Lower Data Center Power Consumption through Use of the Climate Characteristics of Cold Regions and Inter-regional Energy Integration

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***Abstract*— In the achievement of sustainable society, the lower power consumption becomes a worldwide concern. Power consumption at the Data Center is a big share in the entire IT, and is still rapidly increasing. This research focuses on the air-conditioning that occupies the biggest electric power consumption at the Data Center, and proposes to develop the technique to lower the power consumption. We verify those effects by the experiment. Furthermore, we also examined which extent the energy reduction is possible when the Data Center is located and used in Hokkaido remotely from Tokyo region where many IT users in Japan exist.**

Keywords- component; Data Center; Low Energy; Air Cooling

I. Introduction

Global warming has become an important issue in the world, as is shown by COP 15 and discussions at the international conferences, and the targets set by the government of Japan for reduction of Hothouse Gases by 25% by 2020. On the other hand, the fact that power consumption in the field of Information Technology (IT) and its effect on global warming have been increasing over the past 15 to 20 years hasbeen made clear by the data presented in reports by the Study. Group for IT Policy Concerning Global Warming[1] and the Subcommittee of the Task Force for IT Policy concerning the Global Era. [2]

In the cloud computing model, the main functions are placed on the server side[3], which means a huge increase in the power consumption of the Data Centers where the servers are located. The reduction of power consumption by Data Centers has thus become a major problem. We therefore, in this paper, focus on the reduction of power consumption in Data Centers. In sections II and III of this paper, we summarize the current situation. In section IV, we propose the basic idea of cooling facilities by introducing outside air in the cold season and using snow in the warm season. Section V, we report simulations of the effects of that approach. In section VI we identify problems revealed by the simulations, propose countermeasures, and report on verification experiments.

II. Current situation of Data Centers

As shown in Fig. 1, the power consumption by Data Centers shows a big expansion. And as shown in Fig. 2, a breakdown of Data Center power consumption reveals that air-conditioning accounts for 44% while servers and other computers account for only 32%. What is important to note here is that the air-conditioning, which serves the secondary purpose of removing the heat generated by the servers, accounts for a high proportion of the total power consumption.

Looking at a breakdown of the predicted IT power consumption for 2020 (Fig. 3), we see that routers and Data Center air conditioning occupy the highest positions, with each accounting for about 20% of the total. Power consumption by Data Center air conditioning is on an upward trend. In the past there have been efforts in the IT industry to reduce the power consumption of servers by technical measures related to the computing equipment, such as decreasing the power consumption of CPUs, load distribution according to the processing load, and partial shutdown of systems. However, as shown above, Data Center air-conditioning systems account for a high proportion of the power consumed and the trend is for that proportion to increase. Therefore, the work reported here are focused on the power consumption of air conditioning systems. We propose the use of natural energy such as the introduction of outside air for use in reducing power consumption. We also verify the effect of that proposal with simulations and experiments.

III. Conventional Methods of Reducing the Data Center Air-Conditioning Power Consumption

A. Conventional Methods

Efforts to reduce the power consumption of the mechanical air conditioning generally used in Data Centers include the two

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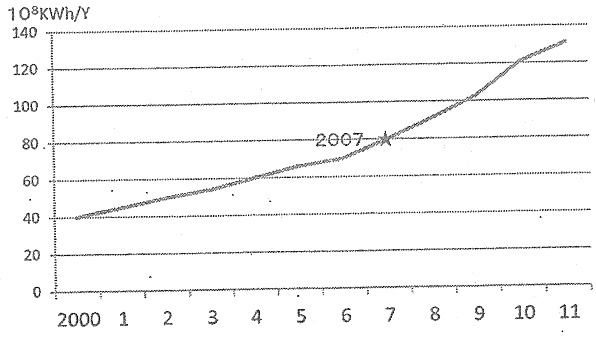

Figure 1. Data center power consumption in Japan [1]

