A Report on Proof-of-Concept Tests for our Next-Generation Modular Eco-Data Center

In February 2010, IIJ began conducting year-long proof-of-concept tests in central Japan using an outside-air-cooled container unit as part of plans to construct a next-generation modular eco-data center. Here we discuss the goals of these proof-of-concept tests, the system configuration used for testing, and the results that have been obtained so far.

4.1 Reasons for Decision to Carry Out Proof-of-Concept Tests using an Outside-Air-Cooling System

4.1.1 The Need to Re-Examine Cooling Systems

Data centers are fitted with high-capacity electrical and cooling equipment to create an environment that facilitates the efficient installation of IT equipment such as large numbers of servers. However, existing data centers now face the problem that servers are emitting far more heat than expected at the design stage, making sufficient cooling impossible. This is due to advancements in the processing power and density of IT equipment, leading to an increase in the power consumed and heat generated by each device. When designing the facilities the effective power consumption for each of the server racks in existing data centers was estimated to be approximately 1 to 3kVA, but this is now commonly 4 to 6kVA, and in the future may rise to 10kVA or more.

Additionally, to fulfill the international commitment to reduce 2020 greenhouse gas emissions to 25% below 1990 levels, and our obligation to reduce total CO_2 levels due to the Tokyo Metropolitan Ordinance on Environmental Preservation, steps must be taken to reduce the power consumption of our data centers.

IT equipment consumes the most power in a data center. However, cooling equipment also consumes a similar amount of power. This means that to make substantial reductions in power consumption it is necessary to review existing cooling systems and introduce new systems that consume less power.

Cooling systems for reducing power consumption include the following two systems, which make use of the outside environment. The term "free cooling" is often used to indicate systems with water-side economizers (chiller-less water cooling systems), but systems with air-side economizers (outside-air cooling systems) fall under the category of free cooling as well, as they also offer reduced power consumption.

- Water-side economizer (chiller-less water cooling systems)
- Air-side economizer (outside-air cooling systems)

As shown in Figure 1, chiller-less water cooling systems use cooling towers that make use of the vaporization heat of water to produce cooling water with less power. On the other hand, outside-air cooling systems make use of cold outside air to cool data centers.

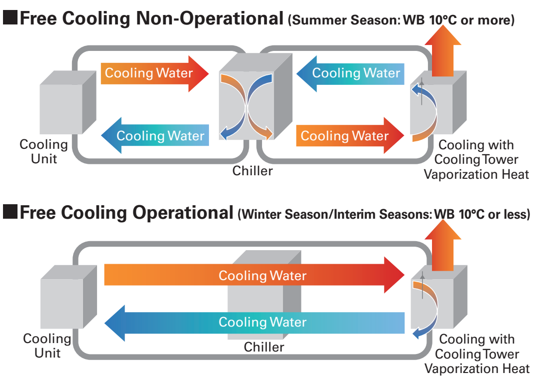


Figure 1: The Principles of Chiller-less Water Cooling Systems

Table 1: Free Cooling System Comparison

	Water-side economizer chiller-less water cooling systems	Air-side economizer outside-air cooling systems
Mechanism	Indirect cooling of interior using cooling water cooled utilizing water vaporization heat (cooling towers)	Direct cooling of interior using outside air
Humidity and Dust Particle Management	Basic humidifiers and filters can be used because interior air is circulated	Humidifiers and filtering equipment are required because outside air is brought directly inside
Facility Characteristics	Cooling towers and chilled water piping are required	Difficult to implement in existing buildings because openings are required in the server room to admit outside air
Main Running Costs	Supplementary water for cooling tower vaporization, power for pump that circulates cooling water, power for indoor equipment	Power for fans that intake outside air
Hours Usable Each Year	3500 to 4000 hours / 8760 hours (Tokyo)	5500 to 6000 hours / 8760 hours (Tokyo)
Implementation Status in Japan	Numerous	Used mostly during interim seasons, with very few examples designed for winter season use

As shown in Table 1, each of these systems has unique characteristics. Following the results of simulations, IIJ decided that the outside-air cooling system was most suitable for our next-generation data centers due to the longer usable hours per year and the lack of a need for equipment such as cooling towers.

However, outside-air cooling systems require openings to be made in the server room for the intake and exhaust of large volumes of air. This posed a large problem that could not easily be resolved when introducing outside-air cooling systems into existing buildings. As a result, IIJ decided to develop container modules that also integrated ducts and housing for the intake and exhaust of air for the installation of IT equipment.

4.1.2 Current Overseas Trends

Let us examine the cooling systems adopted in the United States, which is leading the way in the construction of large-scale data centers. It was said that chiller-less water cooling systems were predominate in the United States, but outside-air cooling systems are also being adopted in an increasing number of cases. Table 2 shows trends for the data centers constructed by Microsoft, Google, and Yahoo in the past two years. It would appear that Microsoft and Yahoo have taken the lead in using outside-air cooling in most of their cooling systems. On the other hand, it has been reported that Google has constructed a data center in Finland that is fitted with a cooling system using sea water, and it seems there is no change in their policy of basing their cooling solutions on chiller-less water cooling systems.

Based on publicly available data, it is thought that the data center Yahoo opened near Niagara Falls in September 2010 follows the construction shown in Figure 2. By making use of the cool climate of Lockport where it was constructed, it seems that cooling can be achieved using outside air only for most of the year. In addition to the three companies mentioned, NetApp and HP have also adopted outside-air cooling systems in their data centers, and IIJ believes the adoption of outside-air cooling systems in data centers to be a worldwide trend. Furthermore, ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) Technical Committee 9.9 eased data center temperature and humidity requirements in 2008 to reduce the power consumed by data centers. IIJ believes that this is one of the primary factors driving the move toward outside-air cooling systems.

4.1.3 Proceeding with Proof-of-Concept Tests

IIJ reached the conclusion that outside-air cooling systems are currently most suitable for next-generation data centers due to merits such as their energy savings, investment cost, and operational cost, as well as overseas trends. Although such systems have been implemented overseas, in order to provide them commercially in Japan's hot and humid climate it was decided that testing was required to determine whether they could withstand real-world operation here. This led to the proof-of-concept tests currently being carried out.

