. Lithium batteries are gradually becoming the mainstream choice in new data centers.

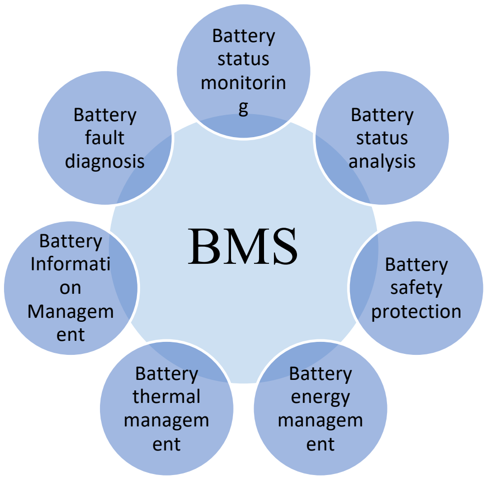
Reliability is the top priority for data centers, and so is the battery system. Data centers have strict requirements on battery safety and quality, and the probability of battery leakage, bulging, or even explosion is minimized. For reliability, the voltage or internal resistance of batteries in series in a data center must be the same. If the voltage or internal resistance is unbalanced, some batteries will fail, and the battery group will fail to supply power.

In order to ensure the safe application of lithium batteries, five level safety design is strongly recommended.

1. **Cell-level safety:** Choose an appropriate cell type to realize cell-level safety.
    - **Stable molecular structure:** The molecular olive-shaped three-dimensional structure makes LFP more stable than NCM's layered two-dimensional structure.
    - **Higher thermal runaway temperature:** The thermal runaway temperature of LFP battery is about 250C°, much better than ternary polymer lithium battery's 180C°.
    - **Does not release oxygen:** LFP battery does not release oxygen elements during thermal runaway which NCM battery does.
2. **Module-level safety:** Emphasize insulation and production process to realize module-level safety.
    - **Insulation:** All plastic Insulated cabin level casing to protect the module.
    - **Production process:** Prevent foreign object intrusion and mechanical deformation during production.
3. **Pack-level safety:** Design pack level fire protection and pack level short circuit protection to realize pack-level safety.
    - **Fire Protection:** The pack level fire extinguishing device is necessary to suppress cell level thermal runaway faults.
    - **Short Circuit Protection:** Pack-level built-in fuse to isolate the battery pack out of the string is very necessary to enhance pack- level safety.
4. **Cabinet-level safety:** Design physical protection and electrical protection to realize cabinet-level safety.
    - **Physical protection:** The ingress protection level of the cabinet should be IP21 rating to prevent water from dripping into the cabinet.
    - **Electrical protection:** Cabinet-level circuit breaker to isolate the battery string is essential to ensure cabinet-level safety. In addition, the leakage current protection function is very important to protect the battery from battery leakage.
5. **System level safety:** Configure an excellent battery management system (BMS) to realize system-level safety. An excellent BMS can not only monitor the healthy state of the battery, but also protect batteries through intelligent control functions. The

typical functions of BMS are shown in Figure 3.9. The BMS should have leakage current detection and protection functions to protect the system.

Figure 3.9. BMS Typical Functions



3.2.3. Mechanical Technology

3.2.3.1. High-Temperature Chilled Water Fan Wall Reduced the Power Consumption of Chiller

The high-temperature chilled water fan wall increases the chilled water temperature to improve the cooling efficiency and reduce the PUE, OPEX, and carbon emissions. The working principle is as follows (Table 3.3).

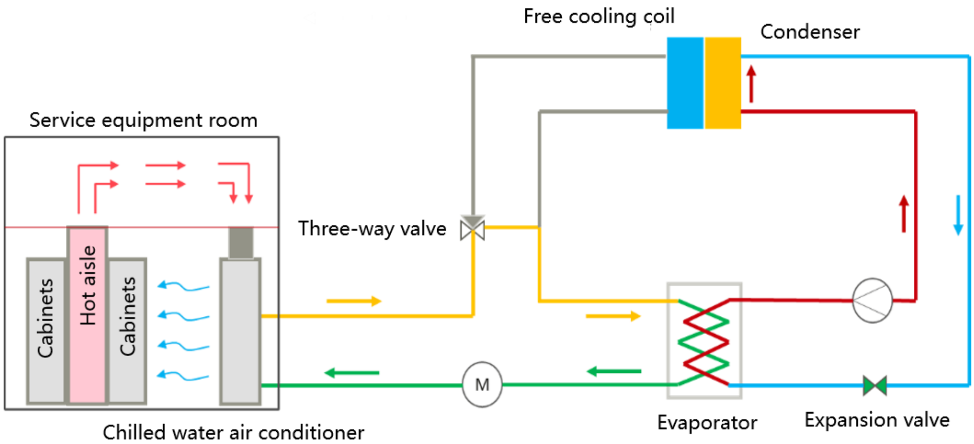
Table 3.3. Water Temperature and Cooling Efficiency

Supply Water Temperature	Return Water Temperature	Chiller Efficient
15	23	A%
16	24	A+3%
17	25	A+6%
18	26	A+9%
19	27	A+12%
20	28	A+15%

The high-temperature chilled water fan wall system consists of the air conditioner terminal in the equipment room and the cooling units outside the equipment room. The chillers outside the equipment room consist of the air-cooled chilled water system and the water-cooled chilled water system.

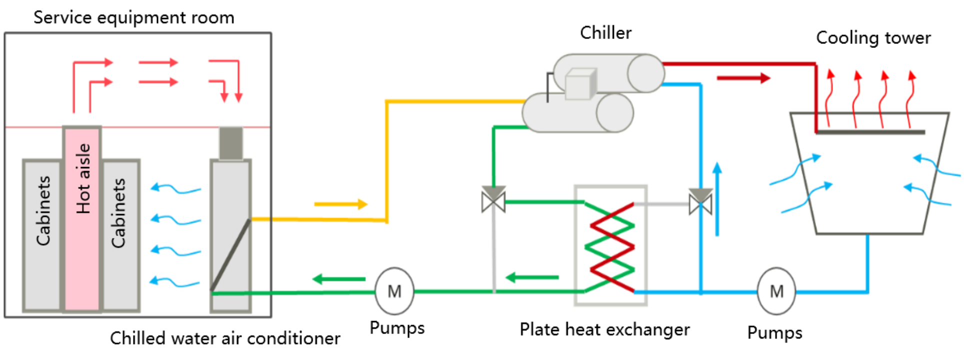
In the air-cooled chilled water scenario, the cooling equipment includes air-cooled chillers and chilled water precision air conditioners (Figure 3.10). The air-cooled chillers use natural cooling coils to bear part or all the indoor heat load and pump the chilled water to the end of the air conditioner. Heat exchange is used to take the heat generated by IT devices out of the equipment room.

