# In Pursuit of Carbon Neutrality in the Data Center

## 3.1 Introduction

Over 120 countries have declared their intention to achieve carbon neutrality—achieve zero greenhouse gas ($CO_2$, methane, $N_2O$, chlorofluorocarbons [CFCs]) emissions—by 2050, a goal of the international climate change treaty known as the Paris Agreement. The Japanese government also declared its 2050 carbon neutrality goal in October 2020. And in the Green Growth Strategy it unveiled in December 2020, it set goals for a wide range of industries, with the following goals being laid out for data centers.

- By 2030, all newly constructed data centers should consumer 30% less energy and be partly powered by renewable energy
- Aim for carbon-neutral data centers by 2040

Data center carbon neutrality is to be achieved primarily by reducing $CO_2$ emissions from power consumption to zero. This will entail costs including for the purchase of renewable electricity, technology development, and capital investment, but achieving carbon neutrality early will help companies differentiate from peers and enhance service value. Carbon neutrality is also starting to appear among procurement criteria for products and services, and equity markets are calling on companies to disclose information on how they are effectively impacting climate change rather than simply mechanically disclosing data, and these developments also no doubt create an incentive for carbon neutrality.

Data center carbon neutrality will be achieved via two avenues: saving energy by using it more efficiently and using renewable energy not tied to $CO_2$ emissions. Matsue Data Center Park (Matsue DCP) and Shiroi Data Center Campus (Shiroi DCC), which IIJ built and operates, feature highly energy-efficient equipment and outside-air cooling systems the technology for which was developed and tested with high energy-saving goals in mind, and the resulting energy savings are reducing IIJ's greenhouse gas emissions.

In addition to such energy savings, we also plan to make increasing use of renewable energy ahead by setting up carbon-neutral data centers so that renewable energy generation systems and the data center can work in concert with each other.

Below, we go over our energy-saving initiatives at Matsue DCP and Shiroi DCC, where we have achieved strong energy-saving performance, and we round out the discussion by presenting a reference model for carbon neutrality in the data center.

## 3.2 Outcomes at Matsue Data Center Park

On April 26, 2011, we opened Japan's first commercial modular data center with outside-air cooling systems, Matsue Data Center Park in Matsue-shi, Shimane Prefecture. Matsue DCP features IZmo units, IT modules developed by IIJ and imbued with its extensive data center operational knowhow. To expand into more enterprises in Japan and abroad and tap into new markets, we also operate co-IZmo/I modular data centers, which use indirect outside-air cooling systems. Matsue DCP has been in stable operation since being opened as the core facility for IIJ's GIO cloud services, and with 90% of the server-housing containers now installed, the total number of servers running is in the tens of thousands. Site 2, added next to Site 1 in 2013, introduced co-IZmo/I units in addition to IZmo and uses a three-phase four-wire configuration to power its servers and other IT equipment, reducing power distribution losses and thus saving energy (Figure 1). Data centers generally house large-capacity electrical equipment and air conditioning systems to create an environment in which large numbers of servers and other IT equipment can be installed efficiently. IT equipment is the biggest consumer of data center power, but air conditioning systems are right behind it. So we needed to rethink the use of conventional air conditioning systems and introduce new systems that consume less power. Based on past demonstration testing, IIJ determined that outside-air cooling systems that use outside air to reduce power consumption and do not require cooling towers and the like would be suited to its next-generation data centers. Outside-air cooling, however, involves the exchange of a large volume of air, so the intakes and outlets need to be installed directly on the server rooms. This raises a number of difficult problems to do with building structure when seeking to install such systems on existing buildings. So we developed the IZmo IT module, in which the air ducts are integrated with the server room.

PUE (Power Usage Effectiveness), a metric developed by the Green Grid, is often used as a measure of how effectively a data center uses power. Figure 2 shows the PUE equation.

Theoretically, the smallest (best) PUE score is 1.0, which occurs when zero power is consumed by air conditioning equipment etc. Figure 3 shows five years of measurements for the IT-module-only metric pPUE (partial PUE, ignores energy losses from shared resources etc.).

The summer pPUE readings are higher than for other seasons because the air conditioning modules run in a


Figure 1: Matsue Data Center Park Site 1 and Site 2
(Photo of Matsue Data Center Park taken around 2019)

$$\text{PUE} = \frac{\text{Total facility energy (energy used by IT equipment + energy used by air conditioners etc.)}}{\text{Energy used by IT equipment}}$$

Figure 2: The PUE Equation

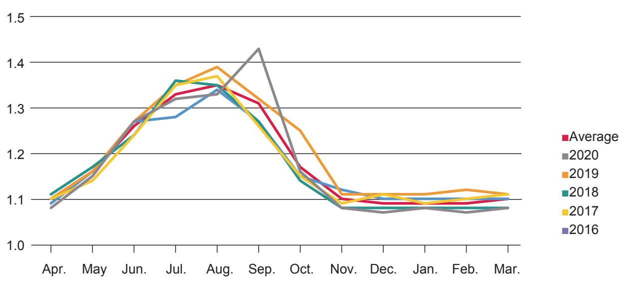



Figure 3: Annual pPUE Scores for the Past Five Years

high-power-consumption mode that does not use outside air. In comparison, spring and autumn pPUE readings are around 1.1 because the modules run in a low-power mode that uses outside air. In winter, the modules mix IT equipment exhaust and outside air to achieve the right temperature, and since this mode also consumes less power, pPUE is around 1.1. The average over the past five years is 1.18.