Table 2: Trends in the Data Centers Constructed Recently by U.S. Companies (Created by IIJ from Press Material)

Company Name	Location	Area	Date of Operation/Construction	Characteristics	Cooling System
Microsoft	Northlake Illinois, US	51,097 m²	Began operation in September 2009	PUE=1.22 1st floor uses a container system, 2nd floor uses a conventional system	Water cooling
	Quincy Washington, US	9,290 m²	Construction of an expansion began in May 2010	Flywheel UPS/IT PAC PUE=1.06	Outside air
	Dublin, Ireland	28,150 m²	Began operation in July 2009	PUE1.25	Outside air
Google	Hainaut, Belgium	Not known	Began operation in 2008	PUE=1.1	Water cooling (chiller-less)
	Hamina, Finland	8,000 m²	Begins operation in Spring 2011	Remodeled a paper mill	Sea water cooling
Yahoo	Omaha Neblasca, US	27,871 m²	Began operation in 2009	flywheel UPS	Outside air + chiller
	Lockport New York, US	14,400 m²	Began operation in September 2010	PUE 1.08 flywheel UPS	Outside air

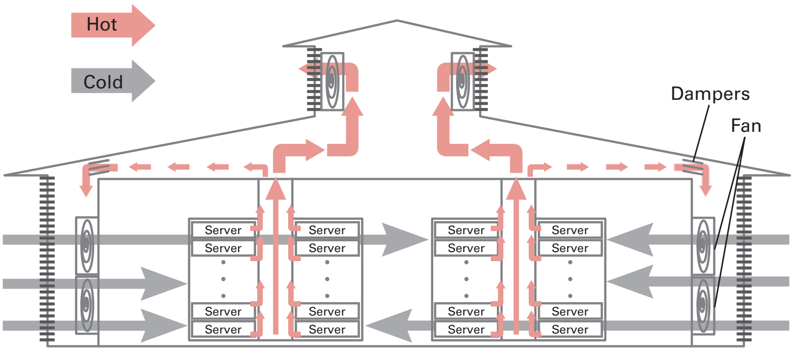


Figure 2: Yahoo Lockport Data Center Construction (IIJ Estimate)

4.2 Proof-of-Concept Test Goals and System Configuration Overview

The goal of these tests is to verify whether IT equipment such as servers can be cooled using outside air, but the ultimate objective is energy conservation, with the aim of adopting this system for commercial data centers constructed in the future. Rather than simply using outside air to cool IT equipment and determining if this was feasible or not, we needed to quantitatively measure whether such a system achieves energy conservation and can withstand use in a commercial data center.

For this reason, IIJ forged ties with professionals and partners in a number of fields when devising the system for proof-of-concept tests. Together with Toshiba Corporation, we developed a cooling module that made outside-air cooling possible, optimized IT equipment cooling, and featured automated control. We asked NLM ECAL Co., Ltd., of the Nippon Light Metal Group, to produce the IT module container units to which IT equipment would be installed. As with conventional data centers, these IT modules contain racks for installing IT equipment, and power distribution boards for delivering power safely to each rack from the main power line. Equipment for measuring electric current and pulse signals from the watt-hour meter was also required to judge whether or not energy savings were realized. We procured these from Kawamura Electric Inc.
Fires are of particular concern at data centers, which consume large amounts of power. Consequently, equipment for detecting fires in advance and extinguishing any fires that occur with minimal effect on IT equipment is required. As large amounts of air flow generally passes through data centers, the proof-of-concept test system also recreates this environment. This means that the fire detection devices used in conventional offices would not be suitable, so we installed fire warning sensors and tested whether fires within the IT module could be detected. To achieve this we collaborated with Nohmi Bosai, Ltd. Additionally, to recreate an actual data center environment as faithfully as possible, we procured and installed server equipment from KSG Company to serve as the thermal load in the IT module.

Here, we will explain the elements that make up this proof-of-concept test system. First we will provide an overview of the energy indicator for data centers.

PUE (Power Usage Effectiveness) is a metric provided by U.S. industry association The Green Grid, and is the most commonly-used indicator of data center power consumption around the world. However, for the proof-of-concept test system we are using this time, we will not be constructing the data center’s equipment or systems in their entirety. For this reason, we decided to introduce the PPUE (Partial PUE) concept. As the name suggests, PPUE indicates the partial PUE for data centers, which continue to migrate towards modular systems such as those using container units. We installed watt-hour meters and other devices in our proof-of-concept test system to make it possible to calculate PPUE using the following formula.

$$\text{PPUE} = \frac{\text{cooling module power consumption} + \text{IT module power consumption}}{\text{IT module power consumption}}$$

Data Center PUE Energy Indicator

- **PUE (Power Usage Effectiveness)**
  - The most commonly-used indicator of data center power consumption around the world, provided by the U.S. industry association The Green Grid
  - Formula

$$\text{PUE} = \frac{\textbf{overall data center power consumption}}{\textbf{IT equipment power consumption}} = \frac{\textbf{(IT equipment power consumption + additional equipment power consumption)}}{\textbf{IT equipment power consumption}}$$

  - When the power consumption of additional equipment is 0, the PUE is 1.0, which is the theoretical optimal level
  - The average PUE of data centers in Japan is said to be about 2 (with IT equipment accounting for half of the power consumed)
  - A PUE of 1.2 or less has not yet been achieved by commercial services in Japan

- Reference example -
The PUE for a data center in which servers consume 100 units of power, and other equipment (such as cooling) consumes 80 units of power

$$\text{PUE} = \frac{\text{IT 100 + Other 80}}{\text{IT 100}} = 1.8$$

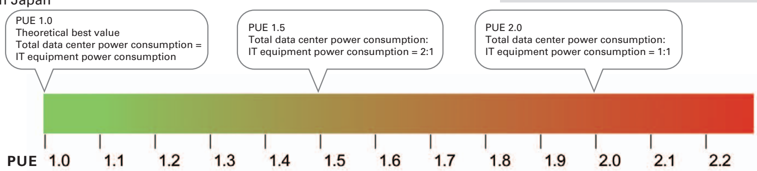


Figure 3: Data Center PUE Energy Indicator

4.2.1 The Cooling Module

As demonstrated above, the cooling module readied for our proof-of-concept tests makes outside-air cooling possible, optimizes IT equipment cooling, and features automated control. We will now examine the type of environment assumed for the optimization of IT equipment cooling. In this case we elected to adopt the temperature and humidity requirements recommended for data centers by ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) Technical Committee 9.9 (henceforth ASHRAE 2008).