Figure 3.10. Air-Cooled Chilled Water Cooling Scenario



In the water-cooled chilled water scenario, the cooling equipment in the room (including the terminal air conditioner, sealed air duct and pipe, and fresh air system) deliver the cooling source to the IT equipment and uses the heat exchanger to transfer the heat generated to the outdoors. While outside the equipment room, there are cooling towers, chillers, and heat exchangers to produce cold water to cool the return water (Figure 3.11).

Figure 3.11. Water-Cooled Chilled Water Cooling Scenario



3.2.3.2. Fan Wall Air-Cooled to Save Water and Shorten 50% Deploy Time

Fan wall air-cooled series room-level smart cooling is suitable for medium and large data centers that can support high-density cabinets up to 20+ kW, to realize high efficiency, high reliability, and fast deployment. It includes an indoor unit and an outdoor unit, with a fan wall horizontal air supply design (Figure 3.12). It is easy to install and expanded with prefabricated indoor and outdoor units. It can shorten the deployment time by at least 50%.

The technology needs no water in the refrigeration process, so it is very suitable for water-scarce areas. If humidification function is required, wet film humidification technology is recommended to implement energy-free humidification. In addition, the high-efficiency variable-frequency drive compressor can implement 10% to 100% stepless cooling capacity adjustment and intelligently match the load requirements.

The technology could endure harsh environments (maximum ambient temperature of 55°C), which ensures that precision equipment such as communication equipment and computers are in a reliable and safe operating environment.

Figure 3.12. Appearance of Fan Wall Air-Cooled Indoor/Outdoor Unit

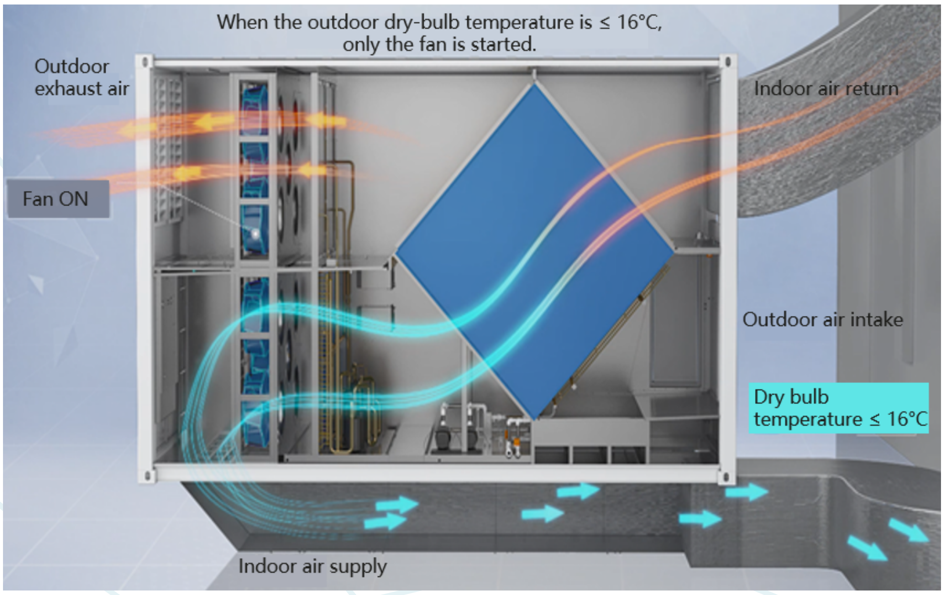
3.2.3.3. Indirect Evaporative Cooling to Reduce PUE by Maximizing the Natural Cooling Use

Indirect evaporative cooling refers to the technology using the temperature difference between dry and wet bulbs to transfer the cooling capacity from the wet low-temperature air (obtained by direct evaporating) to the hot air by non-contact heat exchangers. The indirect evaporative cooling system uses a large capacity indirect evaporative cooling device to cool the data center. The cooling capacity comes from outdoor low-temperature air. When the outdoor temperature is high, the spraying system or compressor will be turned on to produce more cooling capacity. In the whole year, the evaporative cooling system has three operating modes: dry mode, wet mode, and hybrid mode.

Dry Mode

When the outdoor temperature is lower than a certain value, the unit runs in dry mode to meet the cooling requirements of the equipment room (Figure 3.13). In this case, the system only turns on the indoor and outdoor fans to remove the heat from the equipment room. Outdoor air does not directly contact the air from the equipment room. Heat exchange between outdoor cold air and indoor hot air is realized through the air-to-air non-contact heat exchanger. This way, pollution of outdoor air will not affect indoor air.

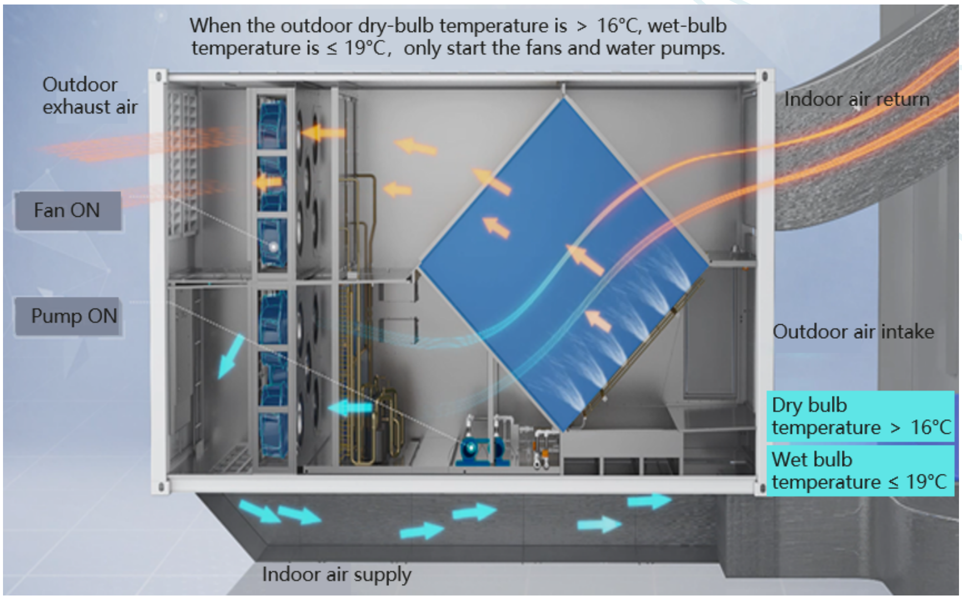
Figure 3.13. Dry Mode Operation Diagram



Wet Mode

When the outdoor environment is higher than the wet mode starting temperature, the unit operates in wet mode (Figure 3.14). At this time, the water pump and water spraying system starts to operate to absorb air's heat by the evaporating of water mist to cool the air.