### ■ IZmo and co-IZmo/I

The IZmo IT module is a non-building container conforming to technical advice issued by Japan's Ministry of Land, Infrastructure, Transport and Tourism in March 2011. The modules are easy to set up because there is no need to apply for building permission. With conventional data centers, the servers had to be unpacked one by one, installed in a rack, and wired up. But with containerized data centers, the servers are installed into IT modules at the server factory, and the IT modules are transported by truck for installation at the site. This eliminates box and packaging waste, makes better use of resources and is better for the environment, and helps reduce CO2 emissions from equipment transportation. Recently, when replacing IT equipment, instead of removing the entire container, operators can opt to remove all of the server racks from the container and take them to the server factory, where the new equipment is installed in the racks so they can then be reinstalled in the containers.

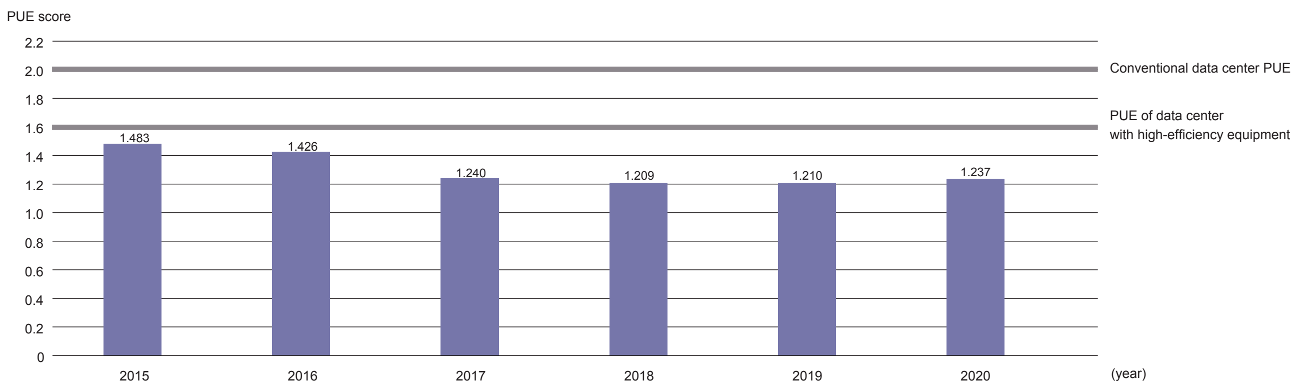



**Figure 4: Annual Average PUE for Matsue DCP as a Whole**

**Figure 5: IZmo and co-IZmo/I**

IZmo uses direct outside-air cooling and automatically switches between three modes depending on outside air temperature and humidity. It controls the temperature at the intake port within the IT module to meet the recommended temperature and humidity conditions set by Ashrae (American Society of Heating, Refrigerating and Air Conditioning Engineers) in 2008.

co-IZmo/I uses indirect outside-air cooling. In contrast with direct outside-air cooling, outside air is not channeled directly into the container, and instead, internal heat is expelled indirectly via a heat exchanger, so this method can be used even when outside air conditions are poor. We have also exported some of these modules internationally. See Figure 5.

Theoretically, IZmo, which uses direct outside-air cooling, is more efficient (lower pPUE) than co-IZmo/I with its indirect outside-air cooling (pPUE value is low), but as Figure 6 shows, the fine-tuning of control mechanisms and the like make it possible to run co-IZmo/I modules at pPUE scores similar to those of IZmo.

### Three-Phase Four-Wire System

At Site 2, we introduced a three-phase four-wire uninterruptible power supply (UPS) system, a first among Japanese data centers (Figure 7). Three-phase four-wire power transmission involves three wires for three-phase AC plus a grounded neutral wire. It is more efficient than single-phase AC, uses a lower current, and conductor (wire) size can be reduced by transmitting power at high voltage (low current). It is widely used in Japanese factories. One of the three 400V wires from the UPS can be isolated along with the neutral wire to pull out a 230V supply without a transformer. This is common in data centers overseas where 100V is not required, but the common need for 100V in Japan means that, until now, transformers have commonly been installed in three-phase three-wire UPSs to transform power from 400V to 100V. Since servers can operate at any voltage from 100V to 230V, and because IIJ uses a lot of servers for its cloud infrastructure, we chose a three-phase four-wire system, eliminating the need for transformers.

Given that power (W) = current (A) x voltage (V), a reduction in wire size means that, for any given load capacity (W), the higher the voltage (V), the more you can reduce the current (A). Specified currents for electrical wire (the maximum current it can carry) are set according to the type of insulating sheath and the size of the wire (mm2). So at lower specified currents, wires with a lower permissible current can be used, and the lower a wire's permissible current, the smaller its diameter, which can help reduce the investment cost. Further, voltage drop can be reduced because three-phase four-wire systems are even less susceptible to voltage drop than three-phase three-wire systems, in which the voltage drop decreases as the current decreases. At Matsue DCP, this allows for a lower transmission current between the UPS output and the server input, and it reduces losses because no transformers are used. This results in a theoretical reduction in losses of around 25%.