The graph in Figure 5 is a basic psychrometric chart showing dry-bulb temperature [°C] on the horizontal axis, and absolute humidity [kg/kg (DA)] on the vertical axis. The most commonly-used psychrometric chart in the cooling industry is the h-x chart, in which h = specific enthalpy [kJ/kg (DA)] and x = absolute humidity [kg/kg (DA)]. Psychrometric charts show the relationships between dry-bulb temperature [°C], wet-bulb temperature [°C], dew point temperature, absolute humidity [kg/kg (DA)], specific enthalpy [kcal/kg (DA)], and relative humidity based on atmospheric pressure (101.325kPa), and it is possible to chart all of these values as long as any two can be determined.

Next, we will explain the three operating modes operating modes of the cooling module.

■ Outside-Air Operating Mode

Outside-air operating mode is the most basic operating mode. In this mode, when the temperature and humidity of outside air are within the targeted levels set in ASHRAE 2008, outside air is used as-is to cool IT equipment, and all exhaust air from IT equipment is discarded. When operating in this mode the only power required for the cooling module is the fans for taking in outside air, making significant energy savings possible.

■ Mixed Operating Mode

Mixed operating mode is mostly used during the winter season, when the outside air has low temperature and humidity. In this mode, outside air and IT equipment exhaust air are mixed using variable blend ratios depending on the temperature and humidity of each source to create air within the targeted ASHRAE 2008 levels.

When the mix point falls below the ASHRAE 2008 range on the psychrometric chart, in other words when there is a lack of humidity, vaporizer-type humidification is implemented. As vaporizer-type humidification also removes heat from the air, the air condition transitions from the lower right to the upper left on the psychrometric chart. This makes it possible to supply air within the ASHRAE 2008 levels to IT equipment. Additionally, unlike steam humidification, vaporizer-type humidification requires no power. This means that like the outside-air operating mode the only power needed in the cooling module is for the fans, resulting in significant energy savings.

■ Circulation Operating Mode

At times it becomes impossible to create air flow within the ASHRAE 2008 levels using outside air as-is or by mixing it with IT equipment exhaust air and carrying out vaporizer-type humidification. In this case conventional cooling methods must be used, requiring the operation of cooling units such as compressors that consume large amounts of power. These functions cannot be completely overlooked simply because they have high power consumption. For this reason, in order

	Dry-Bulb Temperature	Relative Humidity	Dew Point Temperature	Notes
ASHRAE class 1 & 2 recommended level (2008 version)	18 - 27°C	60% or less	5.5 - 15°C	The recommended equipment intake temperature and humidity levels revised by ASHRAE in 2008 to reduce data center energy consumption.
ASHRAE class 1 allowable level	15 - 32°C	20 - 80%	17°C or less	The allowable levels set to extend the period that economizers such as outside air could be used. However, the usable period depends on IT equipment testing and tolerance for hardware failure.

Partial PUE

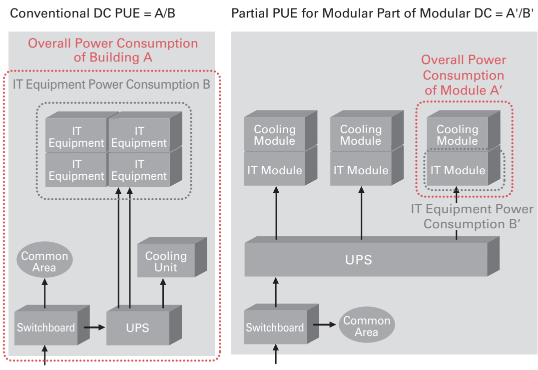


Figure 4: Partial PUE (PPUE)

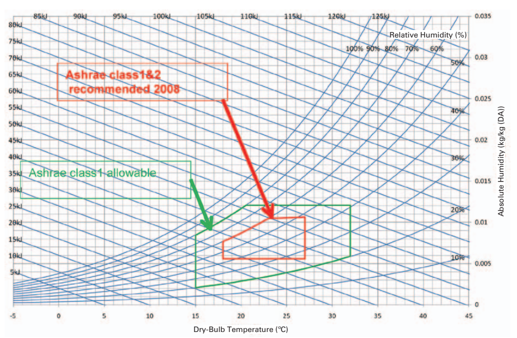


Figure 5: ASHRAE Recommended Temperature and Humidity Levels for Data Centers

to facilitate the circulation operating mode the cooling module is fitted with equipment for shutting off outside air and cooling using compressors.

The power consumed in circulation operating mode depends on the cooling ability of the compressors. For this reason, the questions of what level of product to use and whether they can be controlled to keep the use of circulation operating mode to a minimum are important points to consider to achieve total energy savings throughout the year.

The operating modes detailed here are controlled automatically via a control unit installed within the cooling module, and are transitioned between based on outside air conditions.

Next, we will discuss the components required for the cooling module.

The fans for carrying air to the IT equipment (IT module) allow inverter control, and have a maximum airflow of 27,000m3/h. Vaporizer-type humidification is achieved through the installation of humidifier modules within the cooling module wind tunnels that are supplied with water when necessary. The cooling module has multiple dampers for outside air intake, IT equipment exhaust air, and mixing outside air and IT equipment exhaust air. The blend ratio is regulated through inverter control of the aperture of these dampers. The cooling units used when in circulation operating mode consist of four outdoor compressor units each with 28kW cooling ability installed to the cooling module exterior, connected to cooling coils in the cooling module wind tunnels by refrigerant pipes. The outdoor compressor units allow for both fine control and energy savings using inverter control. Sensors for measuring temperature and humidity are installed to necessary locations both inside and outside the IT module.

A DDC (Direct Digital Controller) for controlling each of these components is installed within the cooling module, performing a variety of control functions such as automated control of each operating mode. In addition to these components, medium efficiency particulate air filters are installed in the cooling module due to the use of outside air, filtering out dust particles of 0.5μm or larger.

For the proof-of-concept tests the cooling module and outdoor compressor units have also been designed with surplus size. The cooling modules and outdoor compressor units for commercial data centers to be built in the future are expected to be about 2/3 the size of those used in the proof-of-concept tests.