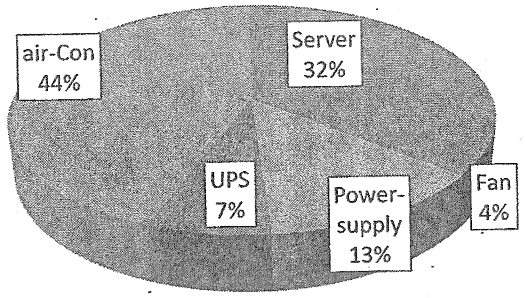

Figure 2. Breakdown of Data Center power consumption [1]

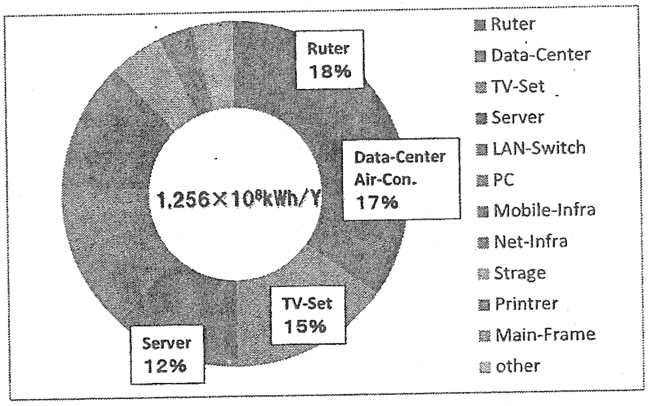

Figure 3. Forecast IT power consumption in Japan for 2020[2]

approaches listed below.

1) Technical improvements related to the air-conditioning equipment such as inverter control.

2) Controlling the air flow in the machine room by the hot aisle and cold aisle method.However such approaches have a small effect in reducing power consumption; the situation demands a method that can produce a large reduction.

B. *Natural Energy Air Conditioning Methods*

In addition to the mechanical air conditioning, methods that are intended to reduce emissions of CO_2 are also being used.

1) One example is the use of underground water for cooling by means of a heat exchanger or evaporation. The problem with this approach is that a very large amount of ground water whose temperature ranges from 13°C to 18°C must be pumped up to handle the huge amount of heat generated by the Data Center. That consumes a lot of power and increases the cost of facilities. Furthermore, recent regulations concerning the drawing out of groundwater have been enacted to prevent ground subsidence and there are also concerns for side effects on the environment.

2) Another example is the introduction of outside air. However, this method cannot be used in the summer when the outside air temperature is above the range required for a Data Center (generally from 15°C to 18°C), so it is most often used as a supplementary system. Also, this method is mostly used in warmer regions so the effect is small. [4]-[8]

These past cases have resulted in much reduction of the power used for air conditioning, so there is hope for even further reduction (to zero if possible).

IV. New Proposal for Reducing Data Center Air Conditioning Power Consumption

As a way to achieve a more dramatic reduction in power consumption compared to the conventional approaches described above, we propose two methods. Method 1 is hybrid cooling that uses outside air and snow; method 2 is the integration of energy between regions. These two methods hold promise for eliminating most of the power consumed for cooling throughout the year. Prediction and verification of these methods is described later. If their implementation can be verified, we believe it will result in a dramatic reduction in power consumption.

A. *Method 1: Hybrid Cooling With Outside Air And Snow*

As shown in Fig. 4, this method takes advantage of the climate characteristics of cold regions by using outside air for cooling in the season when the outside air temperature is low (below the 16°C temperature at which the server rooms are maintained), and using snow cooling when the outside air temperature is high and outside air cooling cannot be used.

1) Outside air cooling

A method of cooling server rooms by introducing cold outside air directly verified (humidity control is described later).

