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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Best practices for green data centres

Recommendation ITU-T L.1300

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Summary

Recommendation ITU-T L.1300 describes best practices aimed at reducing the negative impact of data centres on the climate. It is commonly recognized that data centres will have an ever-increasing impact on the environment in the future. The application of the best practices defined in this Recommendation can help owners and managers to build future data centres, or improve existing ones, to operate in an environmentally responsible manner. Such considerations will strongly contribute to a reduction in the impact of the information and communication technology (ICT) sector on climate change.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T L.1300	2011-11-29	5

Keywords

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

FOREWORD

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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Best practices for green data centres

1 Scope

This Recommendation specifies best practices aimed at developing green data centres. A green data centre can be defined as a repository for the storage, management, and dissemination of data in which the mechanical, lighting, electrical and computer systems are designed for maximum energy efficiency and minimum environmental impact. The construction and operation of a green data centre includes advanced technologies and strategies. The Recommendation provides a set of rules to be referred to when undertaking improvement of existing data centres, or when planning, designing or constructing new ones.

The proposed best practices cover:

- data centre utilization, management and planning;
- ICT equipment and services;
- cooling;
- data centre power equipment;
- data centre building;
- monitoring.
- The efficiency of a data centre should be assessed in line with Recommendations ITU-T L.1400, ITU-T L.1410 and ITU-T L.1420.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ETSI EN 300 019-1-3] ETSI EN 300 019-1-3 V2.3.2 (2009), *Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 1-3: Classification of environmental conditions; Stationary use at weather protected locations.*

[ETSI TR 102 489] ETSI TR 102 489 V1.2.1 (2010), *Environmental Engineering (EE); European telecommunications standard for equipment practice; Thermal Management Guidance for equipment and its deployment.*

3 Definitions

3.1 Term defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 power density: The energy consumption of ICT equipment per rack cabinet of floor area of a server room.

3.2.2 space efficiency: The ratio of floor area employed for ICT equipment in relation to the total floor area of the building.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AHU	Air Handling Unit
BC	Business Continuity
BIOS	Basic Input-Output System
CFD	Computational Fluid Dynamics
COP	Coefficient Of Performance
CRAC	Computer Room Air Conditioner
DC	Data Centre
DCeP	Data Centre energy Productivity
DCiE	Data Centre infrastructure Efficiency
DPPE	Data centre Performance Per Energy
DR	Disaster Recovery
EA	Exhaust Air
GEC	Green Energy Coefficient
HEX	Heat Exchanger
HVAC	Heating Ventilation and Air Conditioning
HVDC	High-voltage Direct Current
ICT	Information and Communication Technology
ITEE	IT equipment Energy Efficiency
ITEU	IT Equipment Utilization
M&E	Maintenance and Engineering
OA	Outdoor Air
PDU	Power Distribution Unit
PUE	Power Usage Effectiveness
RA	Return Air
RH	Relative Humidity
RT	Refrigerant Ton
SA	Supply Air
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol

UPS	Uninterruptible Power Supply
VAV	Variable Air Volume

5 Introduction to best practices for green data centres

In order to improve the energy efficiency of data centres, it is necessary to consider all stages from design through to construction. Even after the building of data centres is complete, they must continue to be managed and maintained to ensure efficient energy consumption.

This Recommendation describes best practices for energy-efficient construction, operation and management of green data centres that contain a number of essential components, including ICT equipment and services, cooling, power equipment, data centre building, etc.

The best practices discussed herein have been numbered for easy reference.

Best practices have been identified and divided into different clauses to cover the different components of a data centre.

1. clause 6 Planning, utilization, and management
2. clause 7 ICT equipment and services
3. clause 8 Cooling
4. clause 9 Data centre power
5. clause 10 Other data centre equipment
6. clause 11 Data centre
7. clause 12 Monitoring
8. clause 13 Design of network

5.1 Role of best practices

This Recommendation is provided as a comprehensive guide to assist data centre operators in identifying and implementing measures to improve energy efficiency of their data centres.

The full list of best practices that are specified in this Recommendation can be of practical help for those who are pursuing green data centres.

5.2 Value of practices

Each practice has not been assigned a qualitative value to indicate the level of benefit to be expected from an action and the relative priorities that should be applied to it.

When there is a choice of practices, a preference should be given to the one having the least impact on the environment.

6 Planning, utilization, and management of data centres

It is important to develop a holistic strategy and management approach to the data centre to support economic efficiency and environmental benefits.

6.1 Involvement of organizational groups

Effective communication between different departments working in the data centres is crucial to ensure efficiency and thereby avoid capacity and reliability issues.

To ensure effective communication, the following steps are proposed:

No.	Name	Description
1.	Group involvement	Establish an "Approval Board" composed of representatives from different departments (e.g., software, ICT, power cooling and other facilities). Submit all important decisions for board approval to ensure that all possible impact has been fully understood and that an effective solution has been identified. For example, one of the decisions could be the definition of standard ICT hardware lists through considering the maintenance and engineering (M&E) implications of different types of hardware.

6.2 General policies

These policies apply to all aspects of the data centre and its operation.

No.	Name	Description
2.	Consider the embedded energy in devices	Carry out an audit of existing equipment to ensure that optimal use is made of existing capability before making any new investment.

6.3 Resilience level and provisioning

One of the most significant sources of inefficiency in a data centre is the over-provision of space, power or cooling, and the use of existing facilities at partial capacity. Monolithic design, as opposed to modular design, of facilities is also frequently an unnecessary capital expenditure.

No.	Name	Description
3.	Build resilience to business requirements	Build or, in the case of a co-location customer, purchase only the level of resilience actually justified by business requirements and an impact analysis. Full backup (1+1) of infrastructure is frequently unnecessary and inappropriate. Resilience for a small portion of critical services can be obtained by using DR/BC sites.
4.	Consider multiple levels of resilience	Build a single data centre to provide multiple levels of power and cooling resilience to different floor areas. Many co-location providers already deliver this, for example, as optional "grey" power feeds without UPS or generator back up.
5.	Design effective resilience	Utilize appropriate levels of resilience at the data centre ICT equipment, software and network levels to achieve the required service resilience. High resilience at the physical level is rarely an effective overall solution.
6.	Lean provision of power and cooling for a maximum of 18 months of data floor capacity	Avoid unnecessary fixed losses as a result of the provision of excess power and cooling capacity in the data centre. Plan a data centre for modular (scalable) expansion and then build upon this capacity in a rolling programme of deployment. This design is more efficient, allows the technology "generation" of ICT equipment, and supports the match of M&E infrastructure, thereby improving both efficiency and the ability to respond to business requirements.
7.	Design to maximize the partial load efficiency once provisioned	All areas of the data centre should be designed to maximize the efficiency of the facility under partial fill and variable ICT electrical load. This is in addition to one-off modular provisioning and considers the response of the infrastructure equipment to dynamic loads, e.g., variable frequency (or speed) drives for pumps and fan units.