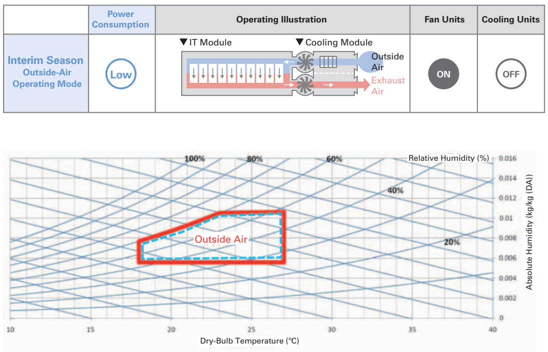


Figure 6: Outside-Air Operating Mode

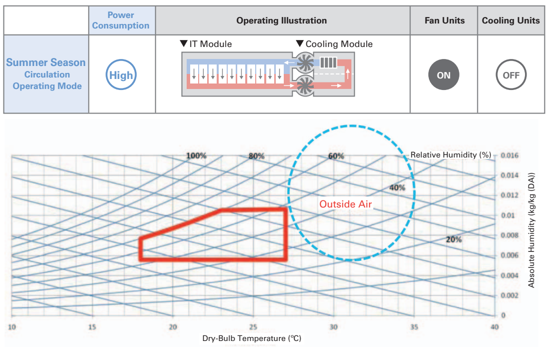


Figure 8: Circulation Operating Mode

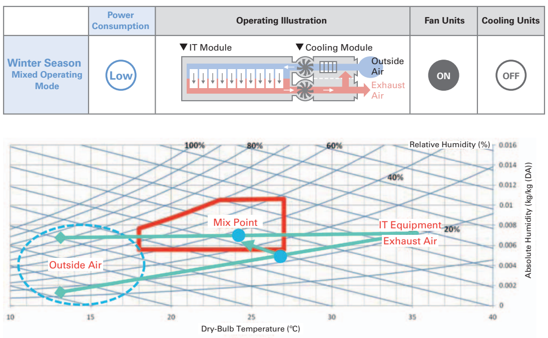


Figure 7: Mixed Operating Mode

Figure 9: From Left - Outdoor Compressor Units, Cooling Module, and IT Module

4.2.2 The IT Module

The container unit for housing IT equipment such as servers is called the IT module. The interior of the IT module is divided into cold area in front of the racks that house IT equipment and the hot area behind them. The cooling module and IT module are connected by two air ducts, with air suitable for cooling the IT equipment sent from the cooling module to the IT module cold area, and exhaust air from the IT equipment returned to the cooling module from the IT module hot area.

For the proof-of-concept tests we set a thermal load of 90kVA for IT equipment such as servers. In the age of cloud computing, data centers must have high-density capacity for housing IT equipment, so we aimed for effective power of 10kVA per rack. We considered that an IT module fitted with nine racks should make for a usable effective power of 90kVA.

However, the purpose of these proof-of-concept tests is only to verify the operation of a cooling system using outside air cooling, and IT equipment is only introduced to serve as the thermal load. For this reason, we explored various options before beginning actual construction. The racks we prepared each had approximately 40U of space for installing heat sources, with consumption of 250VA of power consumption necessary for each 1U of space. To prepare this thermal load inexpensively, one possible solution would be to use a set of light bulbs. If 10 x 100W incandescent bulbs could be installed in 4U of space, it would be possible to achieve a load similar to that necessary. It is possible that hot plates (approximately 1300W), table heaters (approximately 500W), or dryers (approximately 1200W) could also be used. However, all of these devices are difficult to control externally, and for constant 24-hour operation fire hazards become a concern. There is also concern with regard to air flow, as each pieces of IT equipment is fitted with fans. For this reason, it was judged that unless this air flow could be recreated the equipment would not be suitable for proof-of-concept tests, even if its purpose was simply to create a thermal load.

After considering these factors, in the end we decided to carry out proof-of-concept tests with actual IT equipment (servers) installed. We intentionally used second-hand server equipment of about five years old to reduce the procurement cost and generate the power consumption for each 1U of space. Newer servers have more power saving features, so slightly older servers tend to consume more power. We installed multiple server models from a variety of manufacturers. Most of the servers had a rated value of 300 to 400VA in their catalog specifications, but actual power consumption averaged out to approximately 180 to 200VA. We used mainly 1U servers, and by fitting each with two CPUs, the maximum number of memory modules (with a focus on number of modules rather than amount of memory), and two HDDs, we managed to raise the power consumption per 1U to 250VA, attaining the maximum 90kVA for the IT module overall.

Although each server merely serves to contribute to the thermal load, we made it possible to control them remotely by installing operating systems and connecting them to a network. With only the OS running and no processing load the power consumption of servers was about 70% (approximately 60 to 65kVA for the IT module overall), and with benchmark tool processes running the load could be increased to 100% (approximately 90kVA). Also, when installing the servers we raised cooling efficiency as much as possible by covering the gaps between racks with masking tape.

Many other refinements were applied to the IT module. In particular, a large amount of sensor equipment was installed to allow a variety of data to be obtained.

Figure 10: Masking Tape Applied Between Racks to Raise Cooling Efficiency

4.2.3 PPUE Simulation

As detailed above, we constructed a cooling module with three operating modes that are each controlled automatically to supply air within ASHRAE 2008 levels to IT equipment, and an IT module that produces a maximum thermal load of 90kVA. Before discussing the actual results of our proof-of-concept tests, we will present the results of a simulation we carried out to estimate the PPUE when the proof-of-concept test system was used.

The Japan Meteorological Agency releases meteorological statistics such as past temperatures and humidity levels for the various regions of Japan. By plotting this data on a psychrometric chart such as the one in Figure 11, it is possible to calculate the yearly operating hours for each operating mode of the cooling module.

Additionally, as the power consumption of each of the cooling module's operating modes is already known, we can use this data to calculate on paper the PPUE of the proof-of-concept test system if it were used in various locations in Japan. Figure 12 shows the results of this simulation. As Figure 12 demonstrates, a lower PPUE can be expected for colder areas in the north. However, with the exception of Okinawa (Naha), the fluctuation in PPUE was within 0.1 throughout Japan. Meanwhile, when facilities are constructed in colder areas, frosting prevention and snow damage countermeasures are required for the winter season, possibly leading to an increase in initial investment and running costs. Accordingly, it is not as simple as installing the outside-air system used for these proof-of-concept tests in a cold location throughout the year.

