Cooling Technology to Reduce Air-Conditioning Power Consumption in Data Centers

YOSHIKAWA Minoru, NAKAI Yasuhiro, KISHINO Tsuyoshi

Abstract

To help mitigate the effects of global warming, efforts are underway today to reduce the impact of modern society on the environment. Information technology is expected to play a critical role in helping to minimize energy use and conserve resources. Currently, with cloud-oriented approaches and centralization of IT equipment into data centers, progress in IT capabilities is accelerating. This paper introduces some examples of NEC's R&D into highly efficient cooling technology using phase-change cooling system - which helps solve the problem of excessive power consumption by air-conditioning systems in data centers, while ensuring that the center continues to operate efficiently.

Keywords

phase-change cooling, heat transport, local cooling, air-conditioning power consumption, PUE

1. Introduction

Information technology is one of the most important factors expected to help reduce CO_2 emissions in every industry because of its potential to minimize the need for people to move around, while increasing the efficiency of the movement of goods. This shift is evident in online shopping, for example, as well as in more efficient energy consumption such as eco-driving and reduced use of consumables as in "paperless offices".

Promoting the use of IT applications in these areas has driven progress in cloud technology, leading to growing use of cloud-based systems by enterprises and other organizations. This, in turn, has resulted in an explosive increase in the amount of information traffic on the Internet, as well as accelerating the shift towards centralization of IT equipment in data centers provided with dedicated air-conditioning facilities.

However, the increasing load on data centers poses its own set of problems. With so much data being processed, the volume and density of heat generated by the data servers pushes the air conditioning systems to the limit, resulting in huge increases in the amount of power consumed in order to keep the equipment cool. This has a significant negative impact on the efficient operation of data centers.

In this paper, we will look at the cooling technology developed by NEC to solve the problem of increasing air-conditioning power consumption.

Issues of air-conditioning in data centers

One of the indices that represent the energy efficiency of data centers is power usage effectiveness (PUE). This is an index that measures the efficiency of the energy consumed by ancillary facilities such as air conditioners. As shown in **Fig. 1**, it can be represented by the formula of (total data center power consumption) / (IT equipment power consumption). The most energy-efficient data center is the one where PUE = 1.

The PUE distribution at major data centers in Japan is shown in **Fig. 2**. The average PUE of Japanese data centers is approximately 1.9, which makes it clear that about half of the power consumed at data centers is consumed by ancillary facilities.

At data centers, the processing capability of data

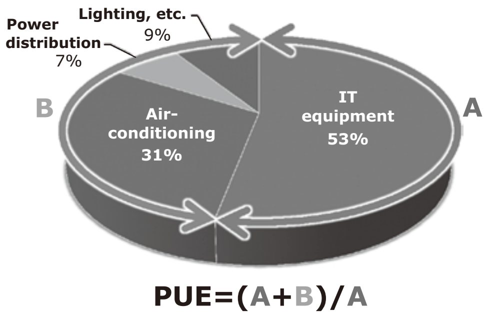

Fig. 1 Breakdown of total energy consumed in a data center.

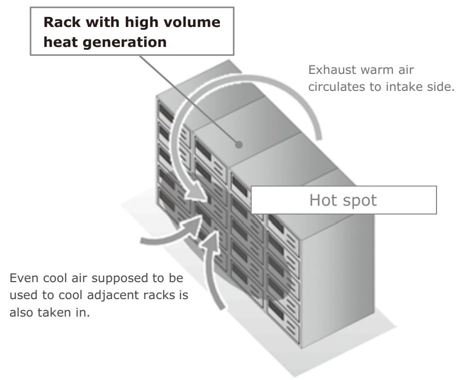

Fig. 3 Generation mechanism of a hot spot.

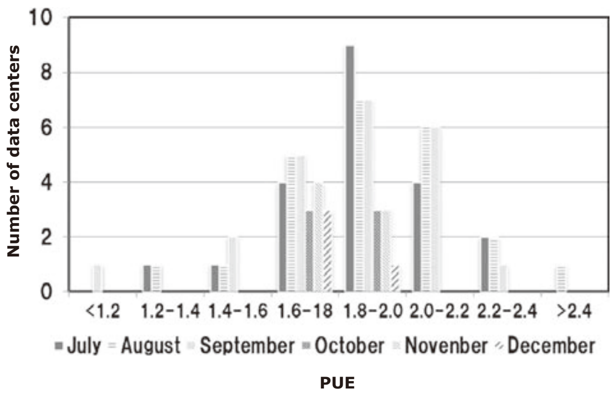

Fig. 2 PUE distribution at data centers in Japan.