7 ICT equipment and services

ICT equipment creates the demand for power and cooling in the data centre. Any reduction in power and cooling used by, or provisioned for ICT equipment will have magnified effects for the utility energy supply.

The purpose of environmental specifications of equipment, as outlined in the next paragraph, is to ensure that new equipment is capable of operating under the wider ranges of temperature and humidity, thus allowing the operator a greater flexibility in operating temperature and humidity.

7.1 Selection of new ICT equipment

Once ICT equipment is purchased and installed in the data centre, it is usually in use for several years, consuming power and creating heat. The appropriate selection of hardware and deployment methods can provide significant long-term savings.

No.	Name	Description
8.	Multiple tender for ICT hardware – power	Include energy efficient performance of the ICT device as a high priority decision factor in the tender process e.g., through application or deployment of specific user metrics more closely aligned to the target environment, which may include service level or reliability components. The energy consumption of the device at the expected utilization or applied workload, should be considered in addition to peak performance per watt figures.
9.	Multiple tender for ICT hardware – operating temperature and humidity range at equipment intake Low priority practices	Include the operating temperature and humidity ranges at the intake of new equipment as high priority decision factors in the tender process. The minimum range, at the air intake to servers, is 18°C-32°C and 5.5°C dew point up to 15°C dew point & 60% RH. This is defined by ASHRAE [b-ASHRAE TC 9.9].
10.	Multiple tender for ICT hardware – extended operating temperature and humidity range High priority practices	Introduce a stronger requirement for new ICT equipment stipulating the need for them to withstand the air inlet temperature and relative humidity ranges of 5°C to 40°C and 5% to 80% RH, non-condensing respectively, and under exceptional conditions up to +45°C, as described in [ETSI EN 300 019-1-3] Class 3.1. All vendors should indicate the maximum allowable temperature and humidity for all equipment, to maximize the efficiency opportunities in refrigeration and free cooling. It should be noted that where equipment with differing environmental requirements are not segregated, the equipment with the more restrictive temperature range will influence the cooling conditions and corresponding energy consumption for all ICT equipment. From 40°C to 45°C intake temperature, it is acceptable for equipment to implement performance reduction mechanisms to continue delivering the intended service at a lower speed whilst preventing damage. These mechanisms should not reduce performance to below 80% of the nominal for that device. Where such performance reduction mechanisms are used, a clear description of the operating parameters and performance impact should be provided.

No.	Name	Description
11.	Environmental exclusions	Exclusions from the requirement for ICT equipment to meet the ETSI specification will be considered under the following specific conditions: – equipment that requires tighter environmental controls to meet the requirements of storage media such as tapes – equipment that requires tighter environmental controls to meet long warranty durations (10+ years) – devices whose primary cooling method is not air (directly liquid cooled) These exclusions would require that equipment unable to meet best practice 10 should be deployed with separate airflow and cooling provision. This allows data centre cooling plants to be set up using equipment that has a less restrictive environmental range without compromising the eco-efficiency of the entire data centre.
12.	Multiple tender for ICT hardware – compliance with green regulations	Tender processes for new ICT equipment that are compliant with green regulations, will be considered as high-priority decision factors. Environmental pollution can be reduced by selecting equipment that is compliant with green regulations of each region or country (e.g., RoHS, REACH, and WEEE).
13.	Select equipment suitable for the data centre – power density	Select and deploy equipment according to the defined power density (per rack or square metre) of the data centre to avoid running the cooling system outside design parameters. Note that increasing power density may create cooling and airflow management problems, thereby reducing both capacity and efficiency. Power and cooling need to be considered as a capacity constraint in addition to a physical space constraint.
14.	Select equipment suitable for the data centre – airflow direction	When selecting equipment for installation into racks, ensure that the airflow direction matches the airflow design for that area. This is commonly front-to-rear or front-to-top. If the equipment uses a different airflow direction to that defined for the area into which it is installed (such as right-to-left when the rack is intended to be front-to-back), then it should only be used with a correction mechanism such as ducts, or special racks that divert the airflow to the defined direction. Uncorrected equipment with non-standard airflow will compromise the airflow management of the data centre, and therefore restrict temperature set points. It is possible to mitigate this issue by segregating such equipment.
15.	Select free-standing equipment suitable for the data centre – airflow direction	When selecting equipment which is free-standing, or supplied in custom racks, the airflow direction of the enclosures should match the airflow design in that area of the data centre. This is commonly front to rear or front to top. Specifically the equipment should match the hot/cold aisle layout or containment scheme implemented in the facility. Uncorrected equipment with non-standard airflow will compromise the airflow management of the data centre and therefore restrict temperature set points. It is possible to mitigate this compromise by segregating such equipment. Suggestions on airflow management are present in an annex to this Recommendation and in [ETSI TR 102 489].

No.	Name	Description
16.	Enable power management features	Formally change the deployment process to include the enabling of power management features on ICT hardware as it is deployed. This includes BIOS, operating system and driver settings.
17.	Provision to the as-configured power	Provision of power and cooling only to the as-configured power draw capability of the equipment, and not the PSU or nameplate rating. Note that this may require changes to provisioning if the ICT equipment is upgraded internally.
18.	Energy Star hardware	The Energy Star labelling programmes for ICT equipment should be used as a guide to server selection when and where available for that class of equipment. Operators who are able to determine the in use energy efficiency of hardware through more advanced or effective analysis, should select the most efficient equipment for their scenario.
19.	Energy and temperature reporting hardware	Select equipment with power and inlet temperature reporting capabilities, preferably reporting energy used as a counter in addition to power as a gauge. Where applicable, industry standard reporting approaches should be used, such as IPMI, DCMI and SMASH. To assist in the implementation of temperature and energy monitoring across a broad range of data centres, all devices with an IP interface should support SNMP polling of inlet temperature and power draw. Note that event based SNMP traps and SNMP configuration are not required. The intent of this practice is to provide energy and environmental monitoring of the data centre through normal equipment churn.
20.	Control of equipment energy use	Select equipment which provides mechanisms to allow the external control of its energy use. An example of this would be the ability to externally restrict a server's maximum energy use or trigger the shutdown of components, entire systems or sub-systems.

7.2 Selection of new telecom equipment

Once ICT equipment is purchased and installed in the data centre, it typically remains in use for several years, consuming power and creating heat. The appropriate selection of hardware and deployment methods can provide significant long-term savings.

No.	Name	Description
21.	New equipment selection	Processes should be put in place to select new telecom equipment solutions that take into consideration the energy efficiency of the equipment and of the related infrastructure required for the correct operation of the telecom product.

7.3 Deployment of new ICT services

The service architecture, software and deployment of ICT services have an impact at least as great as that of the ICT hardware.