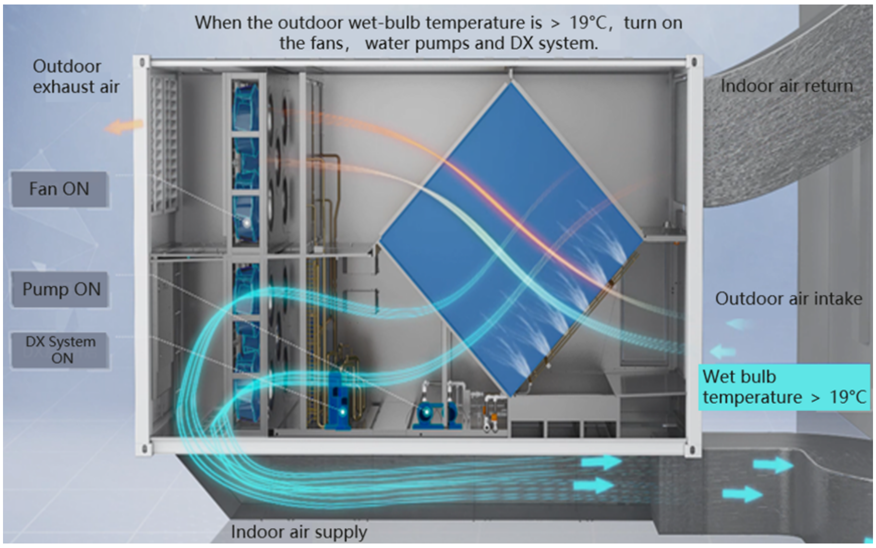
Figure 3.14. Schematic Diagram of Wet Mode Operation



Hybrid Mode

When the outdoor temperature is higher than the start temperature of the wet mode and secondary cooling mode, the unit operates in wet mode and the compressor and water pump are started (Figure 3.15). The DX system cools the indoor air after air-to-air heat exchange again to meet the temperature requirements of the equipment room.

Figure 3.15. Hybrid Mode Operation Diagram



In addition, the three operating modes can combine meteorological parameters and the characteristic curve of the unit itself, and utilize intelligent control to optimize to achieve energy saving.

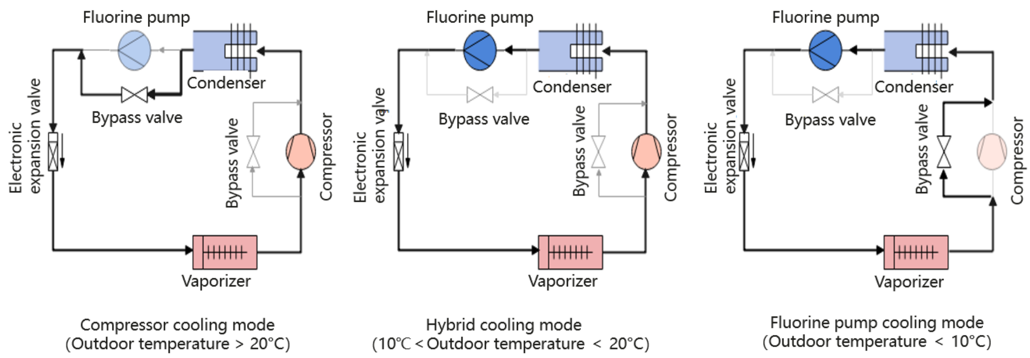
3.2.3.4. Fluorine Pump to Maximizes the Use of Natural Cooling to Reduce Power Consumption

Fluorine pump technology is a kind of natural cooling technology that uses a pump to drive freon working medium and overcomes system resistance to realize the refrigeration cycle. Because the working medium used in the fluorine pump is refrigerant, the fluorine pump is also called refrigerant pump.

The core of the fluorine pump technology is the use of natural cooling sources. Its application is closely related to the special cooling requirements of data centers. Different from traditional buildings, data centers still generate a lot of heat in winter or transition seasons. In this case, the fluorine pump system is used to replace the traditional compressor mechanical cooling system for cooling. It can effectively save energy and reduce consumption and carbon emissions.

In a data center, a fluorine pump refrigeration system and a mechanical refrigeration system that contains a compressor are usually connected in series to form a complete refrigeration cycle system. According to the change in outdoor temperature, the system can work in three modes, namely compressor refrigeration mode, hybrid refrigeration mode, and fluorine pump refrigeration mode. The system cycle of the three modes is shown in Figure 3.16. When the outdoor temperature is > 20°C, the compressor is turned on, the fluorine pump is bypassed, and the circulation of the system is in the traditional compressor refrigeration mode. When the outdoor temperature is > 10°C and < 20°C, the fluorine pump and compressor are turned on at the same time, and the system is in hybrid mode, also known as fluorine pump pressurization mode, to achieve the effect of energy-saving in the transition season. When the outdoor temperature is less than 10°C, the compressor is closed, and the fluorine pump is started.

Figure 3.16. Working Mode System Diagram of Fluorine Pump Energy Saving System

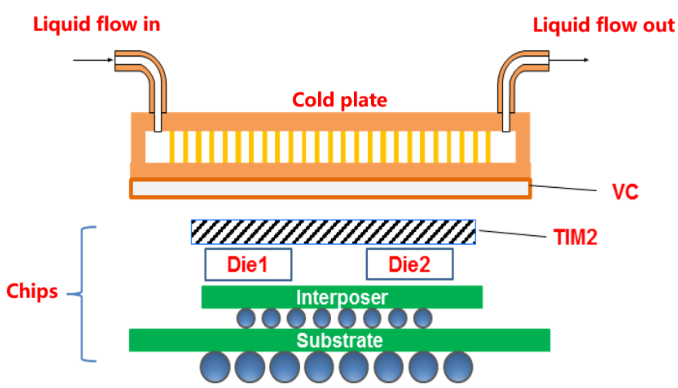


3.2.3.5. Liquid Cooling for High Power Density Scenario to Save Energy and Lower Noise

Clod Plate Liquid Cooling

Cold plate liquid cooling technology uses working fluid as the medium of intermediate heat transfer, which is heat from the hot zone to the remote for cooling (Figure 3.17). In this technology, the liquid is separated from the object to be cooled, and the working liquid does not have direct contact with the electronic device but transfers the heat of the object to the liquid through a high-efficiency heat conduction component such as a liquid cooling plate. Therefore, the cold plate liquid cooling technology is also referred to as an indirect liquid cooling technology. Because the specific heat of liquid is larger than that of air, the heat dissipation speed is much higher than that of air, so the refrigeration efficiency is much higher than that of air-cooled heat dissipation. This technology can effectively solve the heat dissipation problem of high-density servers, and reduce the energy consumption and noise of the cooling system.

Figure 3.17. Working Mode System Diagram of Fluorine Pump Energy Saving System



Immersive Liquid Cooling

The data center immersion liquid cooling technology can be divided into single-phase immersion liquid cooling and two-phase immersion liquid cooling based on whether the phase change occurs during the heat exchange of the coolant. The energy consumption of submerged liquid cooling in data centers is mainly derived from pumps and outdoor cooling equipment that facilitate liquid circulation. Because the outer side of the submerged liquid cooling room is usually high-temperature water, the outdoor cooling equipment can usually use natural cooling sources and is not restricted by the site selection area, thereby achieving the purpose of energy saving and emission reduction.