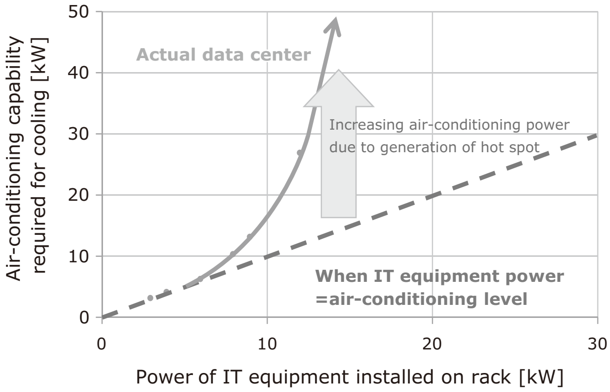

Fig. 4 Electric energy of rack and required air-conditioning capability.

servers is constantly being increased as the volume of data that needs to be processed increases. This means that the power consumption per rack of servers also increases. When the transitions in energy consumption by IT equipment at data centers relative to floor area are actually examined, we find that the amount of electric power consumed per floor area is expanding at an annual rate of 10%. By 2025, power density is expected to double.

As the electrical power used by the server rack increases, the air flow of the fans that cool the equipment also increases. An area called a hot spot with locally high temperature is generated as shown in **Fig. 3** because the warm air from the rack is taken in again or the cool air originally supposed to be used for cooling the rack is also taken in.

If a hot spot is generated, cooling efficiency deteriorates. And, as shown in **Fig. 4**, whereas the air-conditioning system's ability to cool the volume of heat (power) generated by the server rack would initially be sufficient, it quickly becomes necessary to increase air-conditioning to a level that significantly surpass the volume of heat produced by the IT equipment in order to cool it effectively. This naturally leads to a rapid increase in the air-conditioning system's power consumption. For this reason, many data center now operate by setting the upper limit of each rack at a low level from 5 to 10 kW.

2. Local Cooling Technology Using Phase-Change Cooling

This cooling technology features heat receptors on the server rack's exhaust doors that eliminate hot spots by lowering the temperature of the exhaust from the rack as shown in **Fig. 5**.

This cooling technology takes advantage of the energy called latent heat produced when the coolant changes from liquid to vapor. Unlike sensible heat, which involves the transfer of heat into air or water, latent heat can significantly reduce the power required for transfer of heat. The coolant in the heat receptor changes its phase from liquid to the vapor due to the heat exchange with the exhaust heat from the IT equipment rack. The coolant in the vapor phase radiates heat after it has been trans-

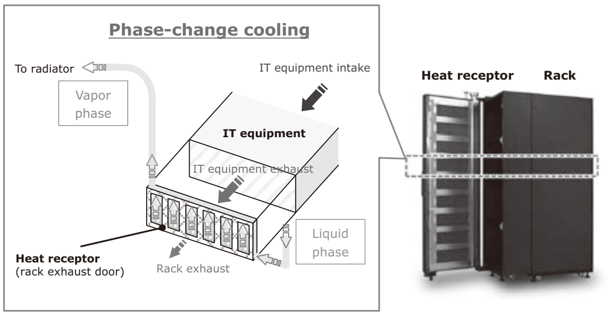

Fig. 5 Local cooling technology using phase-change cooling.

ported to the radiator. Any remaining heat which was not exchanged in the heat receptor is discharged into the server room.

For example, if the IT equipment's intake temperature is 25deg C and the exhaust temperature is 35 deg C, the exhaust temperature from the rack rises just 5 deg C, which is half the temperature rise of the IT equipment, and becomes 30 deg C, once half the exhaust temperature has been removed using this cooling technology. In such a case, air conditioners have to conventionally reduce the temperature by 10 deg C from 35 deg C to 25 deg C; however, with this cooling technology all that needs to be reduced is 5 deg C.

3. Natural Coolant Circulation Technology

The energy conservation law represented by the following formula is valid with fluid.

$$\frac{v^2}{2} + \frac{p}{\rho} + gh = const$$

v : Velocity
p : Pressure
ρ : Density
g : Gravitational acceleration
h : Height of liquid column

The first, second, and third items on the left-hand side of this formula represent kinetic energy, pressure energy, and potential energy, respectively. In a system like this cooling technology where coolant is circulated naturally, v is the velocity of the vapor phase that has been generated, whereas p is the pressure loss of the flow path through which the vapor phase flows and h is the height of the liquid column, which is the height of the heat receptor and radiator in the gravity direction, as shown in **Fig. 6**. To naturally circulate the coolant with gravity alone, it is necessary to maintain the height of the liquid column to overcome the pressure loss in the flow path that occurs when the coolant changes to vapor.

With this cooling technology, a heat receptor divided into multiple stages is installed on the exhaust door of the rack. By supplying the optimum flow rate to each heat receptor according to the volume of heat from the IT equipment, this cooling technology makes it possible to collect heat using the entire surface of the exhaust door of the rack. Also, as shown in **Fig. 7**, a tank is provided on the top of the rack to maintain the height of the liquid column to naturally circulate the coolant. This design enables multiple racks to be connected with a single pair of pipes for the vapor phase and the liquid phase.