No.	Name	Description
22.	Deploy using grid and virtualisation technologies	Processes should be put in place to require senior business approval for any new service that requires dedicated hardware and will not run on a resource sharing platform. This applies to servers, storage and networking aspects of the service.
23.	Reduce ICT hardware resilience level	Determine the business impact of service incidents for each deployed service and deploy only the level of hardware resilience actually justified.
24.	Eliminate traditional 2N hardware clusters	Determine the business impact of short service incidents for each deployed service and replace traditional active/passive server hardware clusters with fast recovery approaches, such as restarting virtual machines elsewhere. (This does not refer to grid or high performance computer clusters.)
25.	Reduce hot/cold standby equipment	Determine the business impact of service incidents for each ICT service and deploy only the level of business continuity/disaster recovery standby ICT equipment and resilience that is actually justified by the business impact.
26.	Select/develop efficient software	Make the energy use performance of the software a primary selection factor. Whilst forecasting and measurement tools and methods are still being developed, approximations can be used such as the (under-load) power draw of the hardware required to meet performance and availability targets. If outsourcing software development, then include the energy use of the software in the bonus/penalty clauses of the contract.
27.	Further development of software efficiency definitions	There is much research and development needed in the area of defining, measuring, comparing and communicating software energy efficiency. Suggested examples are: Software could be made resilient to delays associated with bringing off-line resources on-line, such as the delay of drive spin, which would not violate the service level requirements. Software should not gratuitously poll or carry out other unnecessary background "housekeeping" that prevents equipment from entering lower-power states; this includes monitoring software and agents.

7.4 Deployment of new telecom services

7.5 Management of existing ICT equipment and services

It is common to focus on new services and equipment to be installed in the data centre, but there are also substantial opportunities to achieve energy and cost reductions from within the existing service and physical installation.

No.	Name	Description
28.	Audit existing physical equipment and services	Audit the existing physical equipment and services to establish what equipment is in place and what service(s) it delivers. Consider the implementation of an ITIL type configuration management database and service catalogue.
29.	Decommission unused services	Completely decommission and remove the supporting hardware for unused services.
30.	Decommission low business value services	Identify services whose business value is low and does not justify the financial or environmental cost. Decommission or archive these services.
31.	Shut down idle equipment	Servers, networking, and storage equipment that lie idle for a significant period of time, and cannot be virtualised and archived, should be shut down or put into a low power sleep mode. It may be necessary to validate the ability of legacy applications and hardware to survive these state changes without loss of function or reliability.
32.	Virtualise and archive legacy services	Servers which cannot be decommissioned for compliance or other reasons, but which are not used on a regular basis, should be virtualised and then the disk images archived to a low-power media. These services can then be brought online when actually required.
33.	Consolidation of existing services	Existing services that do not achieve high utilization of their hardware should be consolidated through the use of resource sharing technologies to improve the use of physical resources. This applies to servers, storage and networking devices.
34.	Control of system energy use	Consider resource management systems capable of analysing and optimizing where, when and how ICT workloads are executed, and their consequent energy use. This may include technologies that allow remote deployment or delayed execution of jobs, or the movement of jobs within the infrastructure, to enable shutdown of components, entire systems or sub-systems. The desired outcome is to provide the ability to limit localised heat output or to constrain system power draw to a fixed limit, at a data centre, row, rack or sub-DC level.

7.6 Data management

Storage is a major growth area in both cost and energy consumption within the data centre. It is generally recognised that a significant proportion of the data stored is either unnecessary or duplicated and does not require high performance access, and that this represents an organisational challenge. Some sectors have a particular issue due to very broad and non-specific data retention directions from governments or regulating bodies. Where there is little structure to the data storage, implementation of these regulations can cause large volumes of data that are not required by the regulations to be unnecessarily heavily protected and archived.

No.	Name	Description
35.	Data management policy	Develop a data management policy to define which data should be kept, for how long and at what level of protection. Communicate the policy to users and enforce it. Particular care should be taken to understand the impact of any data retention requirements.
36.	Separate user logical data storage areas by retention and protection policy	Provide users with multiple data storage areas which are clearly identified by their retention policy and level of data protection. Communicate this policy to users to enable them to store data in an area which matches the required levels of protection and retention. This is particularly valuable where strong retention requirements exist, as it allows data subject to those requirements to be separated at source, thereby presenting substantial opportunities for cost and energy savings. Where possible automate the application of these policies.
37.	Separate physical data storage areas by protection and performance requirements	Create a tiered storage environment utilising multiple media types that deliver the required combinations of performance, capacity and resilience. Implement clear guidelines on usage of storage tiers, with defined SLAs for performance and availability. Consider a tiered charging model based on usage at each tier.
38.	Select lower power storage devices	When selecting storage hardware, evaluate the energy efficiency in terms of the service delivered per watt between options. This may be deployment-specific and should include the achieved performance and storage volume per watt, as well as additional factors where appropriate, such as the achieved levels of data protection, performance availability and recovery capability required to meet the business service level requirements defined in the data management policy. Evaluate both the in-use power draw and the peak power of the storage device(s) as configured, both impact per device cost and energy consumption through provisioning.
39.	Reduce total data volume	Implement an effective data identification and management policy and process to reduce the total volume of data stored. Consider implementing "clean up days" where users delete unnecessary data from storage.
40.	Reduce total storage volume	Implement the data management policy to reduce the number of copies of data, both logical and physical (mirrors). Implement storage subsystem space saving features, such as space efficient snapshots/copies or compression. Implement storage subsystem thin provisioning features where possible.
41.	Further development of storage performance and efficiency definitions	Storage performance has multiple dimensions, including throughput and latency, not all of which can be measured at the storage layer. Capacity also has multiple dimensions, allocation and usage, not all of which can be measured at the storage layer. Technologies such as de-duplication, compression, snapshots, and thin provisioning also need to be accounted for in a consistent and informative manner.

8 Cooling

Cooling of the data centre is frequently the largest energy loss in the facility and as such represents a significant opportunity to improve efficiency.

8.1 Airflow design and management

The objective of airflow management is to minimize bypass air that returns to the CRAC units without performing its cooling function. The resultant recirculation and mixing of cool and hot air, increases the equipment intake temperatures. To compensate, CRAC unit air supply temperatures are frequently reduced, or airflow volumes are increased, which has an energy penalty. Addressing these issues will deliver more uniform equipment inlet temperatures and allow set points to be increased (with the associated energy savings), without the risk of equipment overheating. Implementation of air management actions alone does not result in energy saving – they are enablers which need to be tackled before set points can be raised.