2) Snow cooling

In Japan there are very few regions where the highest air temperature in the summer falls below 16°C. Even in cold regions such as Hokkaido, there are days when the temperature reaches 30°C in the summer. Recently, temperatures above 25°C have occurred even in April. Accordingly, we cannot rely on outside air cooling alone throughout the year. Outside air cooling can be supplemented by collecting and storing a certain amount of the snow that falls during the winter in cold regions and using the snow for cooling during the warmer periods. (In areas where there is a lot of snowfall, new snow removed from highways can be collected without cost.) This method has already been the subject of research, mostly in Hokkaido. Although there are experimental and practical applications of this method for the storage of rice, etc., it has not been applied to the cooling of Data Centers in Japan.

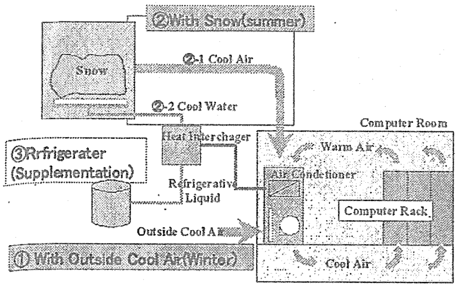

Figure 4. Hybrid air-conditioning with outside air and snow

Method 2: Energy integration between regions

It is possible to greatly expand the energy-saving effect of hybrid cooling by taking advantage of the differences in air temperature and climate between regions. In Japan, most of the IT users are located in the Kanto area and the regions further south. If those users connect to servers installed in Data Centers that are located in the colder northern regions that use hybrid cooling instead of connecting to local Data Centers, thus taking advantage of the air temperature difference between the regions, a great reduction in the energy used by Data Center air conditioning systems can be expected.

In the process of the research reported here, the Hokkaido Green Energy Data Center Study Group[9] was founded on June 18, 2008 to implement this work and begin preparation of a commercial base through enterprise. At this time, there are no other examples of research on using natural energy to cover almost all of the need for Data Center air conditioning and on the effect of expanding energy conservation by intraregional energy integration.

V. Power Reduction Simulations[10]

We executed preliminary simulations to predict the extent of the energy savings that can be expected from implementation of the two methods described above. (The numerical calculations were performed by Mr. Masuda and Mr. Haneda of the Fujitsu Corporation, who are both members of a book titled Green Energy Data Center Study Group, using the basic system concept and computational method provided by the authors.)

A. Regional Settings And Air Temperature

For regional comparison, air temperature samples for Tokyo, as the warm region where the users are located, and Sapporo as the cold region where the Data Centers are located, are presented in Table 1. Those values were used to calculate the difference in energy consumed for Data Center air-conditioning between Tokyo and Sapporo. sentence.

Table I. Average Temperatures For Sapporo And Tokyo (℃)

month	JAN.	FEB.	MAR.	APR>	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Sapporo	−4.4	−3.3	0.7	7.3	12.4	16.4	20.7	22.3	17.8	11.5	4.8	−0.6
Tokyo	5.7	6.5	8.6	15.0	19.2	21.1.	26.6.	27.3	23.1	17.9	12.3	9.0

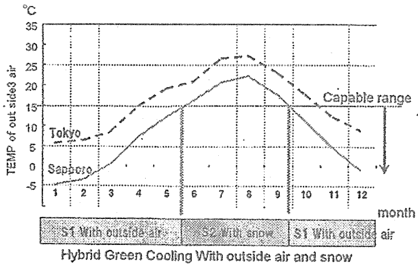

Figure 5. Temperature in Tokyo and Sapporo, and Hybrid coloinng

B. Assumed Model

1) Condition 1: Assumed Data Center size and heat load

a) Number of server racks: 2000

b) Server power consumption: 5 kW/rack

(One rack accommodates from 15 to 30 servers. Although the power consumption varies with the hardware, the value of 5 kW/rack is currently general for the industry in 2010.)

c) Annual server heat load for air conditioning

2000 racks × 5 kW/rack × 365 days × 24 hours = 87.6 million kilowatt hours

2) Condition 2: Server room temperature control

The assumed temperature control range suitable for ordinary servers is from 16°C (the lower temperature limit at the outlet of the air-conditioning system) to 26°C (the upper temperature limit of the air returned to the air conditioning system).