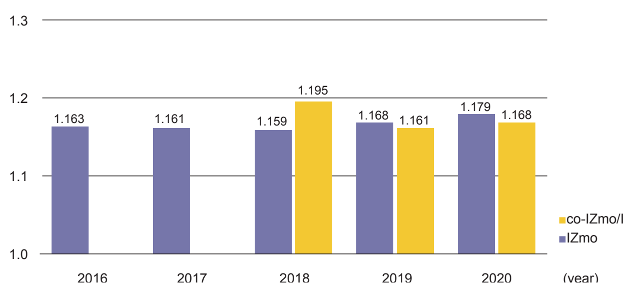



Figure 6: Comparison of IZmo and co-IZmo/I pPUE Scores

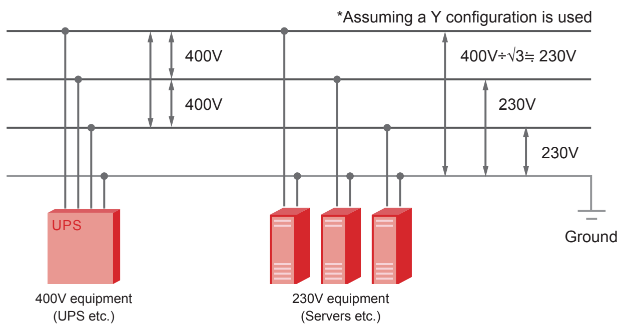



Figure 7: Y-connection Overview of Three-phase Four-wire System

### Environmental Initiatives

In terms of environmental initiatives, we have ISO 14001 (EMS, Environmental Management Systems) certification and work to comply with energy conservation laws and regulations.

Matsue DCP operates in accord with its ISO 14001 certification, acquired in 2013. We set annual targets for environmental initiatives. Our past efforts have included going paperless, reviewing the air conditioner temperature settings within buildings and operations rooms, and reducing pPUE by 0.01 per year. Using power more efficiently is one thing, but the EMS certification also requires us to address the risk of the environmental impact on lives and ecosystems from atmospheric pollution caused by fires and the impact of soil pollution caused by the leakage of fuel from emergency power generation facilities. We have therefore prepared response manuals for emergencies such as fires, earthquakes, and equipment accidents, and we regularly conduct response training sessions, environmental management education and training sessions, and environmental compliance assessments. Matsue DCP is in an area that experiences relatively few natural disasters and earthquakes, but we strive to raise environmental awareness through regular education and training.

On the topic of environment, energy, and CO2 emissions, we have compiled data on our energy usage into periodic reports in accord with energy conservation laws and regulations since Site 1 was opened in 2011. Because Matsue DCP's energy usage exceeded 1,500kL (crude oil equivalent) in fiscal 2013, we have also been working on energy saving measures in accord with the facility's classification as a Type 2 Designated Energy Management Factory. We have appointed an Energy Manager and formulated a medium-term plan, and we implement and evaluate energy-reducing initiatives based on the facility's energy usage every year. As the facility has many air conditioning systems, we also comply with Japan's CFC emissions law by measuring the amount of CFC gas leaked and identifying leaks and their causes through inspections and such.

As Matsue DCP's electricity usage increases by the year, efforts to save more energy and further reduce CO2 emissions are becoming increasingly important. We will continue to focus on environmental initiatives including those to reduce energy consumption, use renewable energy, and install renewable-energy equipment.

## 3.3 Initiatives at Shiroi Data Center Campus

We opened Shiroi Data Center Campus on May 1, 2019 in Shiroi-shi, Chiba Prefecture (Figure 8). Shiroi DCC is a large-scale data center designed to cope with the explosive growth in data center demand for 5G, IoT, AI, cloud services, and the like. It brings together the data center technologies and knowhow that IIJ has developed or evaluated to address issues with data center operations in the past. It is also a system module-type data center where we can actively roll out new technologies.

Shiroi DCC draws on the successes of Matsue DCP and is designed to overcome the obstacles and challenges encountered. On the energy front, it inherits the concept of modular server rooms, direct outside-air cooling systems, three-phase four-wire UPS and bus duct power transmission technology. The entire Shiroi DCC facility runs at an annual average PUE of under 1.2, and we are endeavoring to expand the usage scenarios for its power systems.

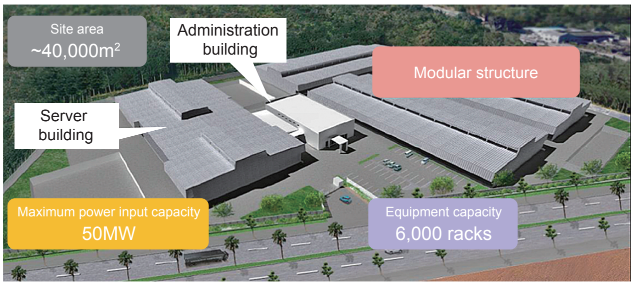



Figure 8: Artist's Impression of Shiroi Data Center Campus Once Completed

## Direct Outside-Air Cooling Systems and System Modules

As a new modular data center, Shiroi DCC takes advantage of operational experience from Matsue DCP and knowhow gleaned from containerized data center development, applying this on a floor scale (several hundred racks or so) and using system modules capable of serving needs on a larger scale. The buildings follow a systematized construction scheme based on standard shapes and arrangements for the steel building frames and outer walls, facilitating rapid construction at low cost and high quality (Shiroi DCC phase-1 building: from start of construction, it took four months to have the roof frame in place, eight months to fully complete). All of the internal elements of the system modules—electrical system, air conditioning system, and server racks—are modularized, making it possible to add or replace (upgrade) equipment for each server room individually.

These system modules are also integral to the reduced energy usage of the air conditioning systems at Shiroi DCC, which has a huge number of racks. Using the system modules' characteristically large space, large apertures, and wide span, we created a side-flow direct outside-air cooling system that utilizes the chimney effect.

