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ITU-T L.1300 – Supplement on a validation test of a data centre cooling method using renewable energy in a cold region

ITU-T L-series Recommendations – Supplement 6

ITU-T

International Telecommunication Union

Supplement 6 to ITU-T L-series Recommendations

ITU–T L.1300 – Supplement on a validation test of a data centre cooling method using renewable energy in a cold region

Summary

Supplement 6 to the ITU-T L series refers to the best practices defined in Recommendation ITU-T L.1300. More precisely, the Supplement first provides a background, purpose and overview of the validation test of a data centre cooling method using renewable energy. Then, test results of such a cooling method are reported together with predictions of future yearly energy consumption.

History

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Keywords

Best practice, climate change (CC), data centre, energy efficient, information and communication technology (ICT).

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ITU-T L.1300 – Supplement on a validation test of a data centre cooling method using renewable energy in a cold region

1 Scope

This Supplement describes a validation test of a data centre cooling method using renewable energy in a cold region based on [b-ITU-T L.1300]. The scope of this Supplement includes:

– a background, purpose and overview of the validation test of a data centre cooling method using renewable energy

– test result of a data centre cooling method using renewable energy

– prediction of annual energy consumption

2 Definitions

None.

3 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AHU	Air Handling Unit
CDP	Cooling Water Pump
CT	Cooling Tower
OA	Outdoor Air
PUE	Power Usage Effectiveness
RA	Return Air
SA	Supply Air

4 Conventions

None.

5 Background and purpose of the test

The test was conducted by the Ministry of Internal Affairs and Communications of Japan in the fiscal year 2009 as part of a promotion project for the realization of a low-carbon society utilizing information and communication technology (ICT). The purpose of the test is to verify the usefulness of outdoor air cooling, and snow and ice cooling, to make effective use of the characteristics of cold regions in order to reduce power consumption for data centre cooling.

6 Overview of the test

6.1 Specifications of the test facility

Figure 1 shows the layout of the test facility. In the "server room" a cold aisle was formed by a total of six racks consisting of two 3-rack rows placed face-to-face. The server room was surrounded by panelling and provided with floor supply air conditioning. Simulated servers with built-in heaters with a total power rating of 24 kW were installed in the server room.

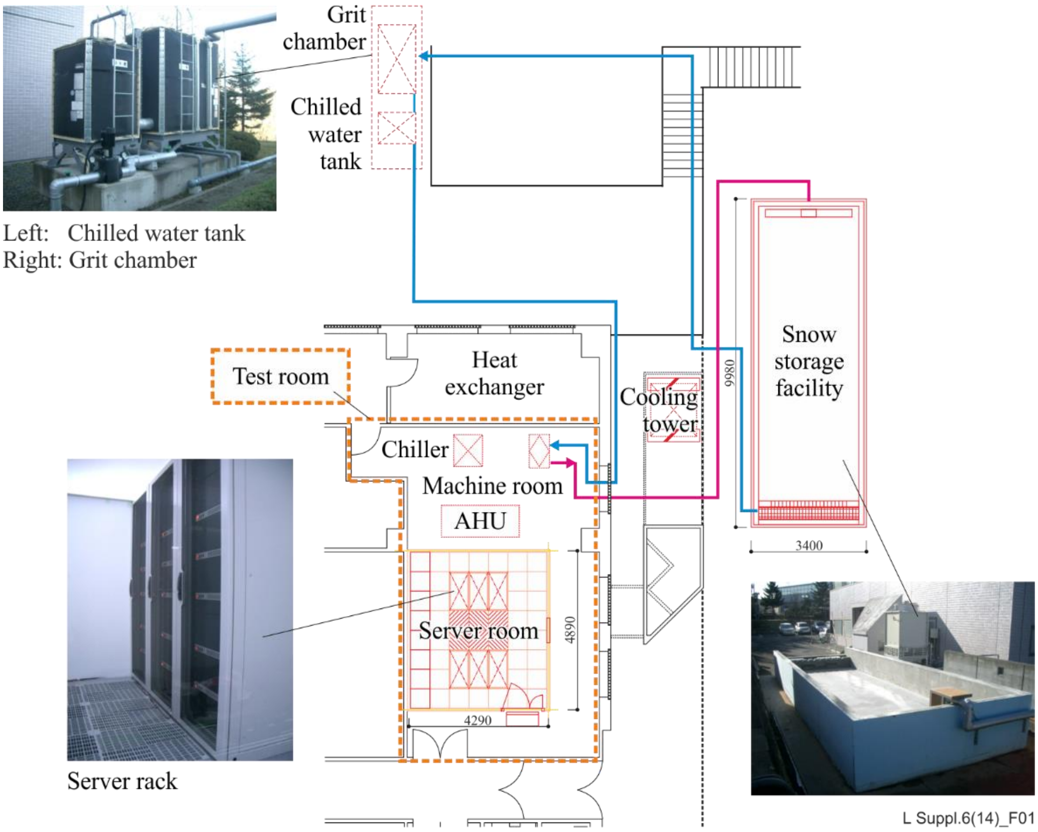


Figure 1 – Layout of the test facility

6.2 Overview of the air conditioning system

In the test, air conditioning conditions were adjusted so as to keep supply air temperature (SA) at 18°C ±2°C, return air (RA) temperature at 24°C ±2°C, and return air humidity at 45% ±10%.

The air conditioning system has the three modes described below. Figure 2 illustrates each air conditioning mode.

- Mode 1 – Conventional air conditioning: ordinary heat source.
- Mode 2 - Outdoor air (OA) cooling: OA and RA are mixed together by the air handling unit (AHU), and the mixed air is humidified to achieve the target SA temperature and humidity.
- Mode 3 – Snow and ice cooling: water that has had its temperature raised by heat exchange is sent to the snow storage facility where it is chilled by snow and stored in the chilled water tank. Then, the water is chilled down by the heat exchange unit and sent to the AHU's snow and ice cooling coils. The SA temperature is kept constant by controlling the flow rate of chilled water to be sent to the coils by means of a three-way valve.