Figure 3.18 shows the technical principle of single-phase immersion liquid cooling. The server is completely immersed in insulating coolant, which takes away the heat generated by the server and circulates the heat to the secondary side refrigerant (usually water) in the heat exchanger. The secondary side refrigerant absorbs heat and then transfers heat to the outdoor cooling device through circulation. In this way, heat transfer from the server to the outdoor environment is completed.

Figure 3.18. Principle of Single-Phase Immersion Liquid Cooling

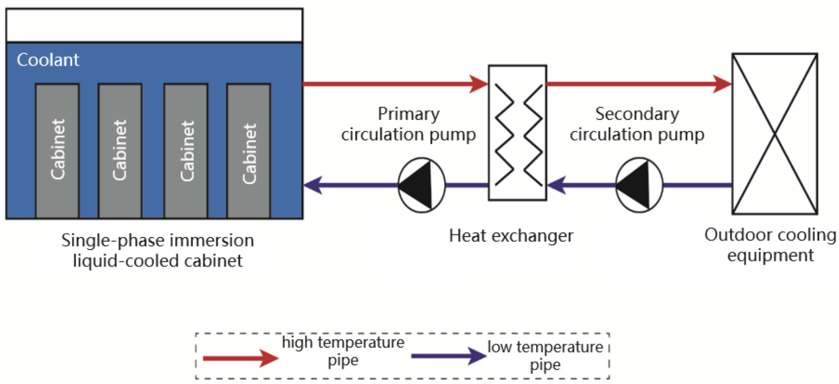
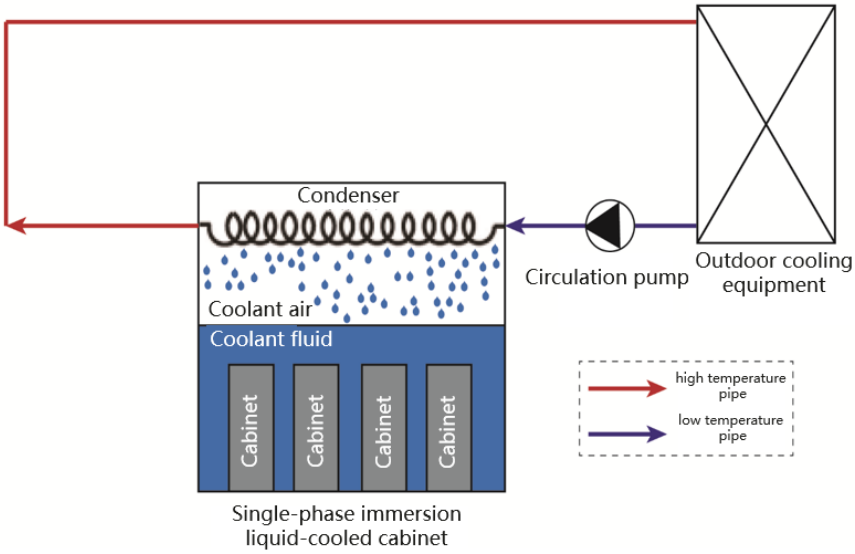


Figure 3.19 shows the technical principle of two-phase immersion liquid cooling. The server is completely immersed in the insulating coolant, and the heat generated by the server causes the coolant to boil locally, during which the coolant becomes a gas phase working medium and takes away the heat generated by the server. The gas phase working medium rises continuously, and after encountering the condenser, heat is transferred to the water in the condenser, which becomes droplets and returns to the liquid cooling cabinet. After absorbing heat, the water circulates heat to the outdoor cooling device, and heat transfer from the server to the outdoor environment is completed.

Figure 3.19. Principle of Two-Phase Submerged Liquid Cooling Technology



3.2.3.6. Comparison and Analysis of Technical Features

Table 3.4. The Comparison and Analysis of Technical Features

The Scheme	High-Temperature Chilled Water	Fan Wall Air-Cooled	Indirect Evaporative Cooling	Fluorine Pump	Cold plate liquid cooling	Immersion Liquid Cooling	Immersion Liquid Cooling
Average Annual PUE	1.42	1.40	1.32	1.41	1.20	1.19	1.11
Peak PUE	1.51	1.55	1.52	1.57	1.32	1.29	1.2
WUE	2.1 (peak: 3.5)	0	0.76 (peak value 2.5)	0	2.1 (peak: 3.5)	2.1 (peak: 3.5)	1.72 (peak: 3.13)
CAPEX	A	0.8A	0.85A	0.75A	2A	5A	5A
System Complexity	The chiller, cooling tower, water pump, pipeline, and valve are composed of multiple components. The system is complex and difficult to control and manage.	Simpler	Simpler	More complex	The chiller, cooling tower, water pump, pipeline, and valve are composed of multiple components. The system is complex and difficult to control and manage.	More complex, cold tower, water pump, pipeline and other components, but no chiller, relatively simple.	More complex, cold tower, water pump, pipeline and other components, but no chiller, relatively simple.
Difficulty of Controlling	Complexity	Simple	Simple	Simple	Complexity	Simple	Simple
O&M Complexity	Complexity	Simple	Simple	Simple	Complexity	Complexity	Complexity
Reliability	Meets requirements of Tier I-IV. A single fault may have a large impact.	Meets requirements of Tier I-IV. Small impact of a single fault	Meets requirements of Tier I-IV. Small impact of a single fault	Meets requirements of Tier I-IV. Small impact of a single fault	Unable to meet the requirements of Class A or Tier III&IV equipment rooms	Unable to meet the requirements of Class A or Tier III&IV equipment rooms	Unable to meet the requirements of Class A or Tier III&IV equipment rooms
Delivery Period	Long, the refrigeration station needs to install a lot of equipment and engineering quantity, and the commissioning time is long.	Short	Short	Short	Long, the refrigeration station needs to install a lot of equipment and engineering quantities, and the commissioning time is long.	Long, the refrigeration station needs to install a lot of equipment and engineering quantity, and the commissioning time is long.	Long, the refrigeration station needs to install a lot of equipment and engineering quantity, and the commissioning time is long.
Architectural Adaptability	Well, the freezing station is flexible, the basement is OK, and the pipeline is long.	Generally, sufficient outdoor unit installation space should be provided, and the distance should not be too far.	Poor. Plan in advance to ensure that the building, equipment, and air distribution match.	Generally, sufficient outdoor unit installation space should be provided, and the distance should not be too far.	Well, the freezing station is flexible, the basement is OK, and the pipeline is long.	Well, the refrigeration station is flexible, the basement is OK, and the pipeline is long.	Well, the refrigeration station is flexible, the basement is OK, and the pipeline is long.

Note: Calculation model in the preceding table: 12 MW data center in Singapore

With the rapid development of cloud, AI, and intelligent computing services, the server density increases, posing higher challenges to cooling. Based on the power density, the recommended cooling solutions differentiated by end type are shown in Table 3.5.