Figure 9: Test of the Chimney Effect (2012)
*Patent no.: 6153772 (granted June 9, 2017)

## Chimney Effect

The direct outdoor-air air conditioning systems in use at Matsue DCP and on IZmo containerized data center units have greatly reduced the annual power consumption attributable to outdoor units, resulting in an annual average PUE of 1.237 for Matsue DCP and annual average pPUE of 1.18 for containers. The systems need ventilation fans to blow cool air into the cold areas year round, however, and the power used by these fans was the next energy-saving issue we faced with the air conditioning systems. To tackle this issue, in 2012 we conducted tests (Figure 9) to see if we could take advantage of the chimney effect (phenomenon whereby the difference in temperature on the inside and outside of a chimney causes an upward current) to cool the servers. If this was possible, we thought, it could greatly reduce the power consumed by the ventilation fans and take us closer to a PUE of 1.0, and if it also made it possible to reduce IT equipment internal fans, this could also help to further reduce overall data center power consumption.

Although the conditions under which the chimneys were installed (weather, air temperature and humidity, wind speed, etc.) did affect the results, our tests showed that airflow volume increased roughly proportionally with increases in the height and load capacity of the chimneys (Figure 10). As a result, we determined that we could assist the air conditioner ventilation fans by grouping several racks into a single module and positioning several modules at the center of the room so that outside air could be drawn in from the sides of the room, and exhaust air from the modules could be expelled from the top of the building. Shiroi DCC is designed with these test results in mind in terms of the system module layout and the direct outside-air cooling systems.

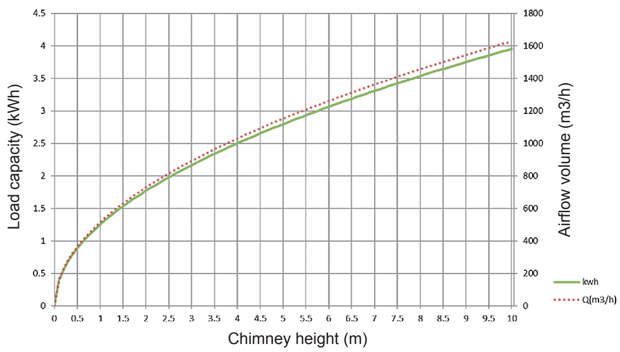



Figure 10: Chimney Effect Test Results
(excerpt: change in airflow volume according to chimney height)

## Side-Flow Air Conditioning

Shiroi DCC uses a side-flow system (IDC-SFLOW, a trademark of Takasago Thermal Engineering Co., Ltd.) that supplies cool air directly into the server room via the partition wall between the server room and the air conditioner room (Figure 11).

Data centers housed in buildings often employ floor ventilation with air supplied via the space under a raised, free-access floor. Space is tight, however, and the speed of airflow through the server room inlet (free-access grille) is high. This sort of design also has communications and power cables routed through the same space, which increases air supply resistance and results in a greater loss of pressure. A large pressure loss means more energy is required for air conditioning, so the ventilation fans use more power. Shiroi DCC's wall-based side-flow air conditioning uses the system modules' characteristically large space, large apertures, and wide span as the air supply air route. The inlet openings are designed to be as large as possible so that when air is blown through the server room, air supply resistance is lower and the pressure loss is thus minimized. Shiroi DCC is designed to use an average of 6kW/rack, and the heat generated by the servers can be dissipated by blowing air via the inlets into the server room at a slow airflow rate of 2m/s. This made it possible to greatly reduce (to around a third) the amount of power consumed by the air conditioning system's ventilation fans. The low airflow rate also makes for a better working environment in the server rooms and greatly reduces the stress on workers.

## Direct Outside-Air Cooling

Shiroi DCC uses direct outside-air cooling systems that are integrated with the system modules. Air is drawn into the air conditioner room via intake ports on the eaves on the side of the system module, passing through a medium-performance filter, and then mixed with server exhaust heat and supplied into the server room at a set temperature and humidity. And server exhaust heat, in the same amount as the outside air drawn in via the eaves, is expelled via exhaust ports at the top of the building.

Figure 12 shows the basic plan for a large-scale data center created in 2012. At the time, there was skepticism within IIJ about whether we could actually build something like this. But the direct outside-air cooling systems designed on top


Figure 11: Side-flow Air Conditioner Outlets

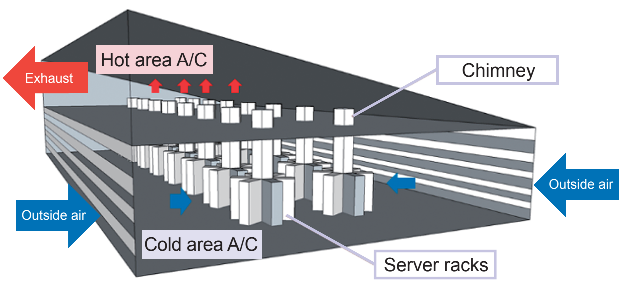



Figure 12: Modular Data Center Design Proposal at Time of Chimney Effect Testing (2012)

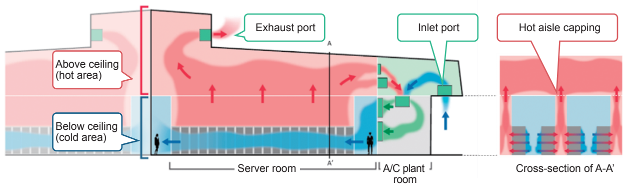



Figure 13: Cross-sectional View of Shiroi DCC System Module (2019)

of knowhow gleaned from Matsue DCP and technical tests on the chimney effect and the like culminated, after almost 10 years of effort, in Shiroi DCC as depicted in Figure 13.

### ■ Using AI to Optimize Air Conditioning Systems

At Shiroi DCC, we use AI to find the optimal combination of parameters for not only the air conditioners but the IT equipment as well. We endeavor to optimize air conditioning system operating conditions based on metrics of energy savings, cost savings, and CO2 reductions.

