Phase Change Cooling and Heat Transport Technologies Contribute to Power Saving

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Abstract

The global warming issue has resulted in the social need to save electrical power in order to reduce the load on the global environment that grows daily. This paper introduces actual case studies from NEC's unique R&D of high-efficiency rack cooling technologies for the IT equipment installed at data centers. The proposed solutions will increase the rack densities and decrease the power consumptions for cooling.

Keywords

phase change cooling, heat transport, rack cooling, energy-saving cooling, air conditioning power, GWP.

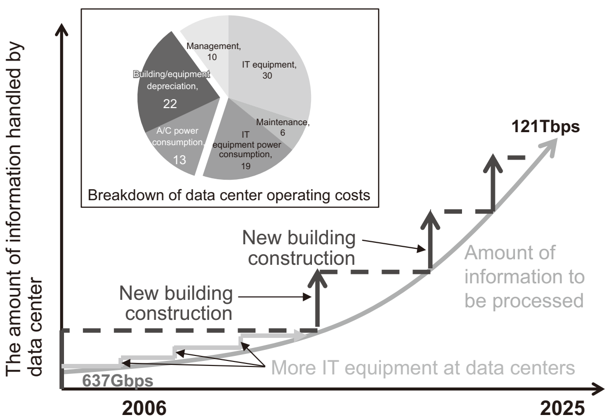
1. Introduction

The use of IT is expected to enable a reduction in the amount of industrial CO_2 because it can decrease the consumption of materials by; 1) a reduction in the migration of humans and goods, as by increased online shopping; 2) efficient energy consumption such as the eco-drive systems; 3) reductions brought by paperless work.

Promoting the use of IT has advanced the cloud services in various fields. This has led to an explosive increase in the amount of information flowing through the Internet and also to a trend in concentrating IT equipment in data centers equipped with private air conditioning systems. This has caused new problems for data centers, including an increase in the power consumption of air conditioning and for the equipment depreciation costs resulting from the construction of new data centers. This paper introduces a cooling technology that is capable of simultaneously resolving these two issues, which are caused by increases in the air conditioning power consumption and the operating costs due to the new building construction work.

2. The Data Center Cooling Issue

The progress of cloud services and the concentration of IT equipment at data centers have brought about an explosive



* Compiled based on data source materials that include, the Green IT Initiative Meeting of the Japanese Minister of Economy, Trade and Industry (METI) and the Open Government Cloud Consortium 2010.

Fig. 1 Changes in the amount of information handled by the data centers and their operating costs.

increase in the amount of information handled by these data centers, as shown in **Fig. 1**. At the same time the need for new data centers to accommodate the extra equipment has also increased.

The increase of power consumptions and the floor area occupied by the IT equipment at data centers shows that the power consumption per floor area is growing at an annual rate of 10%. The power density will be doubled by 2025, at which time the increase in the power consumption for air conditioning will pose a problem. On the other hand, one third of the operating costs of the current data centers consists of the costs of air conditioning power consumption and of building depreciation. Therefore, the increase in the operating costs due to the construction of new data centers becomes a significant factor in obstructing the advancement of the cloud storage services.

A data center increases the processing capacity of its IT equipment in order to handle any increase in the amount of information to be processed. When this causes an increase in the power consumption of the racks on which IT equipment is mounted, the air volume of the fans for cooling the IT equipment also increases. This tends to cause re-intake of warm air exhausted from the racks and/or intake of the cool air that should have been used for cooling the racks, which would lead to the production of locally hot areas called hot spots as shown in **Fig. 2**. As the attempt to resolve the hot spot issue entails a high growth in the air conditioning power consumption, many data centers set the upper limit of their projected power consumption assessment per rack at the low level of 5 to 10 kW.

Many of the traditional strategies aimed at reducing the air conditioning power are attempts to prevent recirculation of exhausted warm air from the racks to the intake area, because the heat exhausted from the racks is the main cause of hot spots.

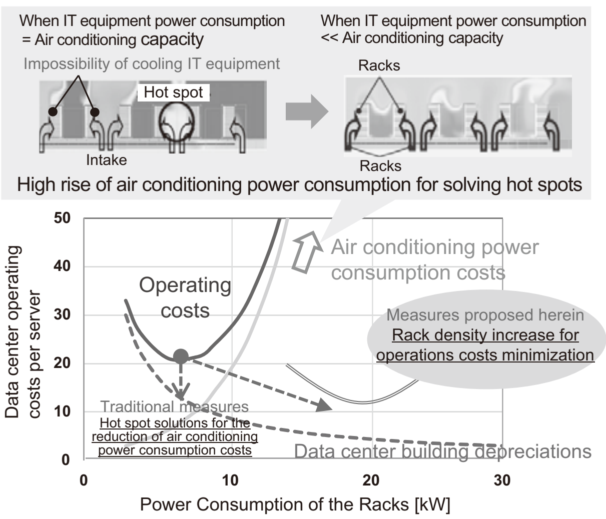


Fig. 2 Power consumption and operating cost of racks.