No.	Name	Description
42.	Design – contained hot or cold air	There are a number of design concepts which intend to contain and separate the cold air from the heated return air on the data floor: – hot aisle containment; – cold aisle containment; – contained rack supply, room return; – room supply, contained rack return, (including rack chimneys); – contained rack supply, contained rack return. This action is expected for air cooled facilities over 1 kW per square meter power density. Note that the in-rack cooling options are only considered to be containment where the entire data floor area is cooled in rack, not in mixed environments where they return cooled air for remix with other airflow.
43.	Design – hot/cold aisle	As the power densities and airflow volumes of ICT equipment have increased, it has become necessary to ensure that equipment shares an airflow direction, within the rack, in adjacent racks and across aisles. The hot/cold aisle concept aligns equipment airflow to create aisles between racks that are fed cold air from which all of the equipment draws intake air in conjunction with hot aisles with no cold air feed, to which all equipment exhausts air.
44.	Design – contained hot or cold air – retrofit	Where hot/cold aisle separation is already in use, but there is no containment of hot or cold air, it is possible to retrofit to provide basic separation.
45.	Rack airflow management – blanking plates	Installation of blanking plates where there is no equipment to reduce cold air passing through gaps in the rack. This also reduces air heated by one device being ingested by another device, increasing intake temperature and reducing efficiency.
46.	Rack airflow management – other openings	Installation of aperture brushes (draught excluders) or cover plates to cover all air leakage opportunities in each rack. This includes; – floor openings at the base of the rack; – gaps at the sides, top and bottom of the rack between equipment or mounting rails and the perimeter of the rack.
47.	Rack airflow management – obstructions	The main cause of rack airflow obstruction is the cables behind racks. Unorganized cables may block hot airflow from ICT equipment and cause re-intake of the air by the rack front, further increasing the equipment inlet temperature. Therefore, cables behind racks should be organized to secure adequate amount of cold airflow.

No.	Name	Description
48.	Raised floor airflow management	Close all unwanted apertures in the raised floor. Review placement and opening factors of vented tiles. Maintain unbroken rows of cabinets to prevent bypass air – where necessary fill with empty fully blanked racks. Managing unbroken rows is especially important in hot and cold aisle environments. Any opening between the aisles will degrade the separation of hot and cold air.
49.	Raised floor airflow management – obstructions	Review the placement and level of obstruction created by cabling, cable trays and other structures in the airflow paths to enable unobstructed airflow and prevent turbulence and increased resistance. The use of overhead cabling trays for signalling, for example, can substantially reduce the energy requirements for air movement.
50.	Design – raised floor or suspended ceiling height	If, when designing a data centre, spaces are created by raising the floor level or suspending the ceiling, such air chambers are commonly used to feed cold air to equipment, or extract hot air from it. Where such voids are utilised, the increased spaces can significantly reduce fan loss in moving the air.
51.	Design – return plenums	Consider the use of return dedicated ducts to return heated air from the ICT equipment to the air conditioning units.
52.	Design – perforated tiles	Mixed use of two or three perforated tiles with different aperture ratios is more advisable than using perforated tiles having the same aperture ratio in all spots of the computer room. In general, areas closer to CRAC units have higher air volume and static pressure, which enables provision of a sufficient amount of cold air to ICT equipment, even with perforated tiles having low aperture ratios. In the areas farther from CRAC units, provision of cold air can be controlled by using perforated tiles with high aperture ratios. It is recommended not to install perforated tiles in areas that are too close to CRAC units. In these areas, the fast airflow under the raised floor creates negative pressure on perforated tiles and causes Venturi reversal, in which the air above the raised floor is pulled down under. The Venturi reversal rather draws hot air to ICT equipment while causing a lack of cold air provision to the equipment.
53.	Equipment segregation	Deploy groups of equipment with substantially different environmental requirements and/or equipment airflow direction in a separate area. Where the equipment has different environmental requirements, it is preferable to provide separate environmental controls. The objective of this practice is to address the issue of the data centre cooling plant settings being constrained by the ICT equipment with the most restrictive environmental range, or poor airflow control, as this compromises the efficiency of the entire data centre.

No.	Name	Description
54.	Disposition of high-heat equipment	As energy consumption and heat from blade servers or large equipment increase, disposition of such high-heat equipment often affects the efficiency of the entire computer room. It is appropriate to position high-heat equipment in places where most cold air is provided. – CRAC units are often installed facing each other in the computer room. In this situation, the air temperature is lowest in the centre of the room. Therefore, high-heat equipment should be installed in the centre of the computer room, rather than in places near CRAC units. – If it is uncertain which place receives the most amount of cold air, it is recommended to measure the temperature of each area and install the high-heat equipment in the place with the lowest temperature.
55.	Provide adequate free area on rack doors	Solid doors can be replaced (where doors are necessary) with partially perforated doors to ensure adequate cooling airflow within the enclosed cabinet further increasing the equipment intake temperature.
56.	Separate from external environment	The more contact the computer room has with the outer environment (outside air and solar heat), the more it is exposed to influences on temperature and humidity, further decreasing the entire air conditioning efficiency. Therefore, blocking contacts with the outer environment is a significant factor that is directly related to reducing energy consumption. For separation from the external environment, the following activities are required: • designing a windowless room or sealing windows; • installing double doors or an automatic door; • restricting entry/exit of unnecessary persons; • blocking channels connected to the outside, such as an outlet, etc. To prevent temperature increase from solar heat in the computer room, it is necessary to deploy a windowless design or shield windows (by way of window shades, curtains, solar screen panels, etc.)

8.2 Cooling management

The data centre is not a static system and the cooling systems should be tuned in response to changes in the facility thermal load.

No.	Name	Description
57.	Scalable or modular installation and use of cooling equipment	Cooling plants should be installed in a modular fashion allowing operators to shut down unnecessary equipment. This should then be part of the review at each cooling load change.
58.	Shut down unnecessary cooling equipment	If the facility is not yet fully populated or space has been cleared through consolidation, non-variable plants, such as fixed speed fan CRAC units, can be turned off in the empty areas. Note that this should not be applied in cases where operating more plants at a lower load is more efficient, e.g., variable speed drive CRAC units.

No.	Name	Description
59.	Review of cooling before ICT equipment changes	The availability of cooling, including the placement and flow of vented tiles, should be reviewed before each ICT equipment change to optimize the use of cooling resources.
60.	Review of cooling strategy	Periodically review ICT equipment and cooling deployment against strategy.
61.	Review CRAC settings	Ensure that CRAC units in occupied areas have an appropriate and consistent temperature, and relative humidity settings, to avoid units working against each other. For example, many CRAC units now have the option to connect their controls and run together when installed in the same area.
62.	Dynamic control of building cooling	It is possible to implement control systems that take many factors into account, including cooling load, data floor air temperature and external air temperature, to optimize the cooling system (e.g., chilled water loop temperature) in real time.
63.	Effective regular maintenance of cooling plant	Effective regular maintenance of the cooling system is essential to maintain the design operating efficiency of the data centre, e.g., belt tension, condenser coil fouling (water or air side), evaporator fouling, filter changes, etc.
64.	Evaporative cooling method and the spot cooling method	Evaporative cooling method and the spot cooling method were proposed as best practice for data centres, with high density ICT devices (see Annex B).

8.3 Temperature and humidity settings

Facilities are often over-cooled, bringing about air temperatures (and hence chilled water temperatures, where used) that are colder than necessary and resulting in an energy penalty. Increasing the set range for humidity can substantially reduce humidifier loads. Reviewing and addressing air management issues is required before set points can be changed in order to avoid risk to operational continuity. Expert advice should be sought before changing the environmental range for the facility. An increase in chilled water temperature set points provides enhanced efficiency for free cooling economisers and a reduction in compressor energy consumption. Unnecessary humidifier loads, generated by water loop or evaporator temperatures below the working dew point causing dehumidification-humidification loops, should be eliminated through adjustment of the lower humidity set point.