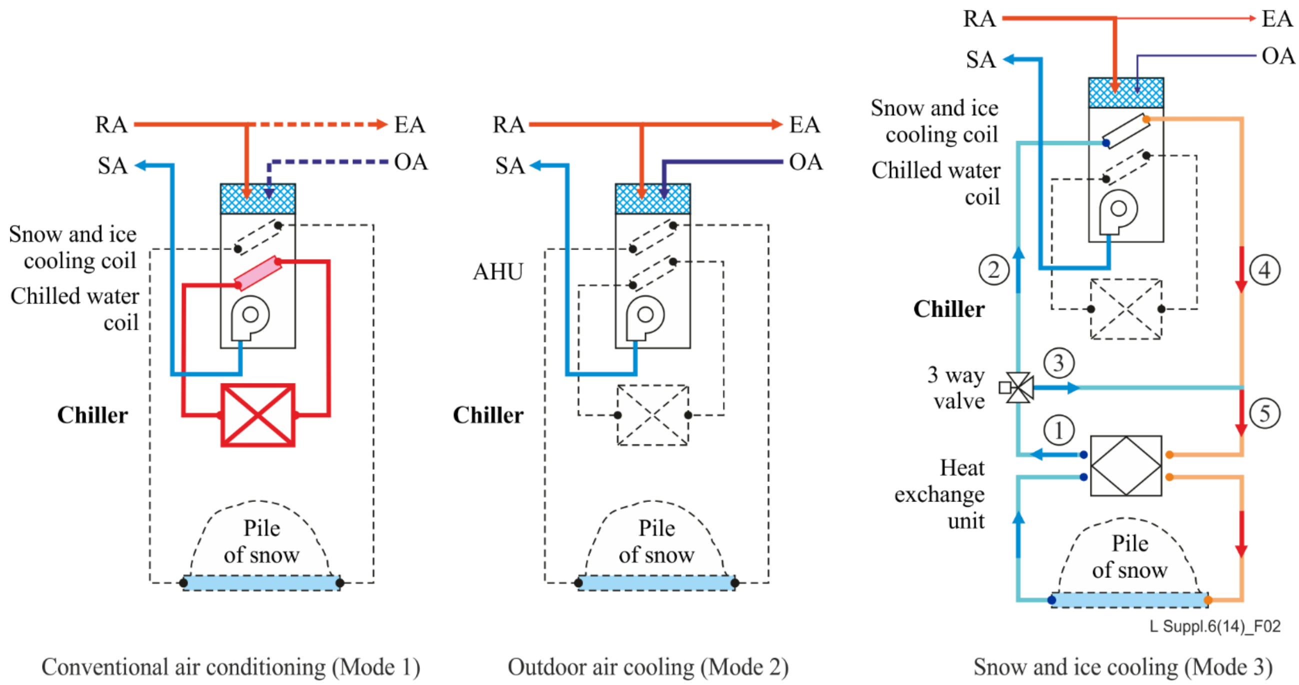


Figure 2 – Image of each cooling mode

6.3 Measurement items

The following items were measured:

(1) Temperature of chilled water and cooling water [°C]

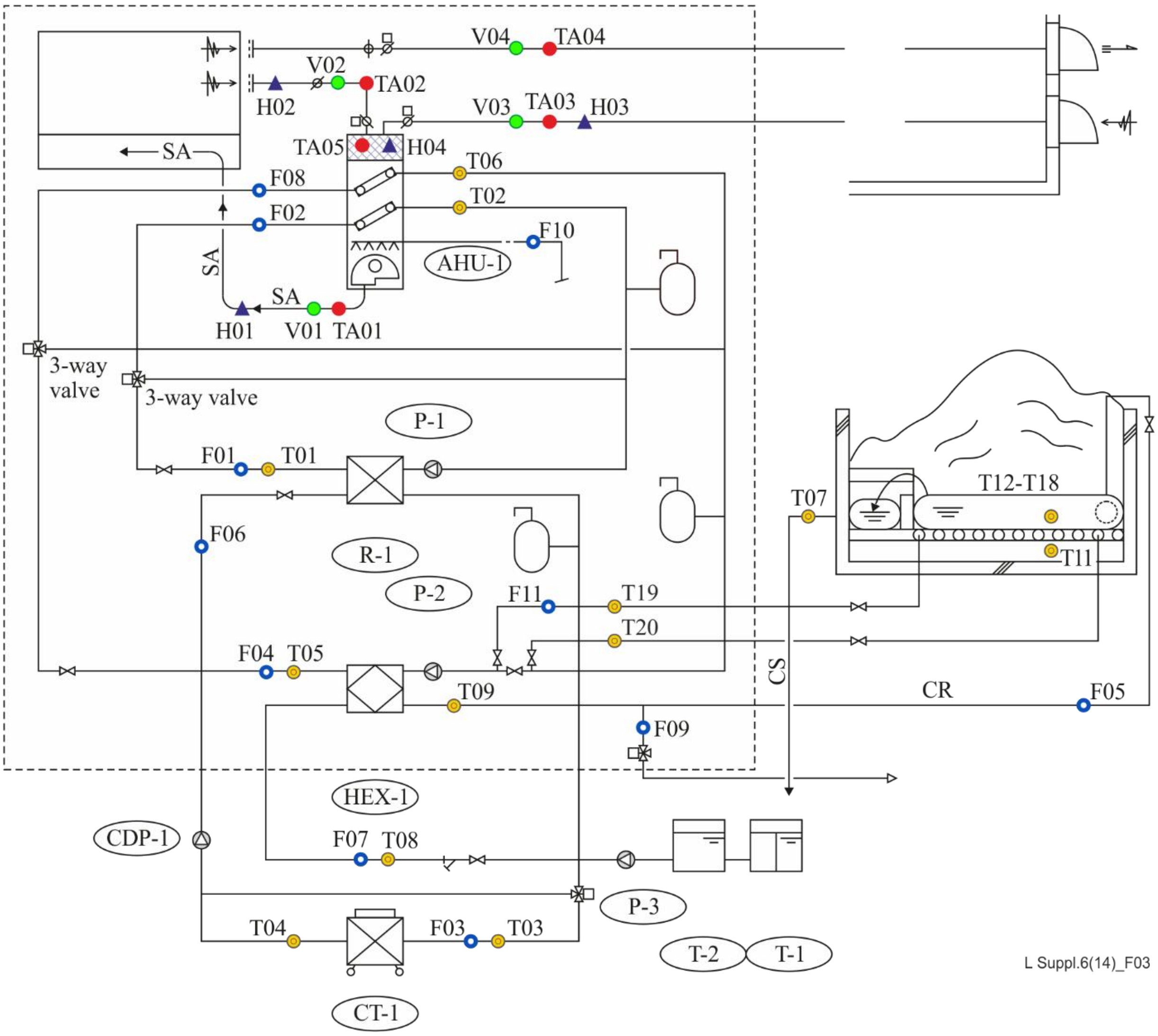
(2) Flow rate of chilled water and cooling water [L/min]

(3) Temperature and humidity of supply and return air [°C, %]

(4) Airflow rate (duct air velocity) [m^3/h]

(5) Power consumption of equipment [kW]

Figure 3 shows the air conditioning heat source diagram and measuring points. Table 1 shows the specifications of the air conditioning equipment.



: chilled water measurement point T01-T20
: air temperature measurement point TA01-TA05
: air humidity measurement point H01-H04
: water flow rate measurement point F01-F11
: air velocity measurement point V01-V04

Figure 3 – Air conditioning heat source diagram and measurement points

Table 1 – Specifications of air conditioning equipment

No.	Name
AHU-1	Air handling unit
CDP-1	Cooling water pump (for chiller)
CT-1	Water cooling tower
HEX-1	Heat exchanger (for snow cooling)
P-1	Chilled water pump (for chilled water)
P-2	Chilled water pump (for chilled water for snow cooling)
P-3	Chilled water pump (for snow cooling tank circulation)
R-1	Water chilling unit
T-1	Settling tank (for snow cooling)
T-2	Chilled water tank (for snow cooling)

7 Test results

7.1 Outdoor air cooling test results

Figure 4 shows the outdoor air temperature. Figure 5 shows the air temperature and air conditioning heat load. The air conditioning heat load was calculated as follows:

Air conditioning heat load [W]= Q [m^3/h] × (T-SA [°C] − T-RA [°C]) × 1.2 [kg/m^3] × 1.006 [kJ/kg·°C]/3.6

where:

Q: airflow rate [m^3/h];

T-SA: supply air temperature [°C];

T-RA: return air temperature [°C].

Outdoor air temperature fluctuated between 0°C and 8°C. The SA temperature was around 18°C, and the RA temperature was 25°C to 26°C. Thus, the SA and RA temperatures were kept within their target ranges. These results indicate that air temperature can be controlled to stay within the specified range by damper operation without relying on heat source (chiller) operation.