### ■ 2012 Chillerless Tests and 2013 IT Equipment Adaption Tests

The air conditioning systems on the IZmo units in use at Matsue act as direct outside-air systems during autumn, winter, and spring, but during summer, the outside air is shut off and indoor units are used to cool and dehumidify (circulation mode), so the energy savings in summer are worse than in the other seasons (autumn/winter/spring pPUE = 1.095, summer pPUE = 1.331). In an effort to resolve these issues, we did an assessment of data center health under a scenario of using outside-air cooling year round and not running the external air conditioners, chillers, etc. When Matsue Site 2 went into service in 2013, we developed co-IZmo/D, a new type of containerized data center module that uses year-round outside-air cooling, and started conducting a whole series of tests (Figure 14). co-IZmo/D integrates air conditioning features and IT equipment modules into an ISO-standard 20-foot container without the use of external air conditioners or humidifiers. In one of our tests, dubbed the 2013 IT Equipment Adaptation Test, we worked with major IT equipment vendors to evaluate the characteristics of IT equipment in summer and winter in a completely outside-air air conditioned environment and assessed the health of IT equipment under year-round outside-air cooling.

We ran the tests on IT equipment supplied with a maximum air temperature of 35°C/40°C, and the IT equipment functioned normally in a high-temperature environment of 45°C without any drop in CPU processing performance etc. In a high-humidity environment, however, we did observe a noticeable deterioration in the IT equipment boards. From these tests, we concluded that high humidity would reduce IT equipment operating life and increase fault rates. The tests also revealed that the rotation speed characteristics of IT equipment internal fans vary a bit depending on the


Figure 14: co-IZmo/D

IT equipment manufacturer's design (Figure 15). From a facilities perspective, letting server room temperature rise by 1°C will save on air conditioner power consumption. But with tens of thousands of IT equipment units all running in a unique way as the temperature rises, the power consumption of those units also changes. To maintain data center quality and achieve true energy savings, therefore, we determined that, instead of simply raising server room temperature, we should understand the individual characteristics of the IT equipment and control operations to be jointly optimal for both the IT equipment and the facility itself.

### AI Control

Shirai DCC uses AI-based air conditioning control that minimizes the combined power consumption of the IT equipment and air conditioning systems, the main data center elements, based on what we learned from our testing efforts, including chillerless operation tests and IT equipment adaptation tests. IT equipment characteristics such as rated current and current draw at different temperatures (as measured in Shiroi DCC's test environment) are recorded in a database, and measurements of server room temperature, actual IT equipment current draw, amount of heat processed, and so forth are taken and analyzed while the facility is in operation to provide (rule-based) estimates of the characteristics of each individual rack. Similarly, air conditioning system characteristics are estimated based on certain operating conditions, parameters, and so forth, and a rule engine infers the operational settings that will minimize the combined power consumption of the IT equipment and air conditioning systems, with the result being to optimize air conditioning system operating conditions.

So we have deployed the direct outside-air cooling systems developed at Matsue on system modules that minimize pressure loss by virtue of a large space, large apertures, and wide span, and combined this with AI control, and we intend to proactively adopt new technologies going forward, our ultimate goal being to achieve an annual average PUE of under 1.2.

### Lithium-ion Batteries

We have chased energy savings at Matsue DCP through the use of outside-air cooling and air conditioning units with high COP scores, and by selecting high-efficiency IT