3) Condition 3: Air-conditioning for Data Centers in Tokyo

Typical Data Centers in the Tokyo area are air conditioned by the sealed building method, and there are no cases in which outside air cooling is used for the most part. Accordingly, the power consumption calculations for Tokyo assume year-round mechanical air conditioning.

4) Condition 4:Air-conditioning for Data Centers in Sapporo

The air conditioning uses one of the three patterns listed below, depending on the outside air temperature (Fig. 5).

S1: In seasons when the outside air temperature is generally below 16°C, outside air cooling is used.

S2: in seasons when the outside air temperature is close to 16°C, outside air cooling is used at times when the outside air temperature is below 16°C and snow cooling is used at times when the outside air temperature is above 16°C.

S3: in seasons when the average air temperature is above 16°C, snow cooling is always used. (Snow cooling can be accomplished by two methods. One is to expose the air from the air conditioning system directly to the snow to cool the air; the other method is to circulate cold water to effect the cooling.)

Note: In both S1 and S3, the air temperature may fluctuate above and below 16°C with the day or the time of day. The situation is simplified here to allow a clear understanding of the cooling mode switching in hybrid cooling.

C. Computational Results

1) Approach to the possible energy savings and trial computations

According to Data Center vendors, it is possible to achieve a COP energy efficiency index of 2.5 with a mechanical air conditioning system that is controlling the room temperature of a Data Center to from 16°C to 26°C for servers operating under the above condition 1 at the air temperatures for Tokyo noted above. (COP is the coefficient of performance, which is the ratio of the heat load to the energy consumed by air-conditioning required to maintain a constant temperature.)
For the heat load of 87.60 million kilowatts mentioned above and a COP of 2.5, the power consumption for mechanical air conditioning in Tokyo is calculated as follows.

87.60 million kW hours ÷ 2.5 = 35.04 million kW

For Data Center operation in Sapporo the other hand, air conditioning by the hybrid cooling method using all natural energy as described by S1, S2, and S3 above is possible, so mechanical air-conditioning is not used at all and the cost is almost zero. Therefore, the energy saved is approximately the annual cost of air conditioning, or 35.04 million kilowatt hours. Thus, it is possible to eliminate 44% of the total Data Center power consumption shown in Fig. 2. The power used to operate fans to move the air is small compared to the power used for air conditioning, so the energy savings can be considered as approximately 40% of the Data Center power consumption.

2) Computing the reduction in cost of power

If we convert the energy savings calculated above to a monetary value assuming a cost of ¥15/kWh, the cost savings is calculated as follows.

35.04 million kW hours × ¥15 = ¥502.560 million / year

That means a cost reduction of about ¥10 billion for a 2000 rack Data Center.

These calculations do not take into consideration other cost factors such as the cost of land in different regions and the cost of network use. Nevertheless, if we use the charges for ordinary power rather than the charges for extra-high voltage, the effect is even greater. A further consideration is reduction of carbon dioxide emissions. Using the national average value of 0.384 kg-CO2 as the unit of carbon dioxide emissions for electric power generation, the calculated energy savings corresponds to a reduction of carbon dioxide emissions of about 13,400 tons. Given that the cost of constructing a 2000 rack Data Center is from 7 to 10 billion yen (according to one construction company), we estimate that the proposals made here can have a major impact.

D. Problems

Of the two cooling elements, outside air and snow, there are already many implementations of snow cooling.[11] However, there are no examples of research on using outside air for cooling to replace mechanical air conditioning of Data Centers in regions where outside temperatures are cold for 70% of the year.There are two approaches to using outside air for Data Center air-conditioning.

a) Pass the cold outside air through a heat exchanger to cool a coolant that is then circulated to cool the facility.

b) Introduce the cold outside air directly to cool the facility, using a filter to remove the salt and dust from the air.