The air conditioning heat load was overestimated (33.6 kW) compared with the amount of heat generated by the servers (24 kW). The reason for this is thought to be that air velocity measurement is prone to error, and measurements tended to be too large in the test.

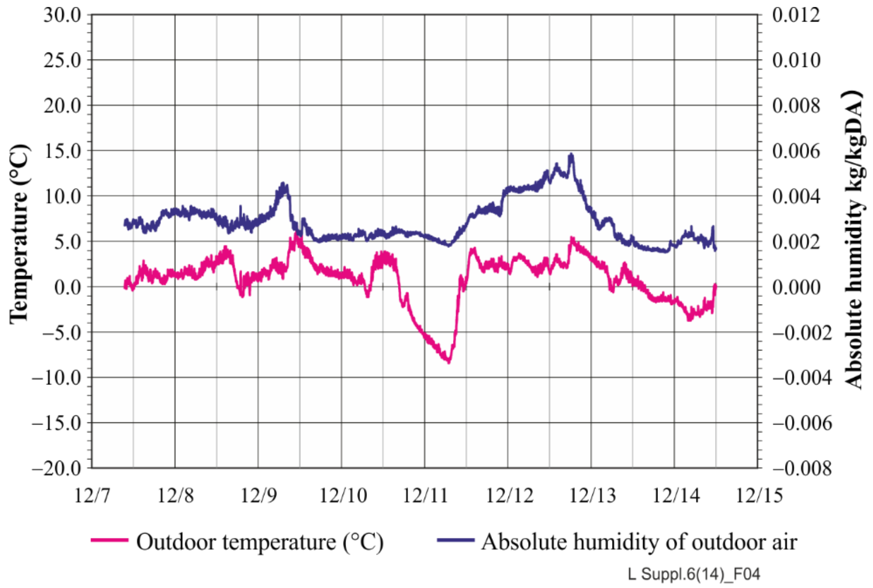


Figure 4 – Outdoor air temperature and absolute humidity

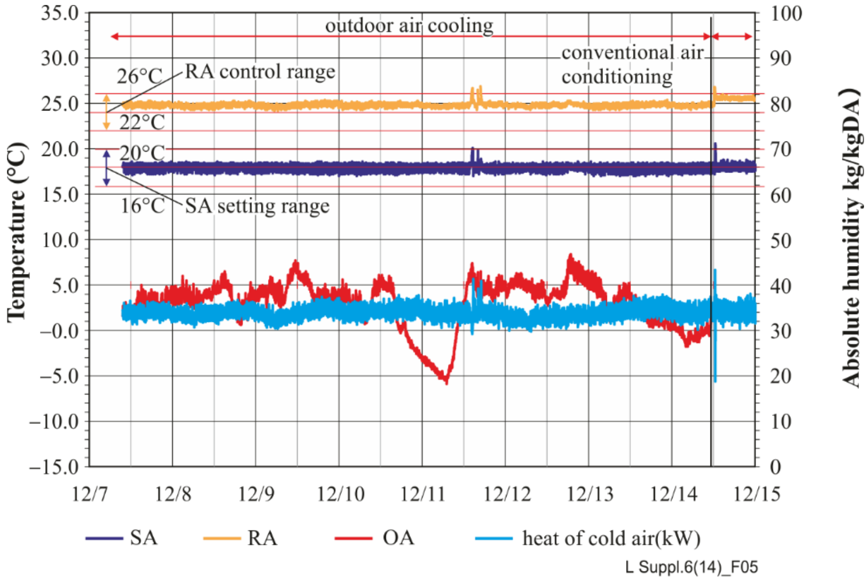


Figure 5 – Air (SA, RA, OA) temperature and heat energy

To evaluate the state of outdoor air cooling operation, Figure 6 shows changes in air temperature and airflow rate during a particular period. As shown, as outdoor air temperature falls, the RA flow rate increases, and the SA temperature is kept constant by changing the RA/OA ratio.

Figure 7 shows absolute humidity and the humidification rate during the same period. The absolute humidity of outdoor air was as low as about 0.002 kg/kgDA. By mixing outdoor air with the RA, however, absolute temperature rose to about 0.007 kg/kgDA and, through further humidification, reached about 0.008 kg/kgDA. This has shown that the required humidification rate is now high if OA and RA are mixed together.

Figure 8 shows the power consumption of the servers and the air conditioning equipment. The power consumption of a server rack averaged 24.0 kWh. The power consumption required to lower the temperature of the servers was 2.4 kWh during outdoor air cooling and 16.1 kWh during conventional air conditioning. This is because outdoor air cooling requires only AHU's built-in fans. Thus, it has been shown that outdoor air cooling is highly energy efficient.