Table 3.5. Recommended Cooling Solutions Based on the Power Density

Typical Scenario	IT Power Density	Adapting the Cooling Solution	Recommended Solution
Enterprise Data Center	<=5kW/R	In-room cooling, In row cooling	In-room cooling
Cloud Data Center	>5kW/R, <=20kW/R	In-row cooling, indirect evaporative cooling, Fan wall chilled water, Fan Wall Air-cooled	Fan wall chilled water Fan Wall Air-cooled
Computing Data Center	>20kW/R, <=35kW/R	Air-liquid fusion solution, In-row cooling, and immersion cooling	Air-liquid fusion solution (Liquid: cold plate liquid cooling, air: chilled water fan wall/air-cooled fan wall/indirect evaporative cooling)
High-Performance Computing Data Center	>35kW/R	Cold plate liquid cooling, submerged liquid cooling	35–50 kW/R. Cold plate liquid cooling is recommended. Submerged liquid cooling is recommended for >50 kW/R.

3.2.4. Management System

The traditional data center management system is only a power and environment monitoring system. It only monitors but does not control the system. It relies on manual experience to determine whether hidden dangers exist. This method is inefficient and error prone. It cannot ensure the security of invisible pipes and devices.

In recent years, data center O&M personnel have been in short supply, and labor costs are high. Resource usage and planning are managed manually, which is a waste of resources. In addition, the energy consumption of the data center remains high. According to the Uptime Institute Global Data Center Survey 2022, the average PUE of the existing large data centers is as high as 1.55, the energy consumption of the cooling system accounts for more than 25%, and the energy consumption of the power supply system accounts for about 8%. In other words, in the data center, in addition to IT equipment, the main energy consumer is the cooling system. Therefore, reducing the energy consumption of the cooling system by effective means is the key to reducing the PUE.

The intelligent data center management system can implement centralized monitoring and smart management of devices in the data center facility. It integrates advanced technologies, such as AI, big data, and 3D to provide functions like digital visualization, automatic energy saving, automatic O&M, and intelligent operation, helping customers maximize the value of data center.

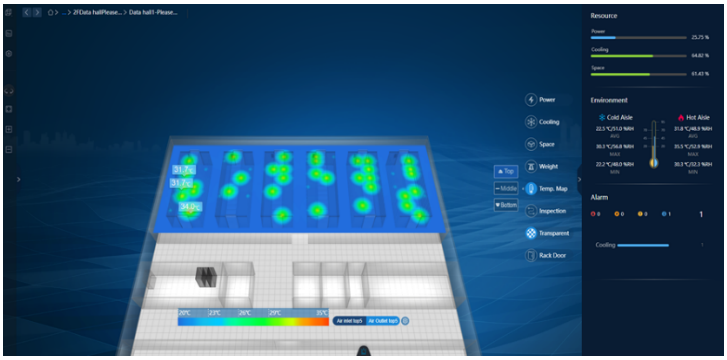
3.2.4.1. Digital Visualization for a Better Intelligent Experience

To implement intelligent data center management, technologies such as 3D, digital large screen, and temperature cloud map can be introduced to provide a visualized management platform for data center infrastructure, implementing "what you see is what you get", helping O&M personnel better understand the data center running panorama and control the overall situation (Figure 3.20-3.22).

Figure 3.20. Digital Large Screen

Figure 3.21. 3D Global Resource Visualization

Figure 3.22. Identifying Local Hotspots in the Equipment Room by Temperature Map



3.2.4.2. AI Energy Optimization to Reduces the Energy Consumption by 8%-15%

In terms of energy efficiency optimization, the federated learning algorithm, Deep Neural Network and big data technologies are used to monitor, diagnose, adjust, and optimize data center energy consumption based on the outdoor ambient temperature and IT load running status (Figure 3.23). Inferring the optimal cooling parameter combination in real time and delivering the combination to the local teamwork control system can effectively reduce the PUE of the data center. According to the test results, the industry-leading AI energy-saving technology can effectively reduce the PUE of data centers by 8% to 15%.

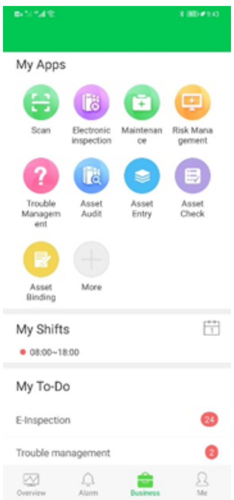
Figure 3.23. AI-based Energy Efficiency Optimization Technology

3.2.4.3. Digital and Intelligent Methods Effectively Improve O&M Efficiency

Digital and intelligent technologies are used to reconstruct data center O&M activities, standardize O&M activities, and reduce manual involvement. In this way, O&M quality and efficiency are greatly improved. The O&M can be implemented based on the following aspects:

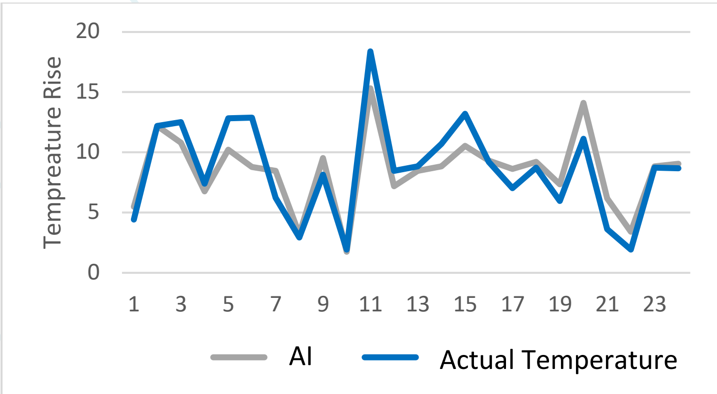
- **Mobile O&M**: Expert experience is delivered to the mobile terminals of O&M personnel in real-time to remotely guide O&M operations, reducing the probability of manual errors in onsite operations and lowering the skill requirements for O&M personnel