Of these two methods, the use of a heat exchanger and coolant involves equipment that is complex and costly. It also suffers from low energy efficiency. Therefore, the direct introduction of cold outside air is that is available over a long period of time in cold regions is the most suitable in terms of both cost and energy efficiency. However, there are a number of problems that have prevented Data Center air-conditioning by direct introduction of outside air.

Problems with direct introduction of outside air

In Hokkaido, the outside air temperature in winter can become extremely low (-10°C to -20°C). If the moisture contained in such cold air remains constant when the air is brought into the server room, the relative humidity of the air becomes abnormally low as the air warms up. If the relative humidity becomes too low, static electrical discharge that may damage the computer equipment can occur. Therefore controlling the humidity of the air is an important problem.

Methods of humidity control

Humidification methods include

a) Atomizing methods

b) Natural humidification

The atomizing method requires a compressor to produce a fine spray of water, and thus requires a large amount of energy. Also, if the public water supply is used, impurities may be introduced into the air. (The problem can be averted by using purified water, but the cost of operation increases.) Therefore, the best choice is to adopt natural humidification, which uses little energy, does not disperse impurities, and does not have high cost.

3) Problems with natural humidification

There are no examples of Data Centers using low temperature outside air for direct cooling of servers in cold regions. Accordingly, there are also no previous examples of using natural humidification methods to counter the problem of the sharply decreasing humidity when the cold air is introduced, and it is not known how well a natural humidification system can perform in the task (humidification range and response). Therefore, verification testing in actual use is required.

VI. Solutions and Verification Testing

Our proposal involves the problem of whether or not temperature control together with humidity control is possible, as described in section IV. The effect of the proposed solutions that are described below.

A. Specific Humidity Control Methods And Their Verification

1) Drip-type natural humidification

We propose the drip-type humidification method as an energy efficient method of humidification for when outside air cooling is used for Data Centers. In this method air is blown across water dripping from a mesh plate, humidifying the air by evaporation. There are no cases in which this method is used with outside air cooling of a Data Center for as much as 70% of the year, so its feasibility must be tested by experiment.

2) Reduction of the required humidification by return air

Because the humidification effect of the drip-type natural humidification is not large, we propose that it be supplemented by taking advantage of the characteristics of the Data Center to reduce the amount of humidification that is required in the following way. From the air line diagram of Fig. 6, we can see that, at point A (0°C and 40% humidity) for example, if extremely cold outside air is brought into the Data Center to cool the servers, the resulting humidity of the air at the temperature of point B (18°C) would be about 7%. That would require humidification of about 30% to 40% to bring the humidity to within the range required for computer operation. However, such a high degree of humidification would require an excessively large scale of equipment for natural drip humidification. Therefore, we propose using the warm return air (about 28°C) to reduce the required degree of humidification by mixing it with the cold outside air. The mixing ratio is kept within an appropriate range by the operation of duct valves that are controlled by temperature and humidity sensors. There are no cases of a Data Center using this method, so its effectiveness must be verified by experiment.

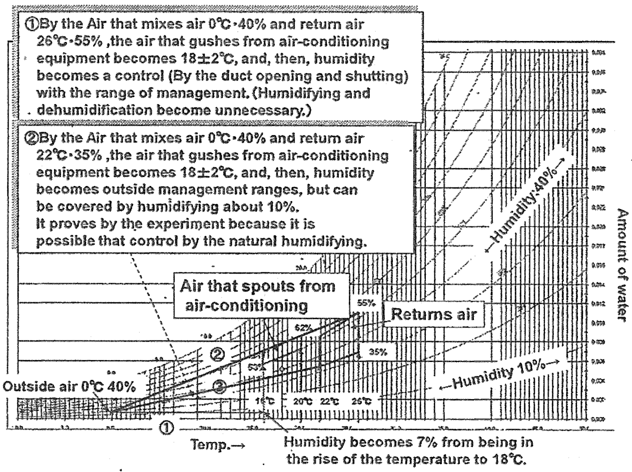

Figure 6. Humidity control (reduced humidification by mixing with return air)