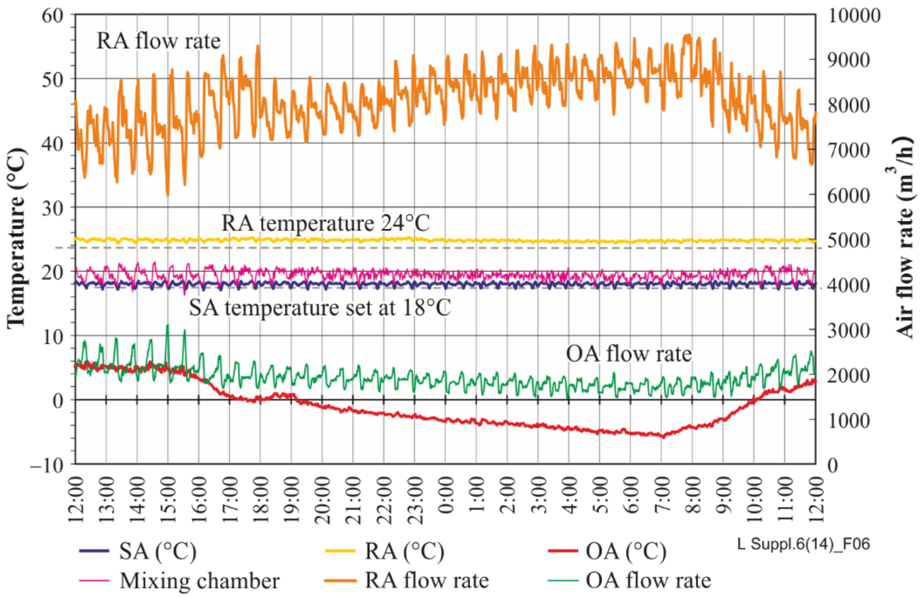


Figure 6 – Air temperature and airflow rate

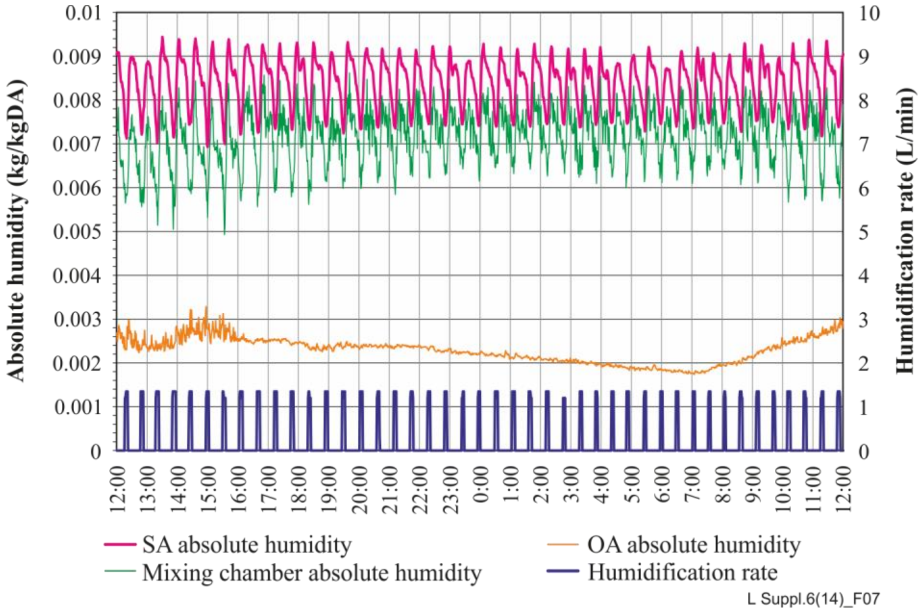


Figure 7 – Absolute humidity of air and the humidification rate

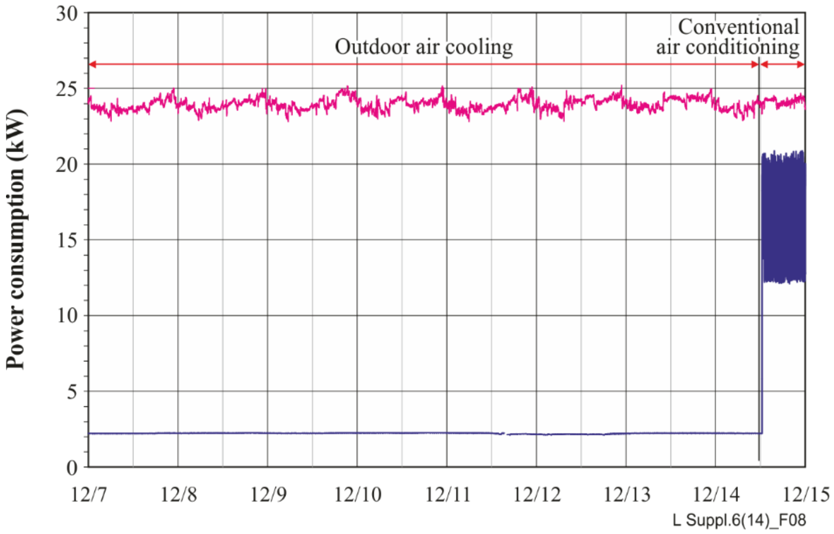


Figure 8 – Power consumption of servers and air conditioning equipment

7.2 Snow and ice cooling test results

Figure 9 shows the chilled water flow rate and the air conditioning heat load in the case where snowmelt water is used. Figure 10 shows air temperature during snow and ice cooling. The air conditioning heat load is calculated as follows:

Air conditioning heat load [W] = V [L/min] × (AHU return water temperature [°C] − AHU supply water temperature [°C]) × 4 200 [kJ/m^3·°C] × 60/3.6/1000

where:

V: chilled water flow rate [L/min].

The amount of heat load removed was about 25 to 27 kW, which was sufficiently large. As shown in Figure 10, the SA temperature was kept constant at about 18°C. This indicates that the flow rate at the snow and ice cooling coil inlet was effectively controlled by a three-way valve.

Figure 11 shows the relative humidity of air and the humidification rate. Relative humidity fluctuated between 38 and 45%, and the amplitude of fluctuation remained constant and stayed within the target range.

To evaluate the state of snow and ice cooling operation, Figure 12 shows the temperature of air and the temperature of chilled water used for snow and ice cooling during a particular period. The temperature difference between the water supplied to and the water returned from the snow storage facility was about 5°C; more or less kept constant regardless of temperature fluctuations. In the test, as the temperature of chilled water from the pile of snow rose, the flow rate at the snow and ice cooling coil inlet increased under the control of the three-way valve so that temperature rose and the amount of heat required was kept constant.

Figure 13 shows the power consumption of the servers and the air conditioning equipment. The power consumption of a server rack averaged 23.9 kWh, and the power consumption for snow and ice cooling averaged 5.5 kWh. The power consumption for air conditioning was small because no heat source was used, indicating high energy efficiency.