Figure 3.24. Mobile O&M App



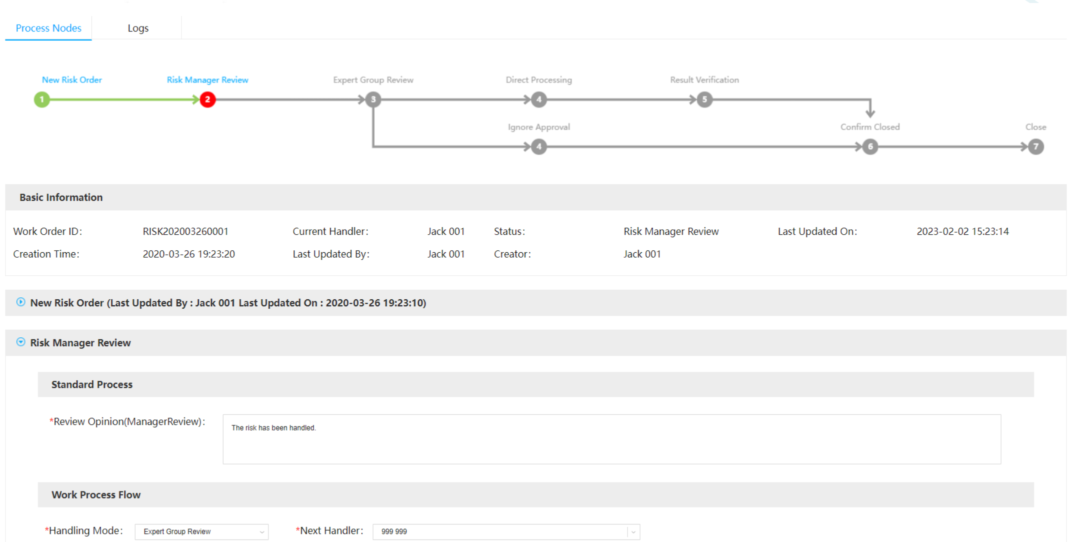
- **Predictive maintenance**: In a data center, predictive maintenance is a policy that uses big data and AI algorithms to monitor and analyze the running status of devices in real-time, to predict and diagnose faults in advance. For example, in a power transformation and distribution system, the temperature rise model and the copper bar contact current, ambient temperature, and adjacent contact temperature information are used to obtain a reasonable temperature under the current load (Figure 3.25). When the measured temperature of contact exceeds the reasonable temperature, it indicates that the temperature of the contact point is abnormal. An overtemperature warning is used to remind O&M personnel to rectify the fault in a timely manner, preventing power interruption caused by high-temperature fire.

Figure 3.25. AI Predicts the Temperature of Power Supply and Distribution Links and Generates Warnings to Prevent Fires due to High Temperatures



- **Closed-loop risk management**: Abnormal items detected during O&M can be closed through process work orders (Figure 3.26). The system traces and drives the closure of risks from creation, review, owner assignment, and closure, preventing accidents from affecting services. In addition, you can import the corresponding process field file in the process configuration as required to customize the process configuration.

Figure 3.26. Process Work Order Management

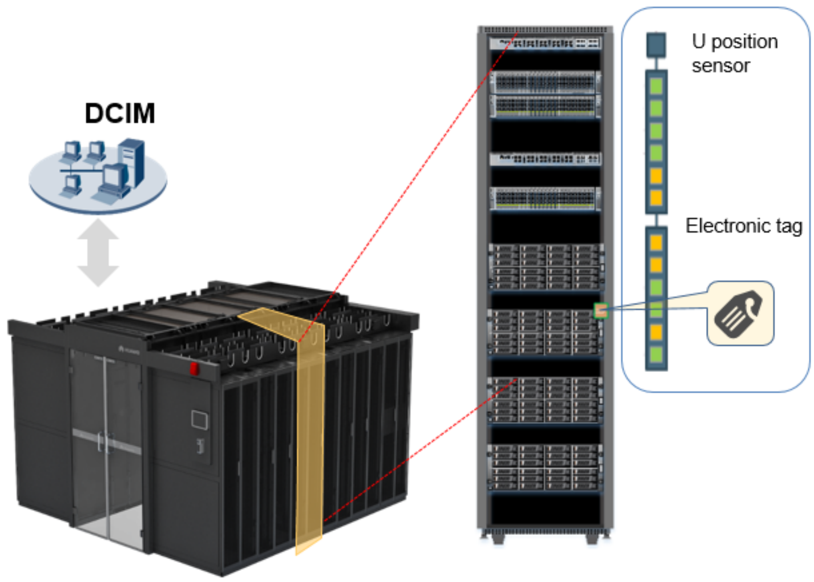


To sum up, the preceding measures can greatly simplify O&M, consolidate expert experience, and lower the requirements for personnel skills. In this way, the O&M labor cost of a single cabinet is greatly reduced, and the O&M efficiency is improved.

3.2.4.4. Intelligent Operation Methods Improves Resource Utilization

In terms of asset capacity management, the data center management system should provide the asset lifecycle management from asset warehousing, installation, and maintenance, to return, intelligent planning of equipment room capacity, visualized and manageable data center resources, and effectively improving resource utilization (Figure 3.27). U-bit electronic labels can be carried out to eliminate manual counting of core assets. AI algorithms can also be used to intelligently analyze the SPCN (space, power, cooling capacity, and network) capacity of a data center and generate the optimal seat recommendation solution, avoiding capacity stranding and maximizing the value capacity of the data center.

Figure 3.27. U-Position Sensors for Automated Asset Inventory



Chapter 4.

Policy Recommendation for ASEAN Member States

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4.1. Mature Market

4.1.1. Establish Leading Standards

Utilizing available international standards and advanced technology would ensure uniformity and efficiency in the implementation of the next-generation data center. Learning from the mistakes of other similar countries may avoid the same problems they face and make the implementation of ASEAN safer and faster. Using international standards may also standardize the standards and guidelines between AMSs.

However, it is important to consider the different conditions in ASEAN compared to the conditions of international best practices. A proper assessment will be required to ensure the standards implemented in ASEAN are feasible and optimized for the region. As mentioned in Section 2.2, Singapore has some data center guidelines and best practices that may serve as a valuable reference point that could be adopted and applied across other AMSs.

Many mature data center markets in the world have implemented policies directed specifically toward data center operations. An example of standardized regional policies is data center regulations in the EU. However, some of the regulations are still only voluntary but implement methods for incentivizing private operators to follow these regulations. The EU has three policies that support sustainable development and energy regulation of data centers. While these policies have been implemented, improvements and adjustments are still being made.

The EU Code of Conduct for Energy Efficiency in Data Center is a set of voluntary guidelines for private data center operators, launched in 2008. Under these guidelines operators who join are eligible to be awarded EU CoC annual awards. Another set of guidelines is currently being explored, under the EU Green Public Procurement (GPP) Criteria for Data Centers, Server Rooms, and Cloud Services. These criteria will directly address the efficiency of performance in data centers. Regulation EU 2019/424 is a legally binding legislation that outlines eco-design and data center products that address energy and resource efficiency. Under these guidelines and regulations, all countries within the EU are obligated to follow any regulations required and can follow best practices guidelines best suited for the region.

4.1.2. Promote Innovation and Knowledge Sharing

The public framework of data centers in ASEAN could be shaped to encourage innovation and follow best practices, for example through pilot projects. Due to the specific requirements of data center operations because of the humid and tropical conditions in ASEAN, regional-specific practices will be required. Some international practices may not be feasible in the ASEAN region. Collaboration between the private sector, government, and academia is necessary for continued development.

The government of a mature data center market could invest in research and development, and provide support to public universities and research institutions towards this goal. Additionally, a regional framework to facilitate information and best practices sharing would significantly aid in this goal. This would maximize the resources of each AMS in fast deployment.