The specification of wider operating humidity and temperature ranges for the data floor should be performed in conjunction with changes in ICT equipment procurement policy. Over time, narrow tolerance equipment will be naturally cycled out and replaced.

No.	Name	Description
65.	Expanded ICT equipment inlet environmental conditions (temperature and humidity) High priority practices	Where appropriate and effective, the data centre can be designed and operated within the air inlet temperature and relative humidity ranges of 5°C to 40°C and 5% to 80% RH, non-condensing respectively, and under exceptional conditions up to +45°C as described in [ETSI EN 300 019-1-3], Class 3.1. It is necessary to consider that some ICT equipment may exhibit significant increases in fan energy consumption as intake temperature is increased (e.g., above 25°C). Validate that your ICT equipment will not consume more energy than is saved in the cooling system.

No.	Name	Description
66.	Review and, if possible, raise target ICT equipment intake air temperature Low priority practices	Data centres should be designed and operated at their highest efficiency within the current environmental range of 18°C to 32°C. This is defined by ASHRAE as allowable for class 1data centres [b-ASHRAE TC 9.9]. Operations in this range enable energy savings by reducing or eliminating over-cooling. This range applies to legacy data centres with existing equipment. Note that other best practices for airflow management (containment, hot aisle/cold aisle, blanking plates, and sealing leaks) may need to be implemented at the same time to ensure successful operations.
67.	Review and increase the working humidity range Low priority practices	Reduce the lower humidity set point(s) of the data centre within the range (5.5°C dew point) to eliminate loop dehumidification and re-humidification. Review and, if practical, increase the upper humidity set point(s) of the data floor within the current environmental range of 20°C dew point & 80% RH to decrease the humidity control loads within the facility.
68.	Review set points of air and water temperatures	Once air management issues have been addressed and ICT equipment target temperatures have been agreed upon, these temperatures can be increased (using less energy), without increasing server inlet temperatures beyond acceptable levels. It is necessary to consider that some ICT equipment may exhibit significant increases in fan energy consumption as intake temperature is increased (e.g., above 25°C). Validate that your ICT equipment will not consume more energy than is saved in the cooling system.
69.	Review and, if possible, raise chilled water loop temperature	Review and, if possible, increase the chilled water temperature set points to maximize the use of free cooling economisers and reduce compressor energy consumption. Where a DX system is used, the evaporator temperatures should be reviewed.

8.3.1 Free and economized cooling

Free, or economized cooling designs, use cool ambient conditions to meet part, or all, of the facilities cooling requirements. Hence, compressor work for cooling is reduced or removed, which can result in significant energy reduction. Economized cooling can be retrofitted to some facilities. The opportunities for the utilization of free cooling are increased in cooler climates and where increased temperature set points are used.

No.	Name	Description
70.	Direct air free cooling	External air is used to cool the facility. Chiller systems are present to deal with humidity and high external temperatures, if necessary. Exhaust air is re-circulated and mixed with intake air to avoid unnecessary humidification/dehumidification loads.
71.	Indirect air free cooling	Re-circulated air within the facility is primarily passed through a heat exchanger against external air, to remove heat to the atmosphere.
72.	Direct water free cooling	Chilled water cooled by the external ambient air, via a free cooling coil, may be achieved by dry (/adiabatic) coolers, or by evaporative assistance through spray onto the dry (/adiabatic) coolers.

No.	Name	Description
73.	Indirect water free cooling	Chilled water is cooled by the external ambient conditions via a heat exchanger which is used between the condenser and chilled water circuits. This may be achieved by dry (/adiabatic) coolers, evaporative assistance through spray onto the dry (/adiabatic) coolers or cooling towers.
74.	Sorption cooling (absorption/adsorption)	Waste heat, produced close to the data centre as a by-product of power generation or other processes, is used to power the cooling system in place of electricity. This is frequently part of a Tri Gen combined cooling heat and power system. These systems should be assessed for viability over their full lifetime against an optimized, economically efficient cooling plant.

8.3.2 High efficiency cooling plant

The next preferred cooling technology is the use of high-efficiency cooling plants. Designs should operate efficiently at system level and employ efficient components. This demands an effective control strategy which optimizes efficient operation, without compromising reliability.

No.	Name	Description
75.	Select adequate cooling methods of CRAC units	Methods of cooling CRAC units mainly consist of air-cooling, water-cooling, and chilled water-cooling. The costs for initial installation, operation and purchasing of CRAC units may significantly depend on which method is selected. This is why the most optimal method should be chosen after considering the features, strengths and weaknesses of each method as well as the data centre environment. – In general, using the air-cooling method is recommended for small-sized computer rooms (with less than 10 CRAC units), as long as the conditions allow for this. – For mid- or large-sized computer rooms (with 10 or more CRAC units), it is recommended to use either chilled water or a water-cooling method, depending on the building conditions. (This will save operational costs.)
76.	Select adequate cooling towers	Cooling towers are used to exchange inside heat with outside air under water or chilled water cooling methods and are largely divided into a closed type and an open type. It is recommended to select closed cooling towers, built solely for ICT equipment despite the high installation cost.
77.	Chillers with high COP	Make the coefficient of performance of chiller systems through their likely working range a high priority decision factor during procurement of a new plant.
78.	Select adequate refrigerants	Refrigerants are used inside air-cooled and water-cooled CRAC units to discharge inside heat effectively. Each type of the refrigerants (R-22, R-134a, R-404a, R-407c, R-410a, etc.) has different prices, cooling efficiency and legal restrictions. Therefore, the most appropriate one should be selected after considering the strengths and weaknesses of each refrigerant. – Serious consideration is especially required with regard to using R-22, for it may destroy the ozone layer and be restricted by international regulations.

No.	Name	Description
79.	Cooling system operating temperatures	Evaluate the opportunity to decrease the condensing temperature or increase the evaporating temperature; reducing delta T between these temperatures means less work is required in the cooling cycle, hence improving efficiency. These temperatures are dependent on required internal air temperatures (see "Temperature and humidity settings").
80.	Efficient partial load operation	Optimize the facility for the partial load – it will persist for most of the operational time, rather than for the maximum load. e.g., sequence chillers, operate cooling towers with a shared load for an increased heat exchange area.
81.	Variable speed drives for compressors, pumps and fans	Reduce energy consumption for these components in the partial load condition, where they operate for much of the time.
82.	Select systems which facilitate the use of economisers	Select systems which facilitate the use of cooling economisers. In some buildings it may be possible to use air side economisers. Others may not have sufficient space available, and may require a chilled liquid cooling system to allow effective use of economized cooling.
83.	Selection of adequate cooling methods considering space efficiency	Four air conditioning methods are available for the typical data centre. 1) Conventional air conditioning cools by supplying the entire room with cold air, cooled with chilled water from a chilling system, which flows through perforated tiles on the floor's surface. Energy consumption of both the water chilling units and the blower that circulates the chilled air through the entire room is high. 2) The outdoor air cooling method introduces cold air from outdoors directly into the room for cooling, permitting a reduction in the chilling system's energy consumption. This system can be envisaged when the outdoor temperature is higher than –30°C but lower than the room temperature. 3) The evaporative cooling method sprays water into cold outdoor air, and cools by heat exchange between the cooled air and the return air from the room, permitting a reduction in the chilling system's power consumption. This system can be envisaged when the outdoor temperature is higher than –5°C but lower than the room temperature. 4) The spot cooling method employs spot cooling units on top of racks (in ceiling) for local cooling and cools high temperature exhaust air from the servers around the server racks. Space efficiency of a data centre is influenced by its power density. Space efficiency indicates the ratio of floor area employed for IT equipment to the total floor area of the building. The higher the value, the smaller the floor area occupied by the air conditioning equipment, and the more effective the use of the floor area. Power density indicates the energy consumption of IT equipment per rack/cabinet of the server room floor area. As the power density of a data centre increases, the footprint for the air conditioning system and the required height of the floor chamber will also increase, affecting the initial cost because of architectural structural changes. On the other hand, the footprint of a spot cooling system does not increase based on power density, because cooling units are implemented on server racks.