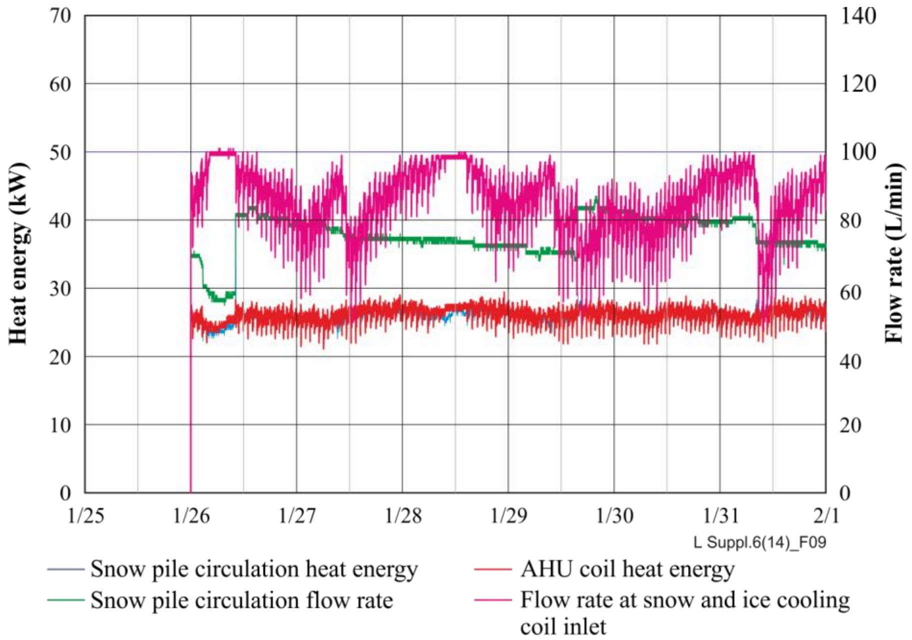


Figure 9 – Chilled water flow rate in snow and ice cooling

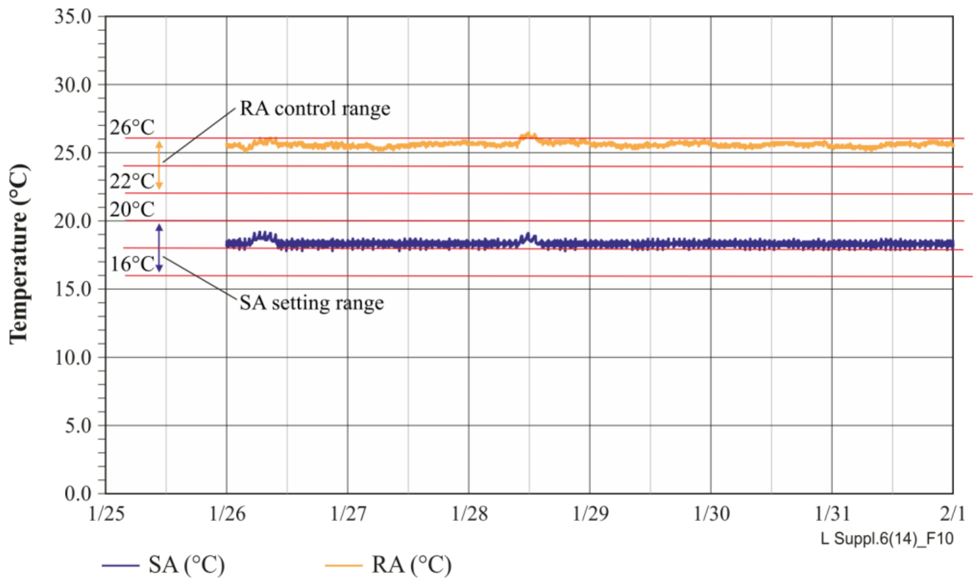


Figure 10 – Air temperature in snow and ice cooling

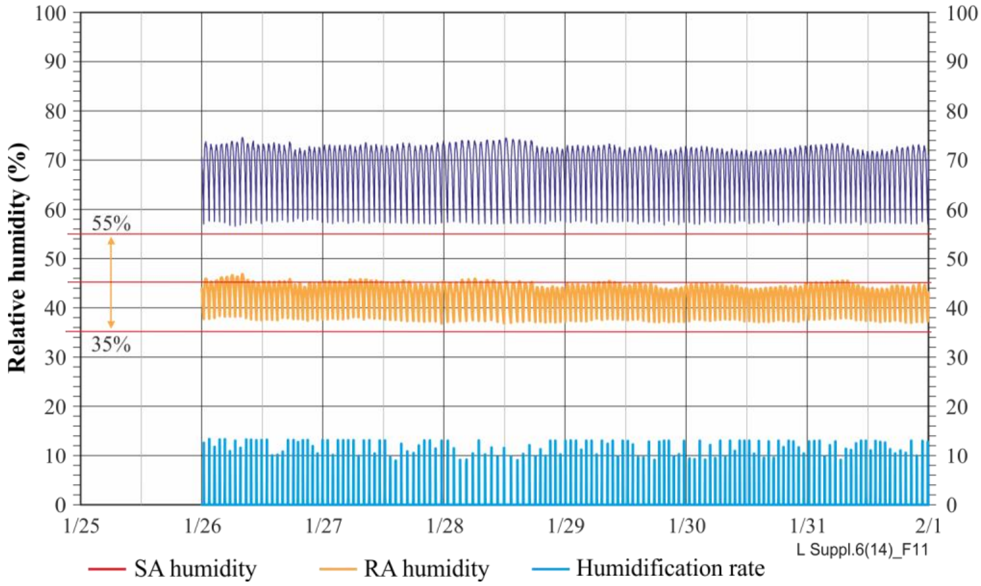


Figure 11 – Relative humidity of air and the humidification rate

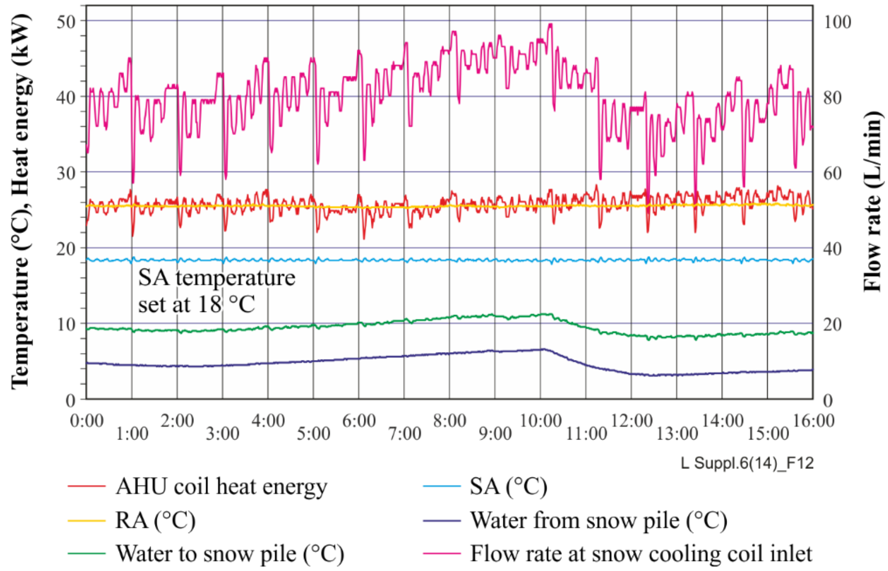


Figure 12 – Air temperature in snow and ice cooling

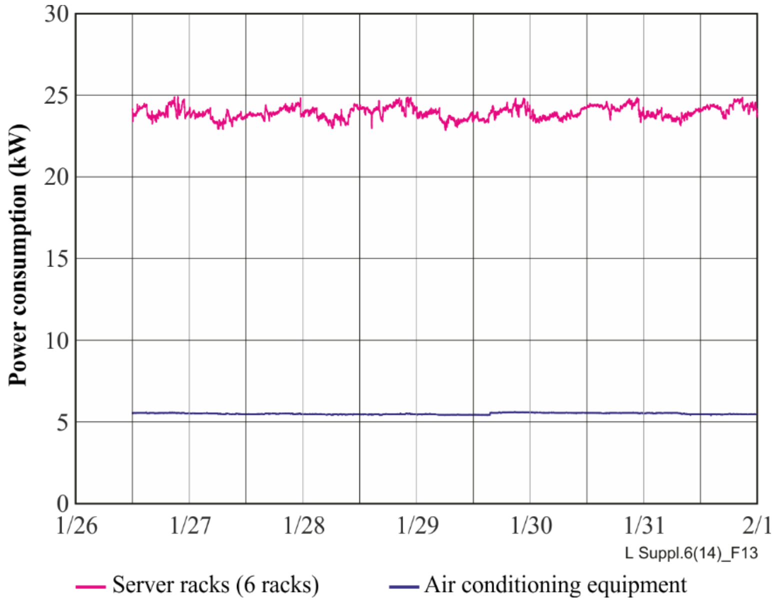


Figure 13 – Power consumption of servers and air conditioning equipment (snow and ice cooling)

Table 2 shows the 10-day power consumption for outdoor air cooling and snow and ice cooling. The percentage reduction from the power consumption for conventional air conditioning is 85.3% for outdoor air cooling and 68.7% for snow and ice cooling, both of which are significantly high.

Table 2 – 10-day power consumption

	Power consumption （kWh）		
	Outdoor air cooling	Conventional air conditioning	Percentage reduction (%)
Outdoor air cooling period	566.4	3 864	85.3
	Snow and ice cooling	Conventional air conditioning	Percentage reduction (%)
Snow and ice cooling period	1 308	4 176	68.7

8 Prediction of annual energy consumption

8.1 Annual energy consumption estimation method

Figure 14 shows a psychometric chart showing plots of Sapporo weather data used to predict annual energy consumption.

The test results have confirmed that outdoor air cooling is feasible even in midwinter. It is thought that the period during which outdoor air cooling can be done is determined by the ranges of temperature and humidity in which the supply air temperature can be controlled so that it is kept within the target range.

Table 3 shows the estimated time during which outdoor air cooling can be done. Under the conditions assumed in this study, outdoor air cooling can be done during 6 267 hours (71.6%) out of the annual total of 8 760 hours.