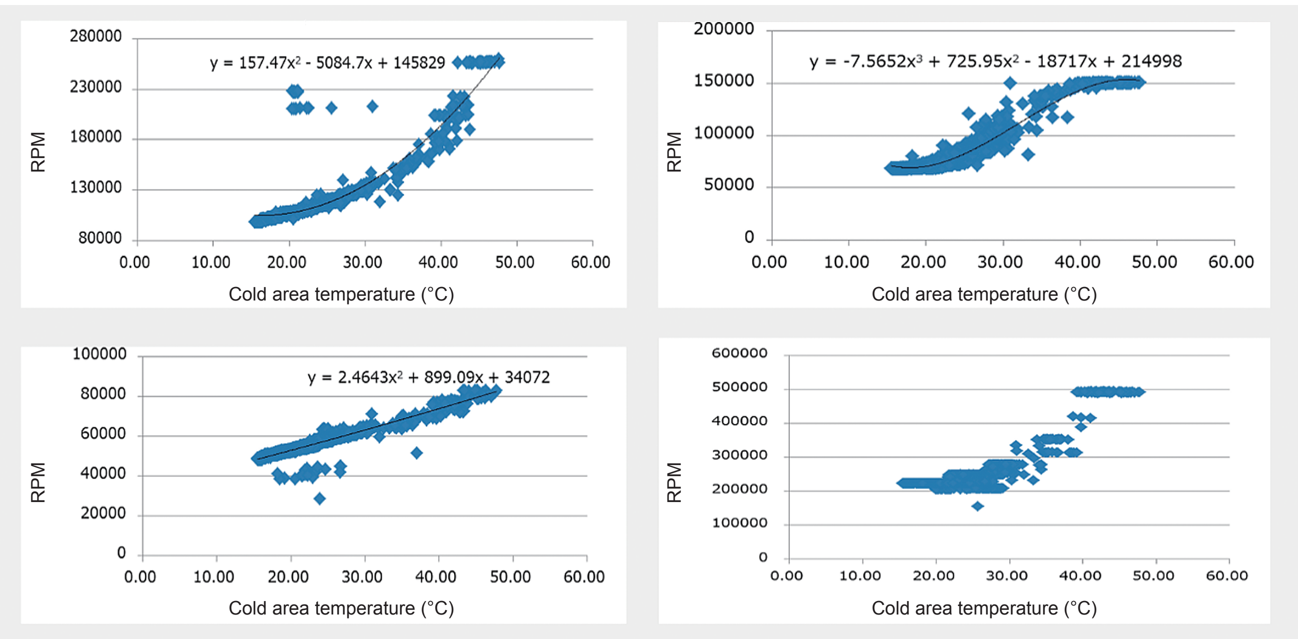



**Figure 15: IT Equipment Internal Fan Rotation Speed Characteristics by Manufacturer (Chillerless Tests, 2012)**

equipment. Air conditioning systems and IT equipment are always the main factor in data center energy savings. The key element in a data center, however, is the power system. We see the power system as the next key avenue for saving energy. Accordingly, we adopted a three-phase four-wire UPS and bus ducts at Matsue DCP Site 2, and we also continue to evaluate software for predicting electricity usage and for peak-shaving control, and continue to devise and evaluate mechanisms for the selective supply of power from fuel cells, PV systems, and DC UPS systems.

Before designing Shiroi DCC, we also conducted a technology survey, mainly looking at lithium-ion batteries, with a focus on two particular themes: (i) highly economically viable power generation systems based on summer usage, peak usage, etc. and (ii) electricity/power systems capable of delivering high efficiency in view of future technology trends. Based on this, we selected Powerpack, a lithium-ion battery storage solution from Tesla that offers operating control features, installing it in November 2019 (Figure 16). Powerpack replaced the lead-acid battery UPS that we initially intended to install as a backup power supply for the air conditioning systems, and it offers the added feature of peak shaving at a similar cost level to the lead-acid battery UPS. Powerpack enables peak shaving and load shifting with respect to the power received by the data center, which peaks during summer daytimes. It makes it possible to reduce basic charges by reducing the demanded power and to reduce electricity charges by using power at off-peak times and thus purchasing electricity at lower prices (Figure 17).

In the past, UPS systems, emergency generators, and other such power systems played a behind-the-scenes role in ensuring high quality. At Shiroi DCC, we are working to develop a new business model by actively looking for more ways to use such systems as data center energy resources.

## 3.4 Carbon Neutral Data Center Model

### ■ IIJ's Carbon Status and Road to Carbon Neutrality

Manufacturing industries are being called on to reduce the CO2 emissions that result from making products in factories, and the transport industry to reduce the CO2 emissions from trucks. Given that over 90% of IIJ's CO2 can be traced back to the power consumed by its data centers, the use of energy-saving equipment and renewables


Figure 16: Powerpack installed at Shiroi DCC

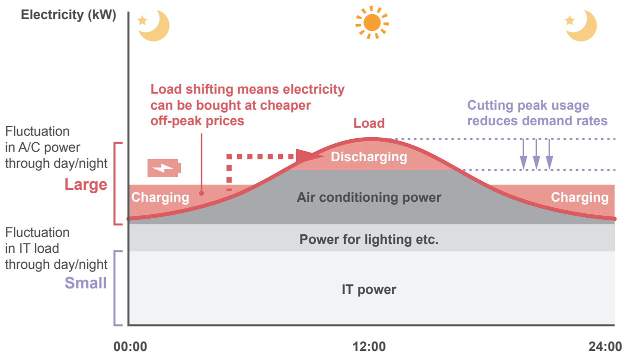



Figure 17: Data Center Power Demand and Peak Shaving / Peak Load Shifting

directly impacts on the carbon neutrality status of IIJ as a whole.

We plan to continuously improve the energy-saving technologies implemented at Matsue DCP and Shiroi DCC as described above to make the facilities even more energy efficient. Meanwhile, we have only just started working on the use of renewable energy, and one of the early possibilities for tackling this will be to switch to an electricity retailer supply contract for the supply of renewable energy certified as non-fossil fuel electricity. There are disadvantages, however. Renewable energy is more expensive than ordinary electricity, and there is no guarantee that it will be supplied at a stable price over the long term. So with the cost of generating renewable energy falling year by year, possible next steps may be to buy electricity directly from renewable energy plants or to have our own generation plants.

Although renewable generation costs are falling, power generated from non-solar sources including wind and biomass remains more expensive than ordinary power purchased from electric utilities. And building a power plant will take time, including the time needed to obtain a suitable site, so it is more realistic as a medium- to long-term proposition. Near term, we need to implement mechanisms for the supply of power with a focus on solar, or photovoltaic (PV), generation.

## Carbon Neutral Data Center Model

In light of all this, with a view to achieving carbon neutrality, we have defined a carbon-neutral data center reference model with the features listed in Table 1, and we plan to continue modifying our data centers and building new ones in this light.

| No. | Feature |
|---|---|
| 1 | Use of energy-saving technologies, such as outside-air cooling systems that substantially reduce air conditioning power consumption and an efficient three-phase four-wire UPS, to reduce absolute power consumption levels. |
| 2 | Absence of other equipment and fixtures on building roofs to make large roof areas available for the installation of on-site PV systems. |
| 3 | In the short term, procure power from a combination of extra-high-voltage, high-voltage, and low-voltage off-site PV systems. Long term, allow for the possibility of procuring power from other sources such as wind and hydrogen. |
| 4 | When daytime power supply exceeds consumption, store the excess in batteries for use at night. |
| 5 | Use of network measurement and control functions between generation equipment and the data center to balance the amount of power generated and the amount consumed. |
| 6 | Use of IT load control to channel loads toward times of surplus power. |