B. *Overview Of The Experiments*

To determine the feasibility of introducing outside air with humidity control to cool a Data Center and its effectiveness in reducing power consumption, we constructed test facilities and equipment for the solution methods described above and performed experiments. Although outside air cooling used together with drip-type natural humidification does not use a large amount of energy, some power is consumed by the operation of fans, the automatic opening and closing of the duct valves, the temperature and humidity sensors, and the control computer. If the total power consumption of the system is not large, a large saving of energy relative to mechanical cooling can be obtained. We therefore measured the total power consumption by experiment. Furthermore, although there are previous cases of snow cooling use, we tested the degree of energy-saving from snow cooling by using the same experimental equipment.

The experiments were conducted to verify the feasibility of hybrid cooling for Data Centers. (The experiment was executed by the Ministry of Internal Affairs and Communications and Fujitsu Japan, according to our proposed method of hybrid cooling system.[10])

1) Experimental region: a server room was set up in an existing building in the city of Sapporo, Hokkaido. The experimental cooling facilities were newly constructed.

2) Experimental time period: December 2009 to February 2010 (winter)

3) Experimental equipment

a) Experimental server room

Mock servers, which are heater units constructed to be similar in shape and heat production to the servers used in Data Centers, were configured as described below.

· Mock servers per rack : 800 W × 5 units = 4 kW (after the industry-standard scale of 4 kW)

· Racks per row : 4 kW × 3 racks = 12 kW

· Total : 12 kW × 2 rows = 24 kW

b) Experimental outside air cooling equipment (Fig. 7)

· Cold outside air is mixed with warm return air from the server room and supplied to the server room (at a suitable temperature and humidity according to Fig. 6)

· The temperature control maintains the temperature of the return air to within the range of 24°C ± 2°C, which is the industry-standard for the upper temperature limit for server management, by opening and closing ducts to change the proportion of outside air and return air in the mixture supplied to the server room.

· The humidity control maintains the humidity of the return air within the range of the industry-standard lower limit of 45% ± 10% by turning the dripping water on and off to vary the amount of evaporation. The humidification is accomplished by incorporating natural drip humidification into the air handling unit.

c) Snow cooling equipment

Although there is previous experience with snow cooling, we used the same experimental equipment to obtain cooling data and conducted additional experiments using the equipment described below for comparison to reconfirm effectiveness.

· Snow was stored in a pool-like storage site. Water flowing through the bottom of the storage site was extracted to obtain cold water.

· The cold water was run through a heat exchanger to cool a coolant.

· The cold coolant flows through the air handling unit to cool the air, which is then sent into the server room.

d) Mechanical air conditioning equipment

For comparison with the outside air cooling method, we obtained power consumption data for when ordinary mechanical air conditioning is used to control the temperature and humidity of the same server room to within the same temperature and humidity ranges. We then estimated the effectiveness from the difference in power consumption.

C. *Experimental Results*

1) Experimental results for cooling by outside air

Using the experimental setup described above, we performed

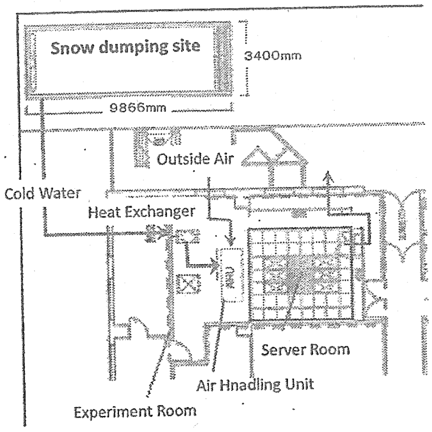

Figure 7. Experimental setup

experiments to determine whether or not it ispossible to control the temperature and humidity of the return air to within a certain range when cold outside air is used for cooling. In particular, we wanted to determine whether or not the drop in humidity that is a concern when outside air is used for cooling can be controlled by the energy-efficient natural drip humidification method. The results were positive for outside air temperatures down to -5.9°C.