No.	Name	Description
		In the case of data centres with high power density (e.g., higher than 5-6 kW/racks, or 8 kW in the case of a high raised floor), a spot cooling system should be selected based on space efficiency. Suggestions on possible climatic range for the selection of adequate cooling methods can be found in Appendix III.
84.	Selection of adequate cooling methods considering outdoor air condition	The wet-bulb temperature of outdoor air affects the energy consumption of a cooling system. Wet-bulb temperature is the indication of the energy condition of air switches. When the wet-bulb temperature for a location is lower, energy consumption for the outdoor air cooling and evaporative cooling method is reduced due to effective use of cold outdoor air. In a location where the wet-bulb temperature of outdoor air is low, the energy efficiency of these cooling systems becomes higher than conventional systems. On the other hand, when the wet-bulb temperature of outdoor air is high, the energy efficiency of spot cooling systems becomes higher than conventional systems due to the effect of the reduction of distribution power, such as fans and pumps. In the case of a data centre location with a low wet-bulb temperature (e.g., lower than 15°C), the outdoor air cooling method, or the evaporative cooling method, should be selected based on energy efficiency. (This type of indication considers both temperature and humidity conditions). Also, in the case of a data centre location with a high wet-bulb temperature (e.g., higher than 15°C), the spot cooling method should be selected based on its energy efficiency. It is necessary to consider that in some locations it is useful to implement not only one of the previous techniques (see best practice 83 "Selection of adequate cooling methods considering space efficiency"), but a combination of different technologies.
85.	Selection of energy and space efficient cooling system	The power density of a data centre affects cooling system space efficiency and has a big impact on initial costs. Also, the outdoor air condition impacts the energy efficiency of a cooling system. We should consider these two factors when selecting an efficient cooling method. If the data centre is located in a warmer zone (e.g., higher than 15°C), a spot cooling system should be selected because of its advantages with regard to maximum space efficiency and maximum energy efficiency.

8.4 Computer room air conditioners

The second major component of most cooling systems is the air conditioner units within the computer room. The computer room side of the chiller plant in older facilities is frequently poorly designed and poorly optimized.

No.	Name	Description
86.	Select adequate CRAC units	There are many criteria for selecting a CRAC unit – cooling capacity, operational conditions (dry-bulb temperature and relative humidity), amount of airflow, etc. – and the process should be taken seriously from a long-term point of view, because the life span of a CRAC unit ranges from 7 to 15 years after installation. – In many cases, RT (Refrigerant Ton) is mainly considered when determining the cooling capacity of a CRAC unit. However, CRAC units having the equivalent RT level may have different cooling capacities, depending on the manufacturer. Therefore, units such as kcal/h or kW, rather than RT, should be considered when measuring the cooling capacity (1RT = 3 024 kcal/h, 1 kW/h = 860 kcal/h). – Among many CRAC units having the equivalent level of cooling capacity, it is recommended to select those with lower dry-bulb temperatures (hot air temperature returned into the CRAC unit) because they have a higher cooling capacity. – Relative humidity of returned air into the CRAC units also affects cooling capacity. Because manufacturers of CRAC units specify the cooling capacity of each product under a certain level of relative humidity, it is necessary to compare them under the same relative humidity conditions. – The amount of airflow is related to the size of motors in CRAC units and therefore should not always be large. The larger the amount of airflow, the more energy is consumed, and it is important to select the optimal amount of airflow.
87.	Variable speed fans	Many old CRAC units operate fixed speed fans which consume substantial power and obstruct attempts to manage the data floor temperature. Variable speed fans are particularly effective where there is a high level of redundancy in the cooling system, low utilization of the facility or highly variable ICT electrical load. These fans may be controlled by factors such as the return air temperature or the chilled air plenum pressure. Note that CRAC units with fixed speed compressors have minimum flow requirements which constrain the minimum operating load.
88.	Calculate adequate cooling capacity and quantity of CRAC units	The cooling capacity and quantity of CRAC units are measured mostly based on the expected amount of heat from ICT equipment, and partly based on the safety factor. However, more factors should be accurately determined in addition, such as the location of computer rooms and the amount of load from solar heat.
89.	Disposition of CRAC units	The most important thing to be considered when installing a CRAC unit is that the focus should be put more on facilitating hot air return than on providing cold air. Returning of hot air depends on the location of the CRAC unit and has a great influence on the temperature and humidity of the computer room. When the installation structure of ICT equipment consists of a cold aisle and a hot aisle, the best place for CRAC unit disposition will be the end of the hot aisle, where the unit shall be placed in a vertical direction. This is very important in that it will help secure the shortest route for heated air to return to the CRAC unit without affecting racks. If a CRAC unit is placed in the same direction as the racks, the heated air returning to the CRAC unit will affect the row of racks located behind the unit.