Connecting multiple racks to a single pair of pipes for the vapor phase and the liquid phase makes it easier to design the piping layout in a server room than when separate pipes are connected to each rack. Moreover, even when the volume of heat varies from rack to rack, the appropriate amount of coolant can be supplied to each rack according to the amount of heat being generated.

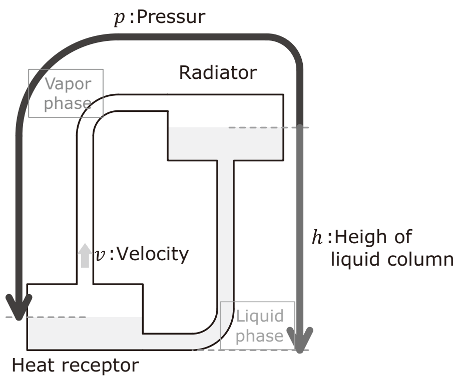

Fig. 6 Energy conservation in the natural circulation system.

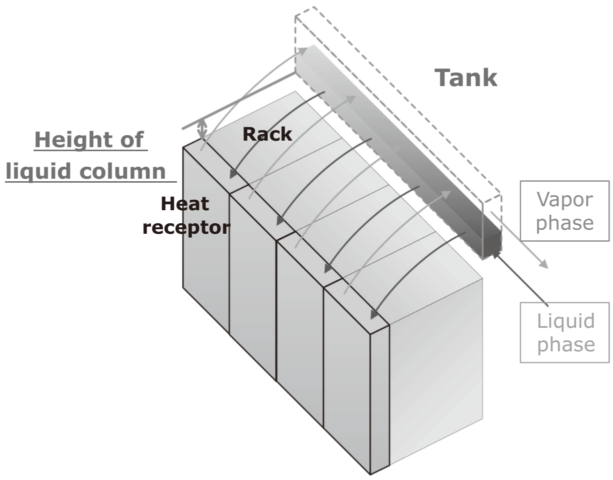

Fig. 7 Single-pair piping connection of multiple racks.

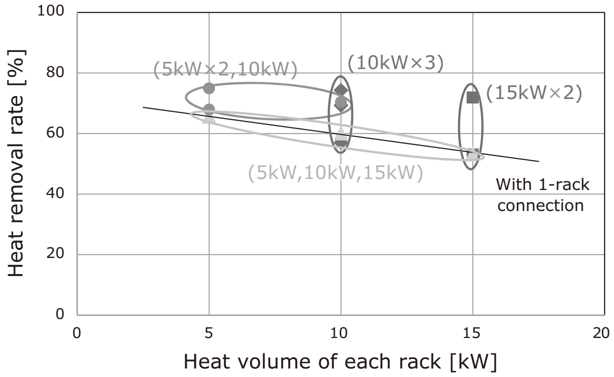

Fig. 8 Heat removal performance of multiple rack connection.

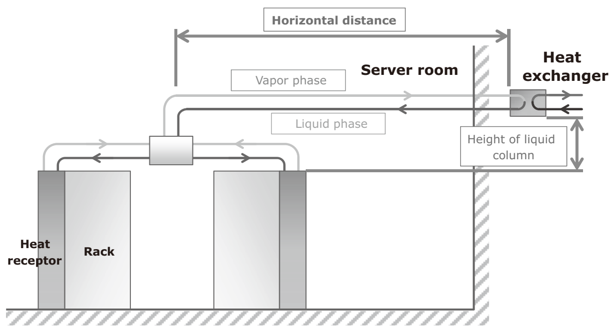

Fig. 9 Height of liquid column and distance of heat transport.

Fig. 8 shows a comparison between the heat removal rate when each rack has its own piping connection and the rate when three racks are connected with a single pair of pipes. Plotted as examples are four distribution patterns of heat removal rates, when the volumes of heat of each rack are: 5, 5, and 10 kW; 10, 10, and 10 kW; 5, 10, 15 kW; and 15, 15, and 0 kW. It is clear that the heat removal performance is equivalent to or better than can be achieved when piping connection is made for each rack.

With this coolant circulation technology, heat transport is possible over a horizontal distance of 30 meters at maximum with only 1-meter height of liquid column, as shown in **Fig. 9**, when the volume of heat of the rack is 30 kW in total.

4. Conclusion

The cooling technology described in this paper - which uses phase-change cooling to naturally circulate coolant - promises to solve the problem of increasing power consumption by air-conditioning systems in data centers brought on by the development of cloud-based systems. We are also planning to apply this technology to data centers in newly emerging economies where local temperatures are high and energy consumption is rapidly increasing. By providing advanced cooling technology, we will continue to promote environmental conservation on a global scale by offering cloud services at low cost and taking advantage of IT.

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