The ranges that we used for return air temperature and humidity are 24°C ± 2°C and 45% ± 10%, which are considered suitable for operation in the industry. (We consulted the opinion of the Fujitsu Corporation concerning these ranges.)

a) Time period for the outside air cooling experiments: December 7 to December 14, 2010

b) Data collection interval: one minute

c) Temperature data (Fig. 8)

Outside air: -5.9°C to 8.4°C (red)

Conditioned air: 17.0°C to 19.9°C (blue)

Return air: 24.2°C to 26.0°C (yellow)

(Return air temperature control range: 24 ± 2°C)

d) Humidity data (Fig. 9)

Outside air: 38.7% to 97.4% (red)

Conditioned air: 50.8% to 72.3% (blue)

Return air: 35.1% to 47.7% (yellow)

(Return air humidity control range: 45 ± 10%)

e) Comparison of power consumption by outside air cooling and mechanical air conditioning

Next, we determined the energy-saving effect of the cold outside air cooling method, the data shows the change in power consumption for when the server room is cooled by outside air cooling, and when it is cooled by mechanical air conditioning. The result is that the average power consumption for outside air cooling is 2.37 kW, compared to 16.06 kW for mechanical air conditioning. A very large energy savings of approximately 85% is achieved.

● Power consumption for outside air cooling

- Power consumption range: 2.26 to 2.44 kW
- Average power consumption: 2.37 kW

● Power consumption for mechanical air conditioning

- Power consumption range: 11.59 kW to 21.10 kW
- Average power consumption: 16.06 kW

●Energy savings for outside air cooling: (16.06 - 2.37)/16.06 = 85.2%

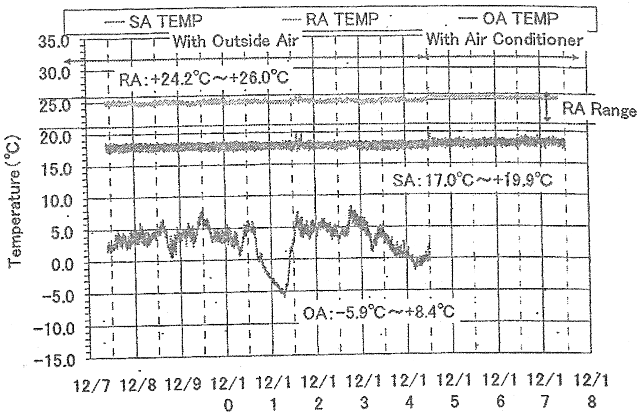

Figure 11. Result of temperature control (cooling with outside air)

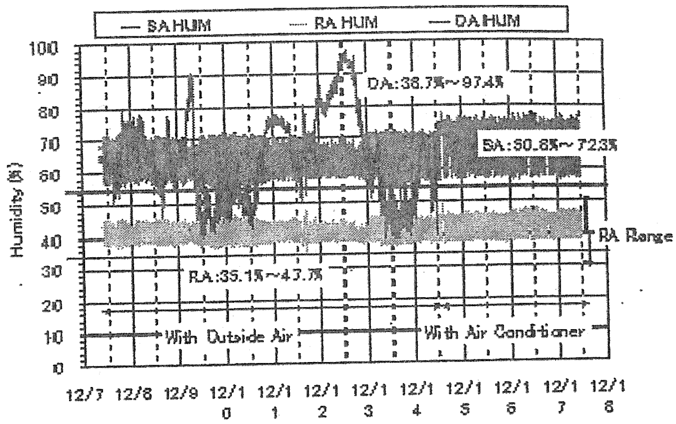

Figure 12. Result of humidity control (cooling with outside air)