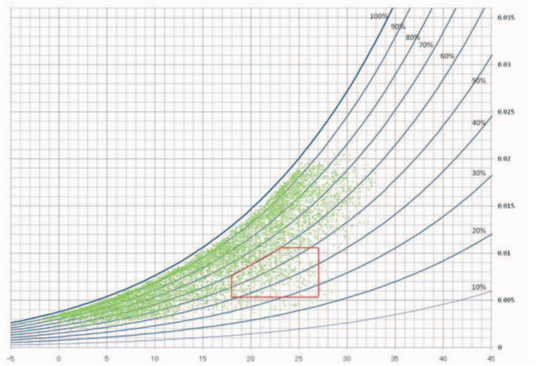


Figure 11: An Example of Outside-Air Temperature and Humidity for Matsue (2009) Plotted on a Psychrometric Chart

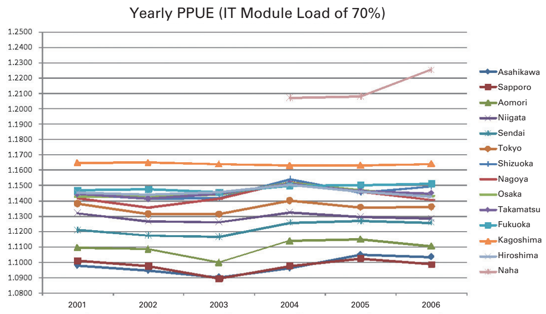


Figure 12: Simulation Results

4.3 Proof-of-Concept Test Results and Discussion

We have already gathered a variety of data from the proof-of-concept tests begun in February 2010 and applied this feedback to the commercial modules. Here, we detail and discuss the results of the proof-of-concept tests based on operating data for the cooling module.

4.3.1 Cooling Module Power Consumption

Power consumption for the cooling module can be divided into that for the SA (supply air) fan and that for the outdoor compressor units. Technically, the power consumption for control equipment should also be added to this, but as the amount is insignificant it is not mentioned here.

■ SA Fan Control

The SA fans supply cold air from outside or generated by the outdoor compressor units to the cold area in the IT module, and return the IT equipment exhaust air expelled into the hot area to the cooling module. As they operate throughout the year, SA fan efficiency has a significant effect on cooling module energy savings.

By lowering the rotation speed of the SA fans and reducing the air flow, their power is reduced proportionally to the third root of the rotation speed. In other words, if air flow is reduced to 1/2, power is reduced to 1/8. Because the air flow supplied to cold area by SA fans is controlled by adjusting the fan motor rotation speed through inverter control, it is possible to produce significant energy savings by supplying the cold area with the minimum amount of air flow necessary to cool IT equipment.

Furthermore, because IT equipment takes in air from the cold area with its own fans and exhausts this into the hot area, the SA fans require constant air flow equal to the total air flow of IT equipment fans. If the air flow of the SA fans is less than the total air flow of the IT equipment fans, a short circuit will be caused on the IT equipment. If the air flow is higher than the total air flow of IT equipment fans, the wasted air may pass through the IT equipment or gaps between the racks. Consequently, as shown in Figure 13, the most energy efficient operation is achieved when the air flow of SA fans and the total air flow of IT equipment fans are equal. However, it is not easy to calculate the total air flow of IT equipment fans because IT equipment can be fitted with a variety of fans depending on the model, and air flow may vary based on the operating state of the IT equipment (CPU or HDD usage) and the air intake temperature (cold area temperature), such as when the rotation speed of the fan is raised to prevent overheating. For this reason, it was necessary to implement a control system in the cooling module for automatically determining variations in IT equipment fan air flow and adjusting SA fan air flow accordingly.

■ Outdoor Compressor Unit Control

Outdoor compressor units are put into operation for the circulation operating mode that does not use outside air. Outdoor compressor units are generally used to cool hot air returned from the IT module, but when the situation calls for it they can also be used to cool and dehumidify hot and humid outside air. The motors for the outdoor compressor units are controlled using an inverter, allowing fine adjustments and linear control over the temperature and humidity of the cold area by modifying cooling ability to match the IT module load. As IT equipment only produces sensible heat (changes in temperature), the cooling module is designed to have a high sensible heat ratio such as those in building-type data centers.

4.3.2 Proof-of-Concept Tests for Outside-Air Operating Mode and Mixed Operating Mode

Between February and May a wide range of data was obtained for the mixed operating mode and outside-air operating mode. Here we will present results based on proof-of-concept tests carried out on April 6. Figure 14 shows the operating report for April 6.

Because the outdoor compressor units are not operational during outside-air operating mode and mixed operating mode, the majority of power for the cooling module is consumed by the SA fans. As explained earlier, by controlling the SA fan air flow (average air flow of 14,627m3/h on April 6) efficiently with inverter control, the minimum necessary operation is carried out. Because of this, as shown in Figure 15 the power consumption of the cooling module is 4% of total power, resulting in a PPUE of 1.044. We recorded PPUE of 1.04 to 1.07 in outside-air operating mode and mixed operating mode on other days, achieving the amount of energy conservation that we expected.

Figure 16 shows temperature and humidity data for the cold area (blue), hot area (red), and outside air (green) plotted on a psychrometric chart in five second increments. The cold area (blue) plotted to 97.84%, which is within

Cooling SA Fan Control

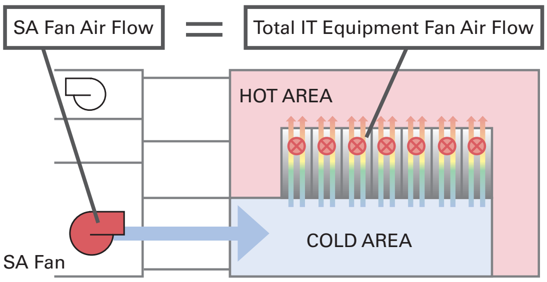
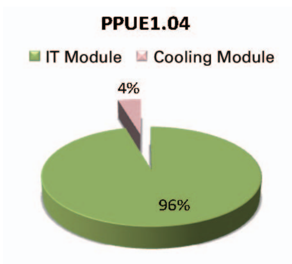


Figure 13: Most Efficient and Energy Saving Air Flow Relationship



IT Module Power	1550.0kW-h	Average 64.6kW (Average 7kVA/rack)
Cooling Module Power	68.0kW-h	Average 2.8kW
PUE (PPUE)	1.044 ((1550kW-h + 68kW-h) ÷ 1550kW-h)	