4.1.3. Adopt Renewable Energy Sources

Utilizing clean energy to power the growing energy demand of data centers is a good way of reducing emissions. Clean energy will facilitate the growing need for data centers and their associated energy needs, without increasing emissions. AMSs could implement policies to incentivize data center operators to primarily utilize renewable sources to power their data centers.

Implementing discounted electricity rates or tax breaks for data center operators that use clean energy as their main source of power can start the shift towards adopting clean energy for data centers. Lower tariffs for clean energy will attract private operators to switch to clean energy due to reducing energy costs. This way all sides can gain benefits due to reduced energy intensity and emissions while also reducing costs for consumers and operators.

4.1.4. Provide Financial Mechanisms

A financial framework within ASEAN’s financial industry to support energy efficiency investments in data centers will be beneficial in establishing investments in this matter. Furthermore, a solid financial infrastructure for investments will enable more domestic and future international investments towards energy-efficient data centers. Cooperation between the financial sector, data center operators, and policymakers will be crucial in ensuring fast implementation of next-generation data centers in ASEAN.

In a mature market, the role of private investment, combined with limited public funds, demonstrates the potential for considerable advances in data center technology and operations through the formation of financial channels. This approach not only creates monetary impacts for the financial industry and data center operators, but also facilitates the adoption of next-generation data center technologies in the ASEAN region, reinforcing the need for collaboration between the financial sector, data center operators, and policymakers.

With the need for evolving data center operations, some frameworks would need to be developed to incentivize this change. For instance, the exploration of green bonds and green loans is instrumental in funding energy-efficient data center operations. Such financial mechanisms are crucial for incentivizing investments in sustainable data center infrastructure, aligning with the ASEAN's commitment to sustainable cooling and energy-efficient practices. This comprehensive approach to financial mechanisms and cooperation among various stakeholders underscores the potential for ASEAN to lead in the development of sustainable and energy-efficient data center markets.

4.2. Emerging Market

4.2.1. Fostering Enabling Policy

Establishing official government policies may provide a regulatory framework that ensures sustainable data center development continues. Governments could implement policies regarding land and electricity usage of data centers. This would provide a legal basis for data center efficiency. Domestic data sovereignty policies could also ensure domestic data center industry would be developed and independent from foreign data center providers and research.

In ASEAN, policies would ensure regional alignment with the ASEAN Digital Masterplan and APAEC to promote regional cooperation and cohesion in developing the growing digital infrastructure.

- Support the development of a regulatory framework that fosters the growth of sustainable data centers. Ensure alignment with the ASEAN Digital Masterplan and APAEC goals to promote regional cohesion in digital infrastructure development.
- Implement energy efficiency measures and introduce sustainable IT policies, such as PUE regulation for a data center.
- Promote policies on land and electricity of data centers.
- Encourage RE use in a data center.
- Data Sovereignty policy enhances the domestic data center industry development.

Tax breaks may be a way to encourage the implementation of energy-efficient data centers. Fiscal incentives may encourage more data center operators to follow energy efficiency guidelines set up. Especially for smaller operators, financial incentives may encourage them to invest in more energy-efficient practices and newer technologies. Incentives need to be set up for the private industry.

Moreover, these fiscal incentives can be designed to reward data center operators who not only meet but exceed energy efficiency standards, fostering a competitive environment where companies strive for innovation in energy efficiency. In AMSs, fiscal incentives have emerged as a key tool to promote energy efficiency and sustainability within the technology sector, particularly among data center operators. For instance, the Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE) of Malaysia are notable examples of how fiscal incentives are being utilized to encourage investments in clean energy technologies and energy-efficient projects. These incentives are designed to reduce the operational costs associated with the adoption of green technologies, making it financially attractive for companies to invest in energy efficiency improvements.

The ASEAN Centre for Energy (ACE) has been working on integrating energy efficiency into the sectoral mutual recognition arrangement, highlighting the regional commitment to sustainable energy practices. This approach not only facilitates the adoption of energy-efficient technologies but also encourages data center operators to exceed standard energy efficiency benchmarks, fostering a competitive environment that rewards innovation and efficiency.

Such fiscal incentives align with the broader policy objectives of AMSs to reduce energy consumption and greenhouse gas emissions, contributing to a more sustainable and environmentally friendly technology sector. By focusing on incentives, emerging markets can encourage voluntary compliance with energy efficiency guidelines, promoting a positive and proactive approach to environmental stewardship within the private sector.

4.2.2. Develop Harmonized Regional Standards

ASEAN could release a harmonized data center standard. Learning from the mature data center standard to develop the local standards for industry/country. Enhance the regulatory environment to foster sustainable digital data center development. Share knowledge on international standards and best practices to create a supportive ecosystem.

ASEAN could release and implement regional data center standards and guidelines. These guidelines can ensure the standards are best suited for the region’s requirements while also ensuring regional cooperation in resource pooling and information knowledge for best practices. Newer data center markets can learn from mature markets in the region. Standardizing regional regulation can ensure all AMSs will create an environment focusing on data center sustainability usage and development. Resource pooling and sharing knowledge can accelerate the development of these standards by maximizing the efficiency of the allocation of resources towards this goal.

In this context, ASEAN could initiate a collaborative process involving stakeholders from different member states to draft comprehensive data center standards and guidelines. This inclusive approach ensures that the standards are reflective of the diverse needs and challenges faced by the region. By incorporating inputs from mature data center markets within ASEAN, emerging markets can benefit from established best practices and industry insights, facilitating a smoother transition towards sustainable data center operations.

Moreover, the implementation of regional guidelines can foster a culture of cooperation and resource pooling among member states. By sharing knowledge and expertise, ASEAN can accelerate the development and adoption of standardized practices that promote energy efficiency, operational excellence, and environmental sustainability. This collaborative effort not only optimizes the allocation of resources but also creates a supportive ecosystem where industry players can learn from each other and drive continuous improvement.

Standardizing regional regulations will ensure a harmonized approach toward data center sustainability and development across all AMSs. This alignment is crucial for creating a level playing field that encourages innovation and adherence to high-quality standards. Through coordinated efforts and shared best practices, ASEAN can establish a robust foundation for the growth of the data center industry, emphasizing the importance of environmental responsibility and operational efficiency.

Overall, the establishment of comprehensive data center standards in ASEAN requires a strategic and collaborative approach that leverages regional expertise and promotes knowledge sharing. By setting clear guidelines, fostering cooperation, and maximizing resource efficiency, ASEAN can pave the way for a sustainable and innovative data center ecosystem that meets the evolving demands of the digital landscape while upholding industry best practices and environmental responsibilities.

4.2.3. Improve Skill and Knowledge Sharing

Capacity building and training that emphasizes sustainability and the most recent technologies will support green data centers in ASEAN. Training programs would need to be established to achieve this goal. A community focused on green data centers can be established to facilitate the training as well. A community bringing together design engineers, operations experts, other industry experts, academia, and consultants could produce advancements in training and practices in the ASEAN region.