The measures taken to prevent the recirculation of warm exhausts are to eliminate hot spots, in order to reduce the excessive cooling power consumption of the air conditioners. Such measures are effective in solving the problem of increases in the air conditioning power consumption, but it cannot increase the maximum power consumption of the IT equipment installed in each rack so the issue of the increased operating costs posed by the construction of new buildings cannot be solved.

3. A Highly Efficient Rack Cooling Technology

The cooling technology developed recently by NEC installs a heat receiving section on the exhaust door of each rack and transports the heat from the IT equipment in the rack directly to the outside of the server room. This mechanism is shown in **Fig. 3**. This solution can reduce the apparent amount of heat generation of the racks being cooled by the air conditioners. For example, if half of the rack exhaust heat can be transported to the outside of the room without a help of air conditioners, then the air conditioner will need to cool only remaining half of the heat, so the air conditioning load can thus be halved.

(1) Phase change cooling technology

It is desirable that the power consumed by a newly added means of transporting the rack exhaust heat to the outside of a room is low. The heat can be transported by means of "air cooling" via air flow using blowers or by "water cooling" via water flow using pumps. These are the sensible heat transfer modes that the amount of heat transfer corresponds to the rise in the temperature of the fluids. Consequently, to transport more heat with a certain temperature rise, it is required to increase the flow by increasing the power consumption of the blowers or pumps. The present cooling technology employs the latent heat transfer mode that is called "phase change cooling" because this method makes use of the phase change of coolant between the liquid and gas phases. The heat transport power (Pow) is determined by the liquid flow rate (Q), pressure drop caused by the fluid flow (ΔP) and the efficiency factor (η). As an example of this calculation,

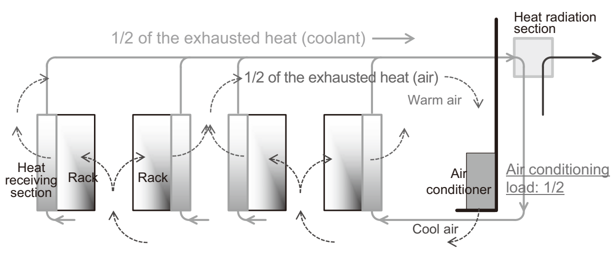


Fig. 3 Air conditioning load reduction by transport of the heat exhausted from the racks.

Fig. 4 shows the comparison of the heat transport power required for transporting 700 W heat load with a fluid temperature rise of 15°C among the different modes. The amount of heat transfer via sensible heat is proportional to the density and specific heat of the fluid. This means that water cooling requires less fluid flow than air cooling so that the heat can be transported using less power. Meanwhile, the flow required for phase change cooling corresponds only to the latent heat of the fluid and the power required for transport can thereby be reduced significantly.

In addition, this cooling technology installs the heat receiving section, or the evaporator, on the exhaust door of each rack as shown in **Fig. 5**. The coolant in the heat receiving section exchanges the heat exhausted from the IT equipment, and then changes phase from liquid to gas. The coolant in the gas phase is then transported to the heat radiating section, or the condenser, to release the heat, and the remaining heat that has not been transported in the heat receiving section is exhausted from the rack into the server room.

For example, if the temperature of the intake air of the IT equipment is 25°C and that of the exhaust air is 40°C, extracting one half of the exhaust heat by using this cooling technology causes the temperature of the exhaust air from the rack to rise by 7.5°C, which is a half of the IT equipment temperature rise, and it thus becomes 32.5°C. As a result, the air conditioner that has traditionally been required to reduce the temperature by 15°C from 40°C to 25°C now needs to reduce it by only 7.5°C, thanks to our newly introduced cooling technology.

(2) Coolant circulation technology

We have implemented two innovative measures; one is the multi-stage heat receiving section design that can collect the equipment exhaust heat, and the other is a coolant circulation technology that can control the optimum flow volume to each heat receiving section by natural means without using any drive source. This procedure enables cooling, even if an explosive increase in the amount of data processed at the data centers should occur by 2025 and the power density of the IT equipment mounted on a rack is in consequence increased by a factor of 2 or more. As shown in **Fig. 6**, if a heat receiving section with a single-stage design is installed on the rack exhaust door, the coolant in the lower part of the heat receiving section has difficulty in coming to the boiling point due to the weight of the fluid. On the other hand, the coolant in the upper part of the receiving section cannot boil anymore because it is converted into the gas phase. As a result, efficient heat transfer using latent heat becomes available only for the IT equipment installed in the proximity of the center of the rack.

In order to enable effective heat transfer over the entire

	Flow rate: Q [m³/s]	Pressure drop: ΔP [Pa]	Efficiency: η	Heat transport power: Pow [W]
Air cooling	0.04	900	0.65	55
Water cooling	12×10^{-6}	40×10^{3}	0.8	0.6
Phase change cooling	4×10^{-6}	11×10^{3}	0.8	0.05

Fig. 4 Comparison of heat transport power between cooling systems.