Figure 15: April 6 PPUE

■Power Consumption
IT Power Consumption : 1550.0 kWh (Average 64.6 kW)
Cooling Power Consumption : 68.0 kWh
PUE : 1.044

■Cooling Operating Mode
1. Outside Air : 29.4% 7 hrs 2 mins
2. Mixed : 70.6% 16 hrs 56 mins
3. Circulation : 0.0% 0 hr 0 min

■Fan Air Flow (SA)
Air Flow Max: 18553 m3/h / Min: 12727 m3/h / Average: 14627 m3/h
Water Supplied to Humidifier: 0.00 m3

■Outside Air Condition
Max Temperature: 23.5°C / Min Temperature: 12.3°C / Average Temperature: 17.0°C
Max Humidity : 92.7% / Min Humidity : 43.5% / Average Humidity : 71.8%

Figure 14: April 6 Operating Report

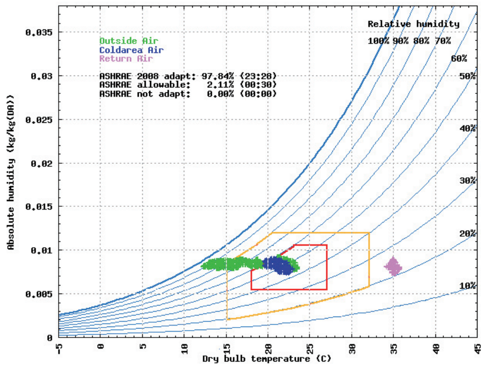


Figure 16: April 6 Psychrometric Chart

ASHRAE 2008 recommendations, and the others were also within the ASHRAE allowable levels. In other words, the temperature and humidity of the cold area remained stable throughout the day.

Furthermore, as shown in Figure 17, temperature and humidity were stable even when transitioning between mixed operation mode and outside-air operation mode, falling within ASHRAE 2008 recommended levels.

In outside-air operating mode and mixed operating mode, temperature and humidity are adjusted via damper control as shown in Figure 18. Data from the temperature and humidity sensors installed in the cold area are obtained by the DDC (Direct Digital Controller) in real time, and the apertures of the outside air intake damper, exhaust heat damper, and mixed damper are adjusted. The fact that temperature and humidity remain stable within ASHRAE 2008 levels during the proof-of-concept tests indicates that damper control is being executed appropriately.

Humidification control is also an essential function in outside-air operating mode and mixed operating mode. Figure 19 shows the operating report for April 30. On this day the absolute humidity (the amount of water vapor included in 1kg of dry air) of the outside air was low, so the vaporizer-type humidifier was activated to bring the cold area temperature and humidity within ASHRAE 2008 levels.

A vaporizer-type humidifier flushes water over the top of humidifying materials, humidifying air that passes over through natural evaporation. Figure 20 shows the psychrometric chart for April 30. The cold area (blue) plotting remains within ASHRAE 2008 levels, demonstrating that humidification control is being carried out appropriately without causing an excess or lack of humidity.

4.3.3 Circulation Operating Mode

Between June and August we gather a variety of data regarding the circulation operating mode. Here we will report on results based on proof-of-concept tests carried out on July 6. Figure 21 shows the operating report for July 6. Circulation operating mode was used throughout the entirety of the day.

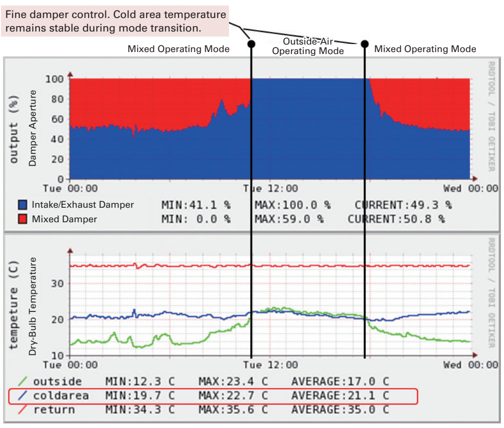


Figure 17: Damper Aperture and Temperature Transition

■Power Consumption
IT Power Consumption : 2123.0 kWh (Average 88.5 kW)
Cooling Power Consumption : 157.0 kWh
PUE : 1.074

■Cooling Operating Mode
1. Outside Air : 17.3% 4 hrs 8 mins
2. Mixed : 82.6% 19 hrs 48 mins
3. Circulation : 0.0% 0 hr 0 min

■Fan Air Flow (SA)
SA Air Flow Max: 24892 m3/h / Min: 17483 m3/h / Average: 20480 m3/h
Water Supplied to Humidifier: 0.48 m3

■Outside Air Condition
Dry-Bulb Temperature Max: 22.1°C / Min: 9.0°C / Average: 15.9°C
Relative Humidity Max: 77.6% / Min: 31.3% / Average: 50.7%
Absolute Humidity Max: 7.2g / Min: 4.4g / Average: 5.5g

Humidification Mode Operating Time 18 hrs 45 mins
Water Supplied to Humidifier 0.48 m³ (480kg)

Figure 19: April 30 Operating Report

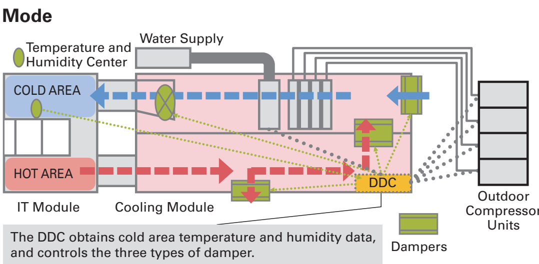


Figure 18: DDC and Dampers

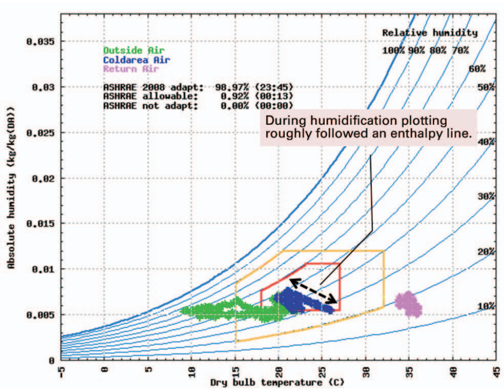


Figure 20: April 30 Psychrometric Chart

As shown in Figure 22, cooling module power on July 6, which had a maximum outside air temperature of 30.6°C, an average temperature of 27°C, and an IT module load of 63.7kW (70% of the maximum 90kW), was 22% of total power, resulting in a PPUE of 1.284. On days other than July 6 that circulation operating mode was used, PPUE between 1.24 and 1.30 were recorded. The reason for the large fluctuation in PPUE is the fact that the power required by the outdoor compressor units varies depending on outside air temperature and humidity as well as IT module load.