Certification for individuals can also be a way to promote green practices in ASEAN. Individual certification may provide additional benefits and incentives to those in the data center industry.

- Conduct comprehensive training programs for data center operators, focusing on sustainable practices and the latest green data center technologies.
- Build a community: Engage data center design engineer, O&M engineer, colleagues, and consultant.

- Certificates: Encourage the employee to get the skill certificate.

Moreover, ASEAN can further enhance the development of the data center industry by exploring opportunities for regional and international exchanges of innovative technologies and best practices. By fostering collaboration and knowledge sharing on regional and international levels, AMSs can leverage the expertise of global leaders in the data center sector to drive innovation and efficiency within the region.

Through multilateral exchanges, AMSs can engage in mutually beneficial partnerships with advanced data center markets to exchange cutting-edge technologies and best practices. This exchange of knowledge can facilitate the adoption of state-of-the-art solutions that enhance energy efficiency, operational performance, and sustainability in data center operations across the region.

Furthermore, by tapping into the expertise of international partners, AMSs can gain valuable insights into emerging trends and innovative approaches in data center design, construction, and operation. This exposure to global best practices can inspire local innovation and drive continuous improvement within the ASEAN data center industry.

Overall, promoting multilateral exchanges of innovative technologies and best practices in data centers presents a valuable opportunity for ASEAN to strengthen its position as a hub for sustainable and efficient data center operations. By fostering collaboration with international partners, ASEAN can accelerate the adoption of advanced solutions, drive industry innovation, and ensure that data centers in the region remain at the forefront of technological advancements and environmental protection.

4.2.4. Public-Private Partnerships

Public and private partnerships (PPPs) are one of the best ways for development and implementation. With support from the government, private operators will be more inclined to develop and implement more energy-efficient data centers. Aligning policy and private sector investment is an important step in harmonizing the process. Regional and private-public cooperation will be crucial in ensuring faster implementation of greener data centers.

One example of PPP in the data center industry is the Data Center Optimization Initiative from the US launched in 2010. This policy/partnership focuses on budget planning to reduce the costs of old and inefficient data centers by targeting government data centers, to also encourage private data centers to take greener practices. The government needs to be the first to take steps to improve data center efficiency while also encouraging the private sector to switch to the same green standards as the government, and possibly in the future, more strict and efficient standards.

Chapter 5.

Conclusion

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ASEAN's growing population is causing a growing digitalization. The associated market digitalization has seen 460 million internet users in ASEAN, caused by increasing demand in many sectors, such as e-commerce, digital financing services, and social media. Data centers will be crucial in facilitating this digitalization. The data center market in ASEAN is expected to grow from USD 300 billion to USD 1 trillion by 2050. These data centers are known to consume enormous amounts of energy. The energy efficiency in this industry will need to be aligned with ASEAN's emission and energy targets.

Currently, in ASEAN, there are no regional standards for data center regulations. In each AMS, there are rarely any data center-specific regulations. Most regulations will fall under general building guidelines. For some of the countries that have data center guidelines, most are still voluntary. In terms of energy efficiency, ASEAN's PUE is still higher than the global average. This may be associated with the need for higher cooling needs due to the tropical and humid climate of ASEAN. ASEAN's PUE will need to be reduced while also continuing to facilitate the growing market digitization.

Next-generation data centers are one of the technical ways to increase energy efficiency in the data center industry. Huawei has identified the four key characteristics of a next-generation data center: reliability, simplification, green, and smart. These four points focus on smooth and seamless operation, while also maintaining energy efficiency. Next-generation data centers are a cost-effective solution compared to traditional data centers, in terms of costs and energy efficiency. Traditional data centers require long building periods, while also retaining low ROI and IRR. The designs are also non-modular, meaning newer technologies cannot be easily implemented and some data centers need to be designed specifically for the region or place, thus accumulating higher costs.

These issues can be addressed with advanced and innovative solutions. Prefabricated data centers can accelerate the time-to-market and reduce any building costs. These prefabricated data centers are also modular and can be adjusted for the unique needs of different data centers. Modular designs will also eliminate the need for purpose-built data centers and reduce costs throughout the industry. Utilizing advanced technologies will also support the creation of the next-generation data center. Replacing old batteries with lithium-ion batteries will ensure a more efficient power supply. Next-generation data centers will also utilize improved and optimized cooling systems and methods, reducing electricity costs and demand for cooling. Smart and simplified O&M will increase energy efficiency and prevent system failure.

Several policies and recommendations can be implemented to achieve the goal of reducing the energy intensity of data centers. These policies can vary from encouraging innovations, creating data center-specific standards, public-private cooperation, and fiscal incentives. Encouraging innovations in data center technology and operations will ensure the continued development of advancements in the sector in both emerging and mature markets. Policies and standards to ensure energy efficiency, using up-to-date technology, and regional-specific best practices are followed are ways for governments to take active measures to ensure the next-generation data center can thrive in ASEAN. Public and private cooperation can support the private sector's commitment to data center advancement through government backing, mitigating the risks associated with investment. Fiscal incentives, such as tax breaks, can incentivize private data centers to follow the regulations and best practices set by governments and industry experts.

As ASEAN continues to grow in terms of economy and population, the energy needs will inevitably increase. With the growing digitalization of ASEAN, data center represents an important tool to facilitate the ASEAN region. Data center operations require an enormous amount of energy and with a global focus on reducing the effects of climate change, increasing energy efficiency will be important, especially in this industry. Sustainable growth in the digital infrastructure is essential for the continuous and stable growth of ASEAN's economy and digital activities.

Through the technical solutions and policy recommendations stated in Chapters 3 and 4, respectively, it is encouraged for data center vendors to construct and implement the next-generation data centers and implement more sustainable practices and technology in the data center industry. ACE plays a pivotal role as a catalyst in advancing the development and implementation of energy-efficient data centers within the ASEAN region. By facilitating knowledge sharing, providing technical expertise, and supporting policy development, ACE significantly contributes to the region's efforts in achieving its energy efficiency and sustainability targets. Furthermore, ACE could expand its role by acting as a bridge between AMSs and global technology leaders, fostering partnerships that accelerate the adoption of innovative data center technologies and practices. Potential collaborations may encompass pilot initiatives for advanced data center technologies, sharing platforms on energy management best practices, and platforms for policy discourse aimed at achieving regional standard alignment. By leveraging its position, ACE can ensure that ASEAN maintains a leading role in the development of sustainable data centers, thereby providing environmentally responsible support for the region's digital economy.

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ASEAN Centre for Energy
Soemantri Brodjonegoro II Building, 6th fl.
Directorate General of Electricity
Jl. HR. Rasuna Said Block X-2, Kav. 07-08
Jakarta 12950, Indonesia
Tel: (62-21) 527 9332 | Fax: (62-21) 527 9350 32
E-mail: communication@aseanenergy.org
www.aseanenergy.org