2) Experimental results for cooling by snow cooling

Although there are results concerning the use of snow cooling for facilities other than Data Centers, such as rice warehouses, there is no information concerning the use of snow cooling for a Data Center. We therefore conducted experiments to verify the feasibility of controlling temperature and humidity when using snow cooling for rack mounted server equipment of from 5.25 kW to 5.86 kW. The results showed that the temperature and humidity can be controlled to within a specified range. Therefore, combining snow cooling with the outside air cooling described above would make it possible to use natural energy alone for year-round cooling of Data Center facilities, with no need for mechanical air conditioning.

Temperature and humidity are both controlled on the basis of return air measurements.

a) Time period: January 26 to February 1, 2011

b) Data collection interval: one minute

c) Temperature data (Fig. 10)

- Conditioned air: 17.8°C to 19.1°C (blue)
- Return air: 25.2°C to 26.5°C (yellow)

(Return air temperature control range: 24 ± 2°C)

d) Humidity data (Fig. 11)

· Conditioned air: 56.5% to 74.5% (blue)

· Return air: 36.8% to 46.1% (yellow)

(Return air humidity control range: 45 ± 10%)

Note: There were extremely short time periods in which the return air temperature partially exceeded the control temperature upper limit of 26°C. However, the extent was 0.5°C, so the effects on the servers can be considered to be extremely small, and operation is fully possible according to a Data Center company.

e) Power consumption for snow cooling

From Fig. 16, the power consumed by snow cooling is:

•Power consumption range: 5.25 to 5.86 kW

•Average: 5.58 kW

Compared to the average power consumed by ordinary air conditioning of 16.06 kW, the energy saved by snow cooling is: 1.0 - 5.58/16.06=65.3%

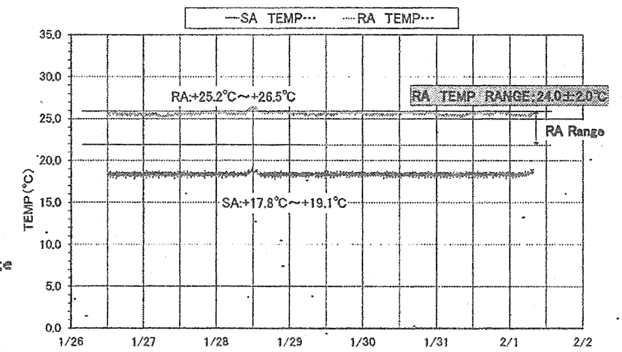

Figure 10. Temperature control result (snow cooling)

VII. Conclusion

1) Although the energy expended to cool Data Centers is predicted to account for a large part of the IT power consumption in future, a large energy savings can be achieved by using a hybrid cooling method. We have shown that the excessive drop in humidity that results from introducing extremely low-temperature outside air can be solved by mixing the cold air with warm return air to reduce the need for humidification and using natural drip humidification, which is simple and uses little power.

2) A large reduction in power consumption can be achieved by the many IT users in the metropolitan Tokyo area accessing Data Centers located in cold regions via a network. That approach is called intra-regional energy integration.

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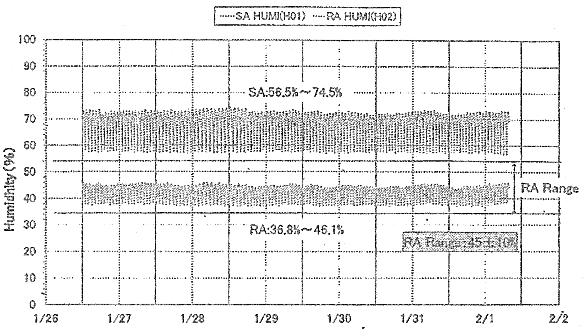

Figure 11. Result of humidity control (cooling with outside air)

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