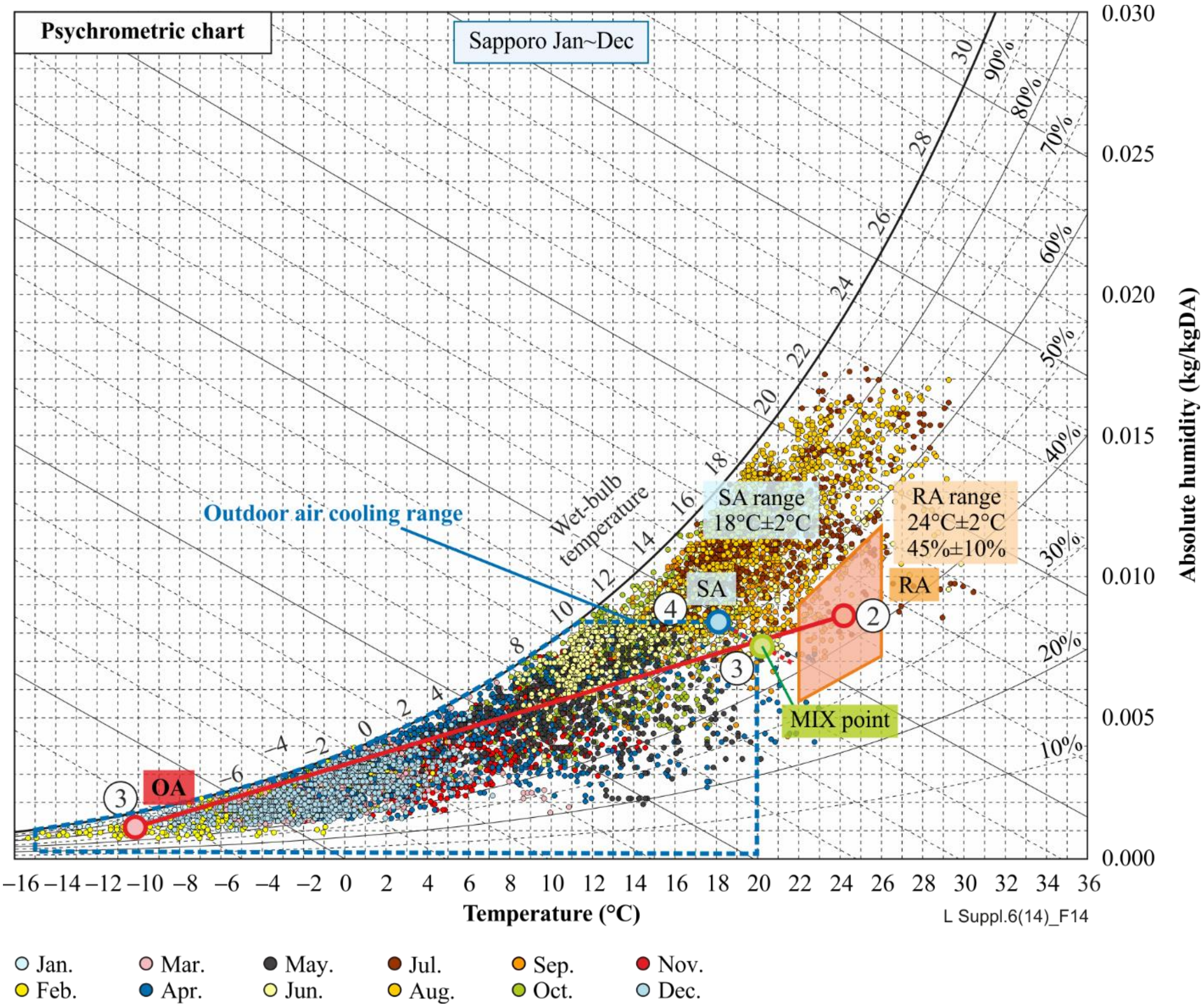


Figure 14 – Psychometric chart: Sapporo weather data

Table 3 – Estimate time during which outdoor air cooling can be done in Sapporo

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Time (h)	744	672	744	720	744	720	744	744	720	744	720	744	8 760
Time during which outdoor air cooling can be done (h)	744	672	744	701	718	384	11	31	177	628	720	744	6 274
Percentage (%)	100.0	100.0	100.0	97.4	96.5	53.3	1.5	4.2	24.6	84.4	100.0	100.0	71.6

Energy consumption during the rest of the year is calculated for a total of six cases (shown below), involving different combinations of the following conditions: snow and ice cooling 75%, 50% and 25% and conventional air conditioning. It is assumed that conventional air conditioning is used during the periods other than the periods during which outdoor air cooling or snow and ice cooling is used. It is also assumed that snow and ice cooling is used, wherever possible, early during the period in which a large amount of snow is available. Table 4 shows the amount of time each air conditioning method is used as the basis for the calculation of annual energy consumption.

Table 4 – Operation time of each air conditioning method

	Outdoor air cooling (h)	Snow and ice cooling (h)	Conventional air conditioning (h)
Pattern 1: outdoor air cooling + snow cooling	6 274	2 486	0
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	6 274	1 865	621
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	6 274	1 243	1 243
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	6 274	621	1 865
Pattern 5: outdoor air cooling + conventional air conditioning	6 274	0	2 486
Pattern 6: conventional air conditioning	0	0	8 760

8.2 Estimation of annual energy consumption of the test facility

Table 5 shows the specifications of the air conditioning system of the test facility. Power consumption is calculated by multiplying the test result (average value) per equipment by the time (hours) during which snow and ice cooling is feasible.

Table 5 – Specifications of the air conditioning system

Element	Test room
number of racks	6
Capacity	4 kW/rack
heat value	24 kW

Heat source	Cooling capacity	Power consumption	Number
water-cooled chiller	24.0 kW	9.5 kW	1

Auxiliary machine	Cooling capacity	Power consumption	Number
cooling tower	24 kW	2.1 kW	1
cooling water pump	142 L/min	2.2 kW	1
chilled water pump	115 L/min	2.1 kW	1

AHU	Cooling capacity	Power consumption	Number
airflow rate	12 000 m^3/h	2.2 kW	1

Table 6 – Calculated annual power consumption of the test facility

	Outdoor air cooling kWh/year	Snow cooling kWh/year	Conventional AC kWh/year	Total power consumption kWh/year	Percentage of reduction %
Pattern 1: outdoor air cooling + snow cooling	13 800	13 670	0	27 470	83
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	13 800	10 260	11 240	35 300	78
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	13 800	6 840	22 498	43 138	73
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	13 800	3 420	33 757	50 977	68
Pattern 5: outdoor air cooling + conventional air conditioning	13 800	0	44 997	58 797	63
Pattern 6: conventional air conditioning	0	0	158 556	158 556	0