Figure 23 shows the psychrometric chart for July 6. The cold area temperature and humidity (blue) stayed within ASHRAE 2008 levels. Also, as shown in Figure 24, the temperature, relative humidity, and absolute humidity of the IT module cold area and hot area remained stable.

In circulation operating mode, efficient operation is made possible by shutting off outside air. Additionally, in the event that outside air with high humidity and temperature is admitted, the outdoor compressor units are fitted with functions for dehumidifying and cooling air to prevent violent fluctuations in the IT module's temperature and humidity levels. We also experimented with different output levels and numbers of operating outdoor compressor units, as well as multiple operation patterns, and implemented functions allowing the DDC to control the outdoor compressor units to consume the least total power (Figure 25).

■Power Consumption

IT Power Consumption	: 1529.0 kWh (Average 63.7 kW)
Cooling Power Consumption	: 434.0 kWh
PUE	: 1.284

■Cooling Operating Mode

1. Outside Air	: 0.0%	0 hr	0 min
2. Mixed	: 0.0%	0 hr	0 min
3. Circulation	: 99.9%	23 hrs	59 mins

■Outside Air Condition

Dry-Bulb Temperature	Max: 30.6°C	/ Min: 25.5°C	/ Average: 27.0°C
Relative Humidity	Max: 99.5%	/ Min: 68.2%	/ Average: 89.9%
Absolute Humidity	Max: 22.2g	/ Min: 18.1g	/ Average: 20.3g

Figure 21: July 6 Operating Report

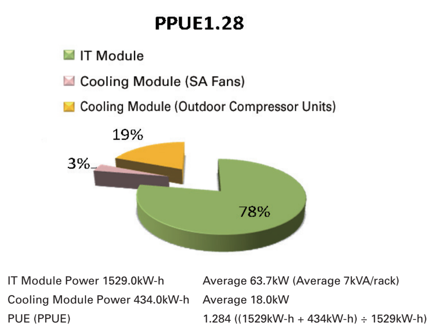


Figure 22: July 6 PPUE

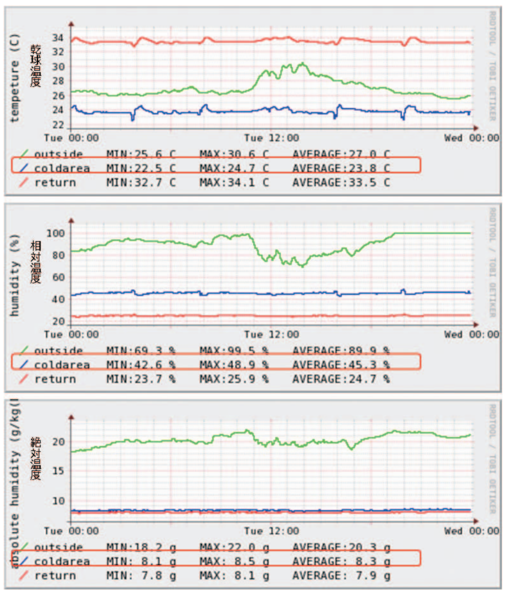


Figure 24: Dry-Bulb Temperature, Relative Humidity, and Absolute Humidity Changes

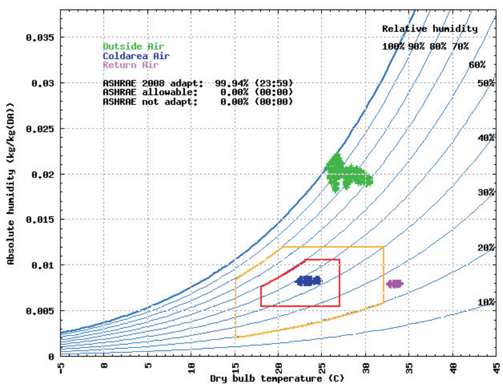


Figure 23: July 6 Psychrometric Chart

Mode

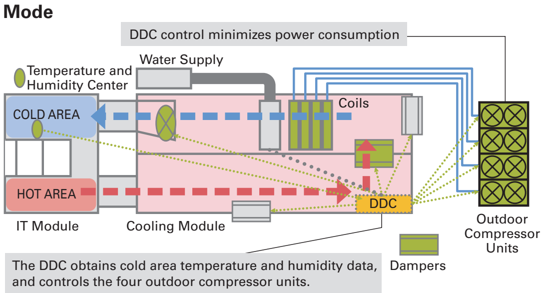


Figure 25: DDC and Outdoor Compressor Units

4.4 Future Considerations

4.4.1 Working Toward Further Energy Savings

Although we now have a clearer idea of the energy savings that an outdoor-air cooling system can provide, we plan to consider and evaluate steps such as the following in the medium- and long-term, with the aim of making further energy savings.

STEP 1 Expansion of existing systems (for example, reducing power consumption by using outside-air operating mode in the summer season as well).

STEP 2 Integration of cooling equipment and IT equipment (for example, due to both cooling equipment and IT equipment having their own fans with separate temperature control, integrating control would reduce the double-up of fans).

STEP 3 Realization of a carbon neutral data center (for example, creating a system enabling energy use without generating CO_2 through the integrated construction and operation of power plants that utilize natural energy (wind power, solar power, etc.) and data centers.

First of all, as part of step one we will provide an overview of the proof-of-concept tests for summer season use of outside-air operating mode carried out in August 2010.
With the cooperation of a number of IT equipment vendors, we carried out tests using outside-air operating mode instead of circulation operating mode in the summer season, aiming to maintain a PPUE of 1.1 or less throughout the year. As use of outside-air operating mode was forced for a 24-hour period, the cold area became the same temperature as the outside air, resulting in a room temperature of over 35°C at its highest (which in turn led to a hot area temperature of 45°C). However, as shown in Table 3, PPUE improved significantly, going from 1.25 to 1.06. That said, total power consumption fell only 6%, going from 70kW to 66kW. This is because although cooling power consumption fell 10kW, the high room temperature caused an increase in the fan rotation speed of IT equipment, consuming an extra 6kW (server fan power consumption generally increases significantly when the intake area temperature exceeds 25°C), and resulting in overall energy savings of just 4kW.
We anticipated achieving a PPUE of 1.07 by reducing the power consumption of cooling equipment while maintaining that of the IT equipment, but feel we have made significant progress by quantitatively measuring that although the PPUE may meet our expectations, it is not possible to reduce overall power consumption greatly.