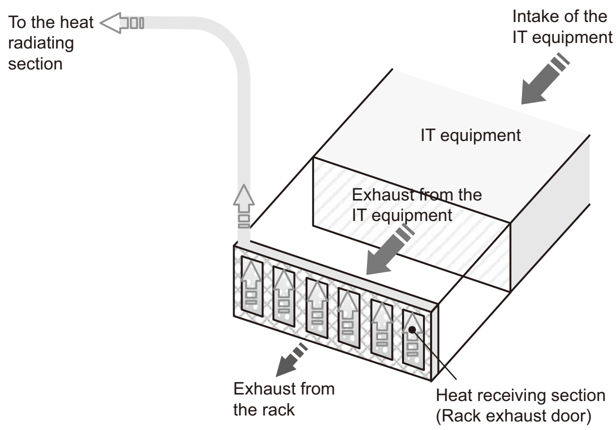


Fig. 5 Phase change cooling of a rack.

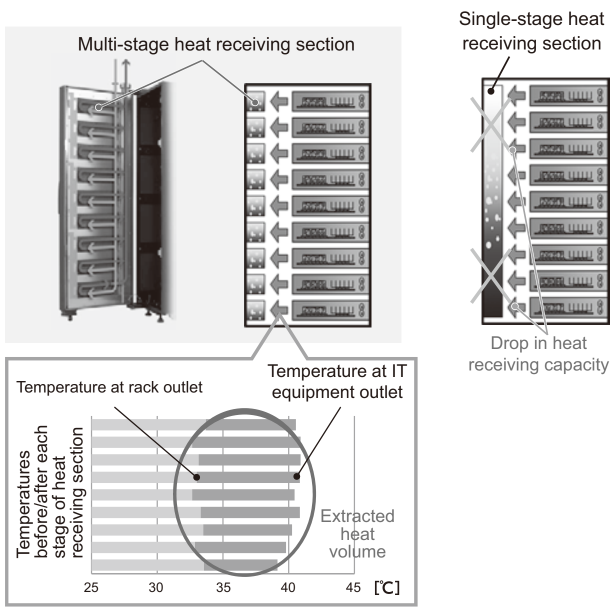


Fig. 6 Coolant circulation technology of the multi-stage heat receiving section.

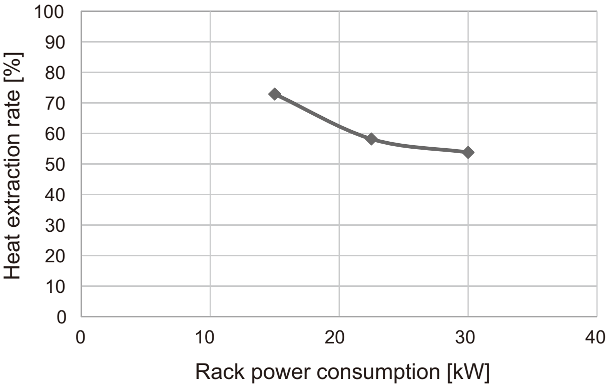


Fig. 7 Power consumption of rack vs. heat extraction rate.

	TYPE-A	TYPE-B(1)	TYPE-B(2)
Rack height	42U	42U	42U
Rack width	700mm	700mm	600mm
Phase change cooling unit external dimensions (mm) Width×Depth×Height (including projection portions)	690×124×2,105	690×124×2,083	590×124×2,083
Correspondent heat generation*1	~30kW	~15kW	~15kW
Weight (including the rack)	45kg (219kg)	45kg (219kg)	38kg (205kg)

*1 per rack

Fig. 8 Phase change cooling unit.

surface of the rack exhaust door, we have divided the heat receiving section into multiple stages and fed the optimum flow rates according to amount of the heat generation of the IT equipment. As shown in **Fig. 7**, the resulting cooling technology has succeeded in extracting more than 50% of the heat via natural circulation. It is not necessary to increase the power for the pumps and valves for circulating the coolant to the heat receiving stages, even if the rack power consumption should rise to 30 kW/rack, which is twice the present value. As a result, part of the power consumption for cooling can be allocated to the IT equipment, so that the information processing capacity of the data center can be enhanced.

The improvement in performance due to the use of this new coolant circulation technology will allow wide use of a coolant with the low environmental load of less than 1/3 of GWP (Global Warming Potential), though this coolant has not diffused widely due to the low cooling characteristics. Our proposed solution suggests that this technology will be applicable long into the future, in spite of the expected regulation of coolant usage.

4. Production Line

We applied this cooling technology at the NEC Kanagawa Data Center in January 2014. In spite of expanding the mounting capacity up to 700 servers in the racks and increasing the information processing capacity by 8 times the previous capacity, we succeeded in reducing the air conditioning power and floor costs by 30% from the previous values. At present, the production line includes three cooling units that consume either 30 kW or 15 kW per rack as shown in **Fig. 8**.

5. Conclusion

In the above, we introduced a highly efficient rack cooling technology that solves the two problems that result from advances in the use of cloud services; the increase in air conditioning power consumption of the data centers and the increase in the operating costs. In the future, based on the proper and active use of IT, we will be able to provide cloud services at lower costs for the developing countries where the temperatures are very high. We will thereby be enabled to contribute to environmental conservation at the global scale.

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Vol.9 No.2

June, 2015

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