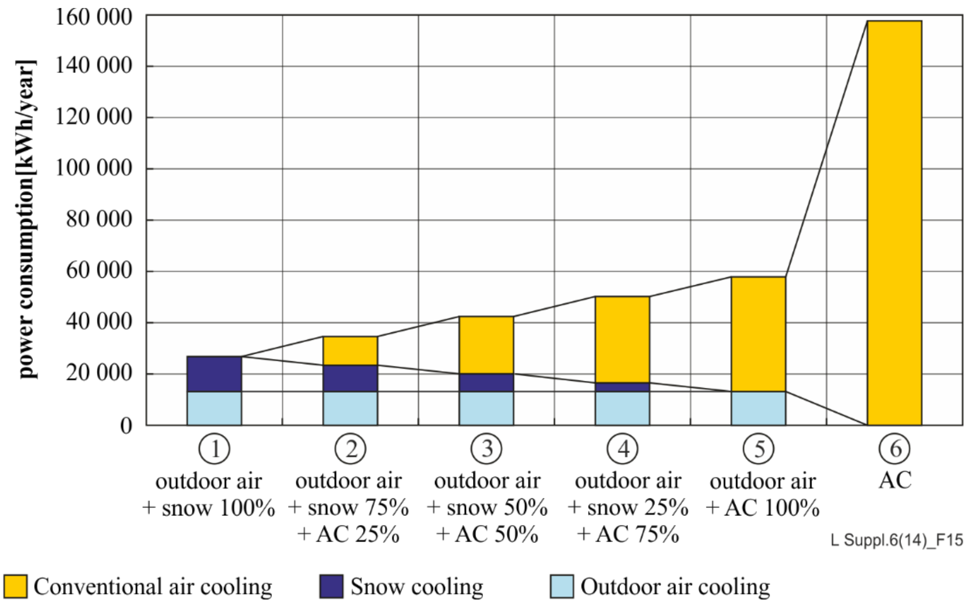
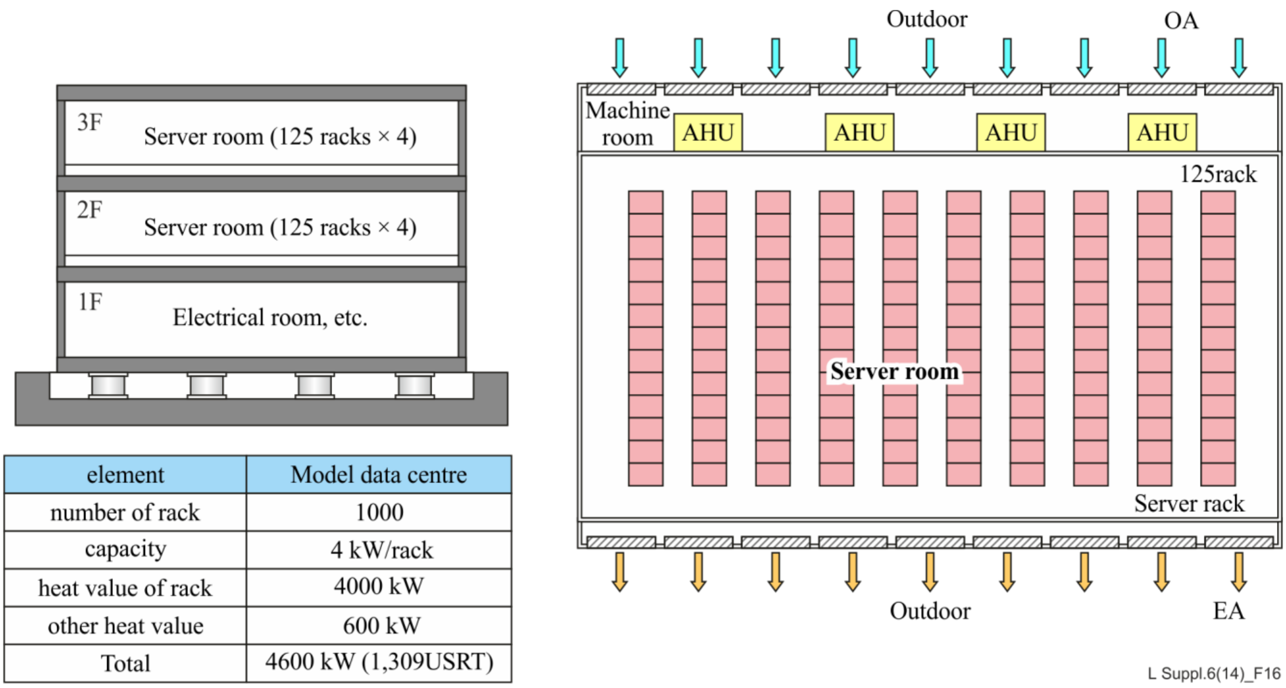


Figure 15 – Calculated annual power consumption of the test facility

8.3 Calculation of energy consumption of the model data centre

(1) Preparation of a 4 kW-per-rack 1000-rack model

Figure 16 illustrates a 1000-rack data centre and the schematic diagram of the air conditioning system. Basically, the air conditioning system shown in Figure 16 is based on the same principle as that of the air conditioning system used in the test.



element	Model data centre
number of rack	1000
capacity	4 kW/rack
heat value of rack	4000 kW
other heat value	600 kW
Total	4600 kW (1,309USRT)

Figure 16 – 1000-rack model data centre

(2) Estimation of energy consumption by air conditioning pattern

Table 7 and Figure 17 show the calculated annual power consumption of the 1000-rack model data centre. As shown, the percentages of reduction of annual power consumption are smaller than those for the test facility. One reason for this is that both supply and exhaust of air are taken into consideration in order to balance the indoor and outdoor pressures when taking in outdoor air. Another reason is that the efficiency of chiller operation has improved, and power consumption for conventional air conditioning has decreased, so that the percentage of reduction has decreased in relative terms.

Table 7 – Calculated annual power consumption of the 1000-rack model data centre

	Outdoor air cooling kWh/year	Snow cooling kWh/year	Conventional AC kWh/year	Total power consumption kWh/year	Percentage of reduction %
Pattern 1: outdoor air cooling + snow cooling	4 972 100	2 372 900	0	7 345 000	44.5
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	4 972 100	1 780 100	982 100	7 734 300	41.6
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	4 972 100	1 186 400	1 986 000	8 144 500	38.5
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	4 972 100	592 700	2 984 500	8 549 300	35.5

Table 7 – Calculated annual power consumption of the 1000-rack model data centre

	Outdoor air cooling kWh/year	Snow cooling kWh/year	Conventional AC kWh/year	Total power consumption kWh/year	Percentage of reduction %
Pattern 5: outdoor air cooling + conventional air conditioning	4 972 100	0	3 971 400	8 943 500	32.5
Pattern 6: conventional air conditioning	0	0	13 244 700	13 244 700	0.0

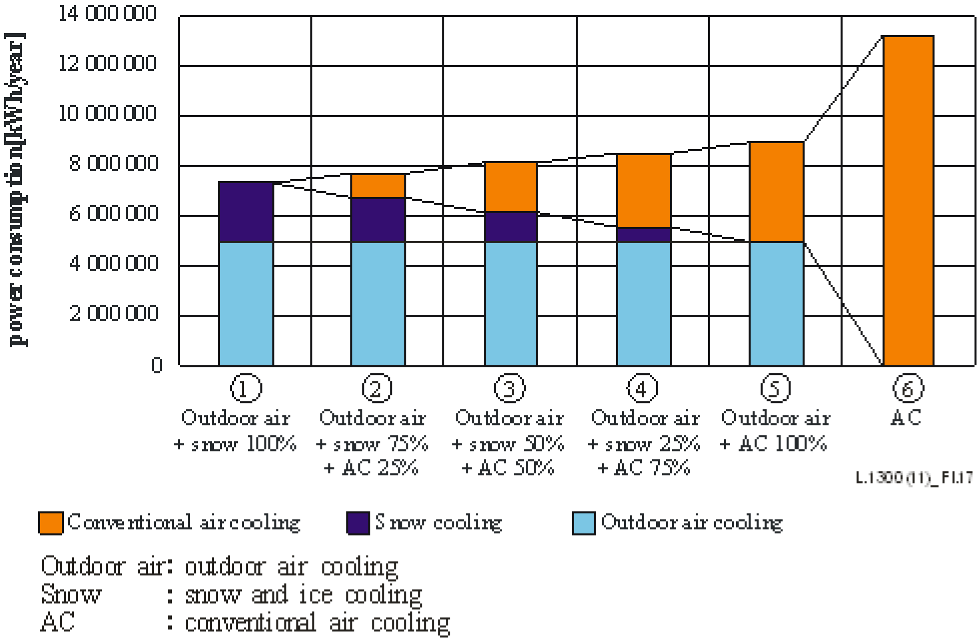


Figure 17 – Calculated annual power consumption of the 1000-rack model data centre

(3) Calculation of running costs

The running cost of the air conditioning system was calculated by using the electricity charge in Hokkaido. Table 8 shows the calculation results. The effect of power consumption reduction is relatively small because of the basic charge.