Table 1: Features of a Carbon-Neutral Data Center

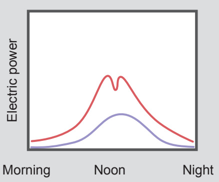
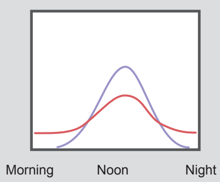
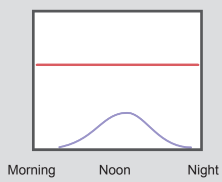
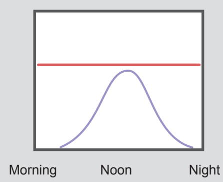
| Type of facility | Office building | Warehouse | Conventional data center | Carbon-neutral data center |
|---|---|---|---|---|
| Power consumption | Low | Low | Medium to high | Medium to high |
| Power density | Low | Low | High | High |
| On-site PV installation space | Small<br>Typically, external A/C units etc. are installed on rooftops | Medium<br>Large-scale rooftop installations possible | Small to medium<br>Similar to office buildings, but dedicated equipment can be used to create space | Medium<br>Roof structure allows for large-scale rooftop installations |
| Typical daily power profile<br>— Generated<br>— Consumed |   |   |   |   |

Table 2: Differences in Electric Power by Type of Facility

The first feature is the use of energy-saving technology to the greatest possible extent to reduce absolute power consumption.

The second feature is the installation of as much on-site PV generation capacity as possible, as the cost of generating electricity this way is now lower than ordinary electricity charges. As Table 2 shows, data centers bring together vast amounts of IT equipment and thus consume several dozen times more power per unit floor area than office buildings and the like (said to be around 50–100W/m$^2$). As they consume so much in absolute terms, PV generation alone cannot keep up with demand for power across the entire data center. But by adopting a warehouse-like building structure and making the roof, where PV systems are installed, as large as possible, you can increase low-cost on-site PV generation capacity.

The third feature is the installation of off-site power generation equipment (off-site equipment that supplies power to your site via the power utility grid). As Table 3 shows, off-site PV is more expensive than on-site PV, but increasing off-site PV capacity is a viable option for securing the required amount of power.

Off-site PV systems can be classified into three types according to the voltage at which they connect to the power grid, as shown in Table 4. To adequately supply a several-dozen-MW-scale data center, a large, extra-high-voltage PV system is efficient, but these tend to take a long time to build because you have to find a suitably large site, negotiate connection terms and conditions with the electric utility, and so forth. The high-voltage and low-voltage options are quicker to build, but if you want to generate the same amount of power as a 50MW extra-high-voltage PV installation, for example, you will need 1,000 50KW low-voltage generation plants. Given the amount of power required and time required, we think off-site PV power needs to be sourced from a combination of extra-high-voltage, high-voltage, and low-voltage systems.

| System type | On-site PV | Off-site PV |
|---|---|---|
| Characteristics | ・No need for a dedicated site if installed on your building rooftops etc.<br>・In contrast with off-site PV, involves no wheeling charges or renewable energy levies, and use of subsidies can make it even more cost effective.<br>・But scale is small (can only supply a few percent of total data center usage). | ・Initial costs, including those for the land, are higher than for on-site if you take on the capital investment yourself.<br>・Need to enter into long-term contracts if having power supplied from another company's equipment.<br>・Involves wheeling costs as power is supplied via the power utility grid.<br>・Systems/procedures can change.<br>・Can adjust the amount of power generated by increasing scale or adding plants. |

Table 3: Differences Between On-site and Off-site PV

| Power grid connection voltage | Extra-high-voltage 2,000kW or more | High-voltage 500–2,000kW | Low-voltage up to 50kW |
|---|---|---|---|
| Required site area (at 10m$^2$/KW) | 20,000m$^2$ (2ha) or more | 500m2 – 20,000m$^2$ (2ha) | up to 500m$^2$ |
| Initial investment | 22.2 yen/kW<br>440mn yen or more | 22.2–25.5 yen/kW<br>13–440mn yen | 25.5 yen/kW<br>up to 13mn yen |
| Construction period | 1 year or more | up to 1 year | up to 6 months |
| No. plants needed for 50MW output | 5MW/plant<br>10 plants | 500kW/plant<br>100 plants | 50kW/plant<br>1,000 plants |

Table 4: PV System Categories

Storage is the fourth feature required for carbon-neutral data centers. As Figure 18 illustrates, as off-site PV increases, the power supplied by PV capacity in the daytime can overshoot data center power consumption, in which case it is stored and used at night. This makes it possible to use renewable energy at night as well, but the fact that the cost of storage batteries is still high is an obstacle to the full-fledged rollout of such systems.

The fifth feature is the use of network functions that enable measurement and control of what happens between the power generation equipment and the data center. This makes it possible to balance supply and demand and ensure the stable operation of the grid.

The sixth feature is the use of IT load control, which involves, for example, halting servers on nights when there is not enough power and only running them in the day, so that the load is channeled toward times when there is surplus power. Information systems generally cannot be stopped for 24 hours at a time, but we can expect more and more new use cases amenable to load control to appear—data analysis tasks that can be given a manageable timeframe to complete or mining tasks that require low-cost processing.