We will continue to analyze the data from these tests together with IT and cooling equipment vendors, and we hope to obtain data that will contribute toward the second step of integrating IT and cooling equipment.
As has been mentioned before, PUE improvements may not necessarily lead to energy savings, and we have reestablished the fact that indicators other than PUE are necessary when pursuing the detailed refinement of energy savings.

4.4.2 Construction of the Matsue Data Center Park for Commercialization

In order to apply the technology we have proven in these tests to real-world operation, on September 1, 2010 we began work on construction of the Matsue Data Center Park as the first commercialized data center using outside-air cooled container units in Japan, with the aim of beginning operations in April 2011. We received backup in the form of investment aid and electric utility fee assistance based on the government's industrial development policies.
This data center park integrates building, electrical equipment, cooling equipment, and IT equipment resources in modular form to meet the needs of cloud services. The first-generation Matsue Data Center Park will be the facility the IIJ GIO cloud service is based on, and as Japan's first container-based data center it will offer low cost solutions, high server capacity, and easy scale-out with the following principle features.

- Utilizes an outdoor-air cooling system
- Utilizes the IZmo (patent pending) IT modules we have developed in-house
- Features efficient placement of data center components

The Matsue Data Center Park implements a highly efficient outdoor-air cooling system based on the results of our proof-of-concept tests. Facility costs for the IT modules have been lowered by integrating the ducts that supply

Table 3: Summer Season Circulation Operating Mode and Outside Air Operating Mode

	Circulation Operating Mode		Outside-Air Operating Mode			
	Actual Value		Expected Value		Actual Value	
IT Equipment Power Consumption	62kw		56kw	+6kw	62kw	Fan rotation speed rises, increasing power consumption
Cooling Equipment Power Consumption	14kw	−10kw	4kw		4kw	
Total	70kw	−4kw	60kw	+6kw	66kw	Power consumption is above expected values
Partial PUE	1.25	−0.19	1.07	−0.01	1.06	PUE was lower than expected values

outside air and module housing. Cooling efficiency has also being raised by separating the hot area and cold area inside the modules, and all racks support effective power consumption of up to 10kVA, reducing running costs such as electric utility fees. On top of this, we are installing racks at an angle within the modules to keep the IT module width within 2.5m while securing the necessary amount of interior space. These measures make it possible to transport the modules using standard heavy trucks rather than requiring a special vehicle such as a trailer, reducing transport costs by roughly 1/3.

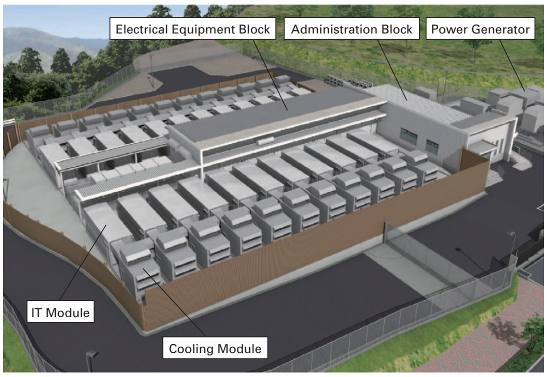


Figure 26: Matsue Data Center Park Illustration

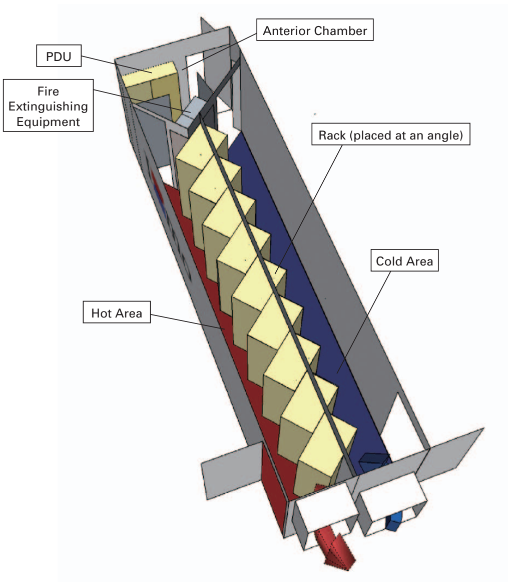


Figure 27: IZmo IT Module Illustration

The Ministry of Land, Infrastructure and Transport is examining whether the containers used for the data center fall outside the scope of "buildings" as defined under Article 2 of the Building Standards Act. Being quick to take to the concept that these are equipment items rather than buildings, we have also implemented a variety of functions for remote operations such as powering on/off IT equipment and checking status lamps.

At the Matsue Data Center Park we are adopting our own original MISP (Module Inter-connection over the Shortest Path) system for the placement of electrical equipment and cooling modules in front and at back of IT modules respectively. This minimizes the connection distance of components such as power cables and refrigerant pipes, and reduces the energy loss from cable distribution while also lowering equipment investment cost.

4.5 Conclusion

The proof-of-concept tests we have carried out to achieve energy savings for data centers will first come to fruition in the construction of our first-generation Matsue Data Center Park, but we will continue our forward-thinking initiatives toward achieving the integration of cooling and IT equipment and carbon neutral data centers while building up our commercial operations experience, and working toward the realization of our second- and third-generation data center parks.

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After working at a major telecommunications carrier, Mr. Kubo joined Crosswave Communications, Inc., and implemented the interconnection of NTT dark fiber in several dozen locations across the country (a Japan first). He joined IIJ in 2008, and now oversees the operation and expansion of its existing data centers in addition to the construction of next-generation data centers.

4.2
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Mr. Kawashima joined IIJ in 2002. Following work promoting the sales of SEIL/SMF and constructing large-scale solutions in the Network Integration Department, he became engaged in planning for its data center operations from 2009.

4.3
Akio Hashimoto
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Mr. Hashimoto joined IIJ in 2009 after working in the design, construction, and operation of communication base stations and as a facility engineer at data centers for telecommunications carriers. He is currently involved in the evaluation, design, and construction of next-generation data centers.