No.	Name	Description
90.	Run variable speed CRAC units in parallel	It is possible to achieve efficiency gains by running CRAC units with variable speed fans in parallel to reduce the total electrical power necessary to achieve the required air movement, as electrical power is not linear with airflow. Care should be taken to understand any new failure modes or single points of failure that may be introduced by any additional control system.
91.	Sequencing of CRAC units	In the absence of variable speed fans, it is possible to turn entire CRAC units on and off to manage the overall airflow volumes. This can be effective where there is a high level of redundancy in the cooling system, low utilization of the facility or highly variable ICT electrical load.
92.	Management of back-up CRAC units	Failure of one CRAC unit may significantly increase the temperature in several zones. This is because even with the sufficient capacity of the entire CRAC unit in a computer room, there are limitations to the processing coverage of each CRAC unit. Therefore, installation of back-up CRAC units needs to be considered, based on the fact that a back-up CRAC unit should be placed for each zone that can be covered by one CRAC unit (N+1). In general, one back-up CRAC unit is recommended for 5-6 CRAC units. However, conditions may vary and it would be advisable to carry out a simulation test based on a CFD (computational fluid dynamics) analysis prior to installation. Setting only one CRAC unit for back-up operation is not recommended due to its impact on even consumption of parts, lifecycle of the CRAC unit, and uncertainties in case of emergency. Therefore, it is better to take turns on regular cycles and make all CRAC units run for a certain period of time. (Naturally, the conditions of all units can be checked.)
93.	Control on CRAC unit supply air temperature	Controlling supply temperature ensures that the server supply air (key temperature to control) is satisfactory, without possible over-cooling of air which may result when controlling return temperature (where sensor location may impact).
94.	Direct liquid cooling of ICT devices	In the place of chilling air, it is possible to directly liquid cool part or all of some ICT devices. This can provide a more efficient thermal circuit and allow the coolant liquid system temperature to be substantially higher, further improving efficiency, and allowing for increased or exclusive use of free cooling or heat re-use. Note that this practice applies to devices which deliver cooling fluid directly to the heat removal system of the components, such as water-cooled heat sinks or heat pipes, and not the delivery of cooling liquid to an internal mechanical refrigeration plant or in chassis air cooling systems.

8.5 Re-use of data centre waste heat

Data centres produce significant quantities of waste heat. Whilst this is typically at a relatively low temperature, there are some applications for the re-use of this energy. As ICT equipment is increasingly used through consolidation and virtualisation, the exhaust temperature is likely to increase, thus providing greater opportunity for waste heat to be re-used. Direct liquid cooling of ICT equipment can further reduce any detrimental impact on the environment by utilizing the capacity of coolant to provide heat.

No.	Name	Description
95.	Waste heat re-use	It may be possible to provide low grade heating to industrial space, or to other targets such as swimming pools, directly from heat rejected from the data centre. This recycling can ameliorate energy use elsewhere, reducing the total energy use of the data centre and the client using the waste heat.
96.	Heat pump assisted waste heat re-use	Where it is not possible to directly re-use the waste heat from the data centre due to the temperature being too low, it can still be economic to use additional heat pumps to raise the temperature to a useful point. For example, this can supply heating for offices or the district utilities.

9 Data centre power equipment

The other major part of the facility infrastructure is the power conditioning and delivery system. This normally includes uninterruptible power supplies, power distribution units, and cabling, but may also include backup generators and other equipment.

9.1 Selection and deployment of power equipment

Power delivery equipment has a substantial impact upon the efficiency of the data centre and tends to remain operational for many years once installed. Careful selection of power equipment at the design stage, can deliver substantial savings throughout the lifetime of the facility.

No.	Name	Description
97.	Power equipment with consideration of further extension	Power equipment such as power reception/distribution/transformation systems, UPS, and cabinet panels can be extended phase-by-phase. To extend the power equipment, energy consumption data of the entire data centre should be monitored to an accurate level and the room for extension must be planned in the first place. Cabinet panels, which are the most sensitive to extension or transformation of ICT equipment, have a significant influence on the power capacity, space, and amount of airflow of CRAC units. Therefore, extra sub-circuit breakers should be prepared for cabinet panels in case of ICT equipment extension, and extra circuit breakers should be prepared for the main cabinet panels that are for extending sub-cabinet panels. The need for extensions should be considered at the design stage.
98.	Modular UPS deployment	It is now possible to purchase modular (scalable) UPS systems across a broad range of power delivery capacities. Physical installation, transformers and cabling are prepared to meet the design electrical load of the facility but the sources of inefficiency, (such as switching units and batteries), are installed, as required, in modular units. This substantially reduces both the capital cost and the fixed overhead losses of these systems. In low power environments, these may be frames with plug in modules, whilst in larger environments these are more likely to be entire UPS units.
99.	High efficiency UPS	High efficiency UPS systems of any technology, including electronic or rotary, should be selected to meet site requirements.

No.	Name	Description
100.	Use efficient UPS operating modes	UPS should be deployed in their most efficient operating modes, such as line interactive. Technologies such as rotary and high voltage DC (direct current) can also show improved efficiency, as there is no dual conversion requirement.
101.	Efficient battery selection and deployment	Select batteries that are eco-friendly (free from hazardous substances and heavy metal). Moreover, select those that are less likely to be self-discharged and that consume less charging power. Extending the back-up time of the batteries to longer than 30 minutes for securing availability of the data centre is unnecessary. Instead, it is recommended to design 15-20 minute battery back-up time, depending on the field conditions.
102.	DC (direct current) power distribution	Consider the use of high voltage DC (direct current) power distribution within the data centre. This can reduce the overall power conversion and distribution losses within the facility.
103.	Power reception, distribution and transformation system	Selection of the method of power reception and transformation between one-step and two-step methods may vary according to the characteristics of the data centre. However, selecting the one-step vertical drop method is recommended to reduce no-load loss of electrical transformers. In addition, application of one method to all systems can also be possible to prevent undue financial investment incurred by excessive duplex configuration and an increase in the amount of power consumed. – Use highly efficient switch gears and electrical transformers. – Use active filters to improve power quality and reduce power loss. – Use tuned and de-tuned filters to improve harmonics and power factors. – Deploy peak power control systems to efficiently use electrical power and manage peak power in a reasonable manner.
104.	Cabinet panel deployment	With the increasing amount of energy consumption by ICT equipment, cabinet panel deployment should satisfy the following conditions: – Provide single-phase power to each server rack with 4 kW or less energy. – If server racks have energy of more than 4 kW, providing three-phase power to rack-typed and measurable cabinet panels will be more efficient. – Power supply can be made easier by installing a rack-typed cabinet panel next to each server rack, which can also contribute to easier facility extension in the case of an increase in the number of ICT equipment (the more three-phase breakers, the easier equipment extension will be in the future). – This method also needs fewer cables than when providing power supply from cabinet panels to each server rack, which will further facilitate cooled air provisioning under the raised floor and reduce harmonics and heating of neutral conductors by maintaining load balance.
105.	PDU deployment	Specifications of PDU (power distribution units) should be differentiated according to the power capacity demanded by servers. As there is an increasing number of high-capacity servers, it is impossible to deploy a common PDU to all servers but PDUs should be customized to each in-rack server and installed.

No.	Name	Description
106.	Use new and renewable energy	Actively consider use of new renewable energies to cope with the increasing energy cost and the amount of carbon emissions. – New renewable energies include, fuel cell and hydrogen energy, which are based on new physical power and new substances. – Renewable energies include solar thermal energy, solar photovoltaic energy, biomass, wind power, tidal power, hydraulic and geothermal power generation.