Figure 19 illustrates how a carbon-neutral data center with these features could be set up. To realize carbon neutrality while maintaining the reliability and other quality attributes required of a data center, we need to create a new model

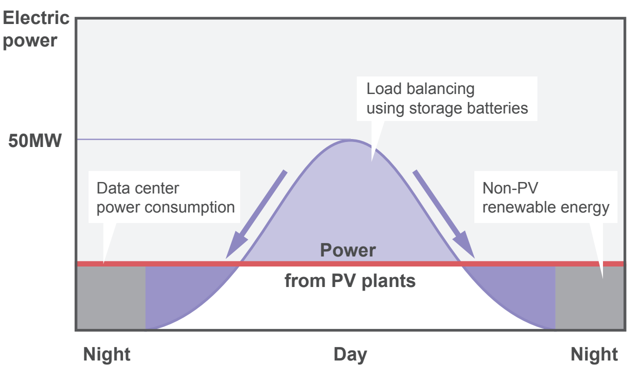



Figure 18: Data Center Power Supply/Demand Overview

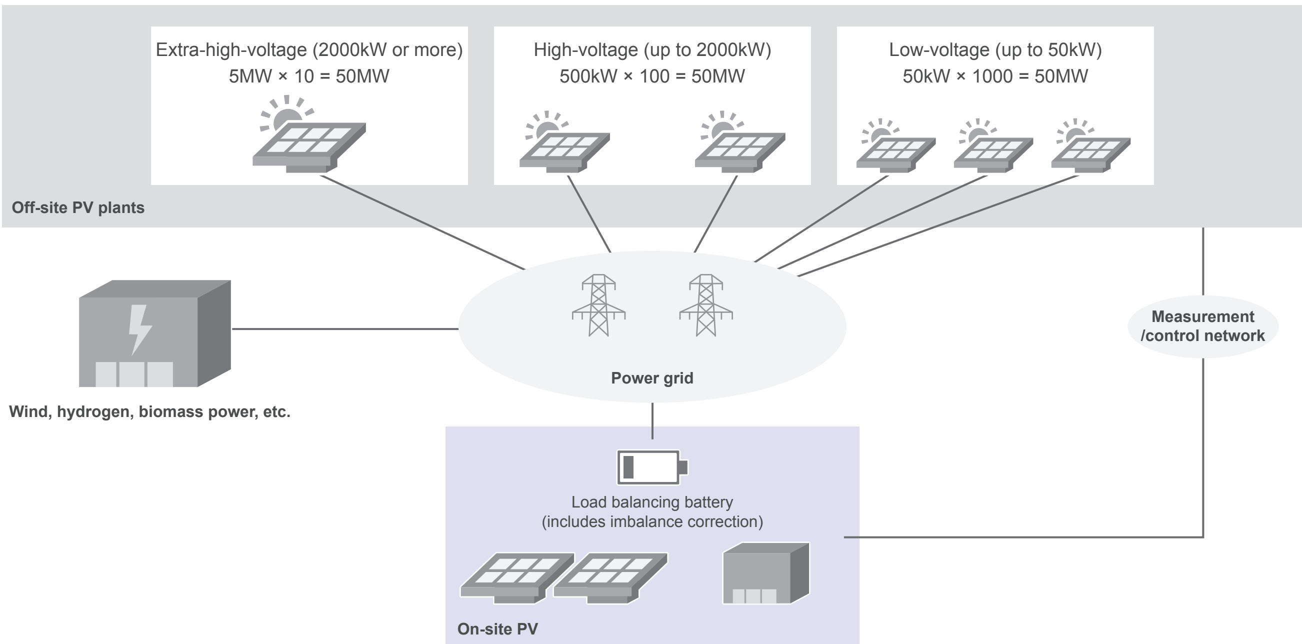



Figure 19: Carbon-Neutral Data Center Model

that organically combines the generation equipment that supplies the power and the data center that consumes that power. While we only have a conceptual model to illuminate the way forward at this stage, we will be conducting technical tests and working with external partners going forward, on both the business and technological fronts, to sort out the details and apply what we have learned when modifying our own data centers or building new ones.

## 3.5 Conclusion

IIJ has also been involved in external initiatives using the technologies it has developed in-house, one example being a NEDO (New Energy and Industrial Technology Development Organization) demonstration project aimed at using the JCM (Joint Crediting Mechanism) to reduce greenhouse gas emissions, as part of which IIJ provided support for the construction and operation of a highly energy-efficient containerized data center in the Laotian capital of Vientiane.

The road to carbon neutrality will no doubt be long and challenging, but we will continue to take advantage of Internet technologies, including IoT and mobile, and test and implement systems, and we will seek to apply the knowledge and insight we gain not just internally at IIJ but also in the world at large, our aim being to contribute toward carbon neutrality in the data center and, ultimately, across society as a whole.

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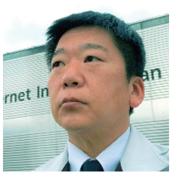
General Manager, Infrastructure Services Department, Infrastructure Engineering Division, IIJ.
Mr. Kubo joined IIJ in 2008. He oversees the data center business and the construction of Matsue DCP and Shiroi DCC. His aim is to achieve carbon neutrality as soon as possible.




3.2 Outcomes at Matsue Data Center Park
**Yoshimasa Kano**
Manager, Matsue Data Center Park, Infrastructure Services Department, Infrastructure Engineering Division, IIJ.
Mr. Kano joined IIJ in 2016. He is engaged in the operation of containerized data centers and the testing of next-generation modular data centers.

3.3 Initiatives at Shiroi Data Center Campus
**Akio Hashimoto**
Deputy General Manager, Infrastructure Services Department, Infrastructure Engineering Division, IIJ.
Director, Shiroi Data Center Campus, Infrastructure Services Department, Infrastructure Engineering Division, IIJ.
Mr. Hashimoto joined IIJ in 2009. He works on the study and design, construction, and operation of next-generation data centers and actively pursues data center automation and efficiency gains.