Table 8 – Calculated annual electricity charges for the 1000-rack model data centre

	Electric power charge (1 kW=9.77 yen)	**Electric power base charge yen/year**	**Total cost yen**	**Reduction of electric power cost yen**
Pattern 1: outdoor air cooling + snow cooling	71 760 700	21 768 300	93 529 000	74 076 200
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	75 564 100	36 857 500	112 421 600	55 183 600
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	79 571 800	38 204 500	117 776 300	49 828 900
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	83 526 700	38 204 500	121 731 200	45 874 000
Pattern 5: outdoor air cooling + conventional air conditioning	87 378 000	38 204 500	125 582 500	42 022 700
Pattern 6: conventional air conditioning	129 400 700	38 204 500	167 605 200	0

Table 9 shows estimated volumes of snow required for snow and ice cooling calculated by assuming a remaining snow percentage of 70%. A 20 metre high pile of snow, in the shape of a 45-degree frustum, served as the basis of the calculation for the area of the snow storage facility.

The required size of the snow pile is calculated according to the snow and ice cooling period assumed. The required volume of snow is calculated as follows:

Required volume of snow (m^3) = Cooling load (kW) × Snow and ice cooling period (h) ÷ Amount of heat available for snow and ice cooling (kWh/kg) ÷ Density of snow (kg/m^3)

where the amount of heat available for snow and ice cooling is 0.1 kWh/kg and the density of snow is 500 kg/m^3.

Table 9 – Estimated volumes of snow required for snow and ice cooling of the 1000-rack model data centre

(Remaining snow percentage: 70%)

	Required snow volume m^3	**Snow pile volume m^3**	**Snow storage area m^2**	**Width m**	**Depth m**
Pattern 1: outdoor air cooling + snow cooling	228 700	326 700	21 693	147	147
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	171 600	245 100	16 900	130	130
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	114 400	163 400	12 022	110	110
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	57 100	81 600	6 860	83	83

(4) Evaluation in terms of PUE

For the purpose of evaluating the effect of outdoor air cooling and snow and ice cooling on PUE (power usage effectiveness), an advanced 1000-rack data centre is assumed. To calculate the power consumption of equipment other than the ICT and air conditioning equipment, it is assumed that power supply facilities, and other facilities, account for 9% and 1% respectively of the total power consumption. The power consumption of the ICT equipment is calculated as 4 000 kW × 8 760 hours = 35 040 000 kW. Table 10 shows the PUE calculation results.

Table 10 – Estimated annual PUE of the 1000-rack model data centre

	IT equipment kWh/year	**Cooling kWh/year**	**Power-supply kWh/year**	**Other equipment kWh/year**	**Total kWh/year**	**PUE**
Pattern 1: outdoor air cooling + snow cooling	35 040 000	7 345 000	4 829 400	536 600	47 751 000	1.36
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	35 040 000	7 734 300	4 829 400	536 600	48 140 300	1.37
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	35 040 000	8 144 500	4 829 400	536 600	48 550 500	1.39
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	35 040 000	8 549 300	4 829 400	536 600	48 955 300	1.40
Pattern 5: outdoor air cooling + conventional air conditioning	35 040 000	8 943 500	4 829 400	536 600	49 349 500	1.41
Pattern 6: conventional air conditioning	35 040 000	13 244 700	4 829 400	536 600	53 650 700	1.53
Percentage of electric power consumed(%)	65.3	24.7	9.0	1.0	100	–

Table 11 shows annual carbon dioxide emissions due to air conditioning operation. As shown, when compared with Pattern 6 (conventional air conditioning), Pattern 1 (outdoor air cooling + snow and ice cooling) enables a reduction of about 3 500 t-CO_2/year.

Table 11 – Carbon dioxide emissions due to air conditioning of the 1000-rack model data centre

	Total power consumption kWh/year	Carbon dioxide emission rate t-CO2/year	Percentage of reduction %
Pattern 1: outdoor air cooling + snow cooling	7 345 000	4 318.9	44.5
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	7 734 300	4 547.8	41.6
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	8 144 500	4 789.0	38.5
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	8 549 300	5 027.0	35.5
Pattern 5: outdoor air cooling + conventional air conditioning	8 943 500	5 258.8	32.5
Pattern 6: conventional air conditioning	13 244 700	7 787.9	0.0

9 Conclusion

The verification test has yielded the following findings concerning the air conditioning methods that make effective use of the characteristics of a cold region:

(1) In outdoor air cooling, indoor supply air temperature can be controlled to a target level by appropriately adjusting the damper opening of the OA and RA ducts.

(2) Humidification during outdoor air cooling can be controlled with vaporizing humidifiers because the humidification of introduced outdoor air is done at the point where the outdoor air is mixed with indoor return air.

(3) Concerning snow and ice cooling, the temperature of snowmelt water obtainable from the snow pile turned out to be about 5°C, and the required amount of heat was made available through heat exchangers. Even if the temperature of melt water changes under the influence of water paths or cavities, the rate of chilled water flow to the coils is adjusted according to such changes, and a constant amount of heat is made available.

(4) In the test, the power consumption during outdoor air cooling, snow and ice cooling and conventional air conditioning, were about 2.4 kWh, 5.5 kWh and 17.4 kWh respectively. Thus, it has been verified that outdoor air cooling and snow and ice cooling are much more energy efficient than conventional air conditioning.

(5) When conventional air conditioning is not used, power consumption for the air conditioning of the 1000-rack data centre can be reduced by about 45% by using outdoor air cooling and snow and ice cooling. It can therefore be said that in cold regions, the method of using outdoor air and snow and ice for air conditioning will greatly contribute to air conditioning energy reduction, which has been a difficult problem to solve.

(6) The power usage effectiveness (PUE) evaluation of the 1000-rack data centre has shown that the use of outdoor air cooling and snow and ice cooling may make it possible to improve the PUE to 1.36, which is better than the PUE (1.53) that can be achieved by conventional air conditioning.

(7) The test and the annual power consumption estimation have confirmed that the air conditioning system utilizing outdoor air and snow and ice in a cold region is highly energy efficient. This result indicates that even in non-cold regions, energy efficiency can be improved by using similar methods if outdoor air conditions are met.

Bibliography

[b-ITU-T L.1300] Recommendation ITU-T L.1300 (2011), *Best practices for green data centres.*

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