9.2 Management of power equipment

No.	Name	Description
107.	Optimal power density	Guideline recommendations on the most efficient range for power density.
108.	Reduce engine-generator heater temperature set-point	When using engine heaters to keep generators ready for rapid starts, consider reducing the engine heater set-point. Block heaters for the standby generators should be controlled to operate only when the temperature conditions warrant it.
109.	Wiring of power cables	All power cables connected to ICT equipment should be wired under the raised floor and the cables must not be installed in the cold aisle to prevent blocking of cold air for CRAC units. In exceptional cases cable wiring can be placed above the ceiling when it is high enough. In order to prevent any failures (electromagnetic interference, noise, optical cable damage, etc.) caused by installing power cables and communication cables together under the raised floor, it is necessary to set up power cables under the raised floor before installing communication trays on the floor. EMC aspects shall be considered. Separating power cables and other wires will allow easier identification and management of them and improve efficiency in air conditioning.
110.	Power factor management	Considering that the higher the power factor, the lower the proportion of reactive power – and thus, the less power loss; it is recommended to use independent equipment that can maintain the power factor at the most appropriate level. – Using de-tuned filters is the least costly yet the most reasonable way to lower harmonics and improve power factor in electric power systems.
111.	Load balance management	The current value of each phase reaching the load at the end of the electrical transformer in fact varies from each other. Intensified imbalance may cause an excessive load level and heating in the power distribution system and joint parts. This can be a serious threat to safety and ultimately bring about unnecessary energy consumption. Therefore, not only the entire amount of electricity used, but also the amount of energy consumed in each phase, should be monitored at the same time.

No.	Name	Description
112.	Heat management on joint parts	Heat is generated on parts where there is an increasing level of resistance in power distribution and arrangement system. The main causes of such increasing resistance are equipment malfunction, loose connection, and current level exceeding the stable capacity level. If the heat is left unmanaged, it can lead to fire, thereby threatening data centre stability. Since the energy loss caused by the heat is also too great to be neglected, regular check-ups and fastening of joint parts is necessary. In most cases, thermal burn cameras are used to monitor abnormal heating.

10 Other data centre equipment

Energy is also used in the non-data floor areas of the facility, in office and storage spaces. Energy efficiency in non-data centre areas should be optimized based on relevant building standards, such as relevant EU standards, LEED, BREEAM, etc.

10.1 General practices

These general practices apply to the data floor and may be extended to the remainder of the building if no sustainable building standard is in use.

No.	Name	Description
113.	Turn off lights	Lights should be turned off, preferably automatically, whenever areas of the building are unoccupied, for example, by switches that turn off lighting within a specified time following manual activation. Motion-detector activated lighting is generally sufficient to support security camera systems.
114.	Low energy lighting	Low energy lighting systems should be used in the data centre.

11 Data centre building

The location and physical layout of the data centre building is important to achieving flexibility and efficiency. Technologies, such as fresh air cooling, require significant physical plant space and air duct space that may not be available in an existing building.

11.1 Building physical layout

The physical layout of the building can present fundamental constraints on the applicable technologies and achievable efficiencies.

No.	Name	Description
115.	Locate M&E plant outside the cooled area	A heat-generating mechanical and electrical plant should be located outside the cooled areas of the data centre wherever possible, to reduce the loading on the data centre cooling plant.
116.	Select a building with sufficient ceiling height	Insufficient ceiling height in the data centre will obstruct the use of efficient air cooling technologies, such as raised floor, and suspended ceiling or ducts.
117.	Optimize orientation of the data centre	Optimize the layout and orientation of the building to reduce insulation heat loads and optimize the efficiency of heat transfer.

No.	Name	Description
118.	Facilitate the use of economisers	The physical layout of the building should not obstruct the use of economisers (either air or water).
119.	Location and orientation of plant equipment	Cooling equipment, particularly dry (adiabatic) coolers, should be located in an area of free air movement to avoid trapping it in a local hot spot. Ideally, this equipment should also be located in a position on the site where the waste heat does not affect other buildings and create further demand for air conditioning.
120.	Minimize insulation heating	Minimize solar heating of the cooled areas of the data centre by providing shade or increasing the albedo of the building through the use of light-coloured roof and wall surfaces. Shade may be constructed, or provided by trees or "green roof" systems. Low e-coating, which disposes a thin metal film on a glass surface, reflects radiant heat to the inside of the room in cold weather and to the outside in hot weather. Low e-coating on double-glazed glass will reduce cooling or heating expenditure as effectively as more costly transparent triple-glazed glass.
121.	Other technologies for energy efficient building – double skin	Double skin technology uses the air convection between the outside and the inside of the room by making a layer of space in between. In summer, the air heated inside the double skin rises and is emitted, carrying the heated air inside the room with it and further lowering the temperature. On the other hand, the air cooled inside the double skin flows into the room, leading to energy savings.
122.	Other technologies for energy efficient building – light shelf	A light shelf is energy-saving lighting equipment which uses the solar light reflected from a shelf installed in the top-lower part of the vertical window into the room. The most efficient distance range for using the natural light in a room is 4-6 metres from the window. Natural light has better luminous efficiency in terms of light quality than artificial light. The light shelf is also easy to build and can achieve a quality lighting environment and energy saving at lower cost.
123.	Utilize heavy water	Utilizing heavy water means the use of advanced treatment of sewage water, such as waste water, river water and groundwater, so as to provide water for non-drinking purposes (e.g., flush toilets, cooling air conditioners, cleaning, sprinkling, landscaping and fire-fighting). An eco-friendly data centre which uses the heavy water system reduces river pollution by decreasing the amount of newly-produced sewage water as much as the heavy water used. In addition, it can save a significant amount of water for enabling data centres, mostly using a large amount of water, to reduce cooling water consumption. In general, heavy water can be easily recycled as cooling water after being filtered and chlorinated only.
124.	Utilize rain water	Utilizing rain water means collection, filtering and storing the rain water on the roof and then using it for non-drinking purposes.

11.2 Building geographic location

Whilst some operators may have no choice of the geographic location for a data centre, it nevertheless impacts achievable efficiency, primarily through the impact of the external climate.

No.	Name	Description
125.	Locate the data centre where waste heat can be re-used	Locating the data centre in places where there are available uses for waste heat can save substantial energy globally. E.g., heat recovery can be used to heat office or industrial space, hydroponic farming and even swimming pools.
126.	Locate the data centre in an area of low ambient temperature	Free and economized cooling technologies are more effective in areas of low ambient external temperature and/or humidity. Note that most temperature climates, including much of Northern, Western and Central Europe, present significant opportunity for economized cooling.
127.	Avoid locating the data centre in high ambient humidity areas	Free cooling is particularly impacted by high external humidity as dehumidification becomes necessary, many economiser technologies are also less effective.
128.	Locate near a source of free cooling	Locating the data centre near a source of free cooling, such as a river, subject to local environmental regulation.
129.	Co-locate with power source	Locating the data centre close to the power generating plant can reduce transmission losses and provide the opportunity to operate sorption chillers from power source waste heat.

12 Monitoring

The development and implementation of an energy monitoring and reporting management strategy is core to operating an efficient data centre.

12.1 Energy use and environmental measurement

Most data centres currently have little or no energy use or environmental measurement capability. Many do not even have a separate utility meter or bill. The ability to measure energy use and factors impacting energy use is a prerequisite to identifying and justifying improvements. It should also be noted that measurement and reporting of a parameter may also include alarms and exceptions if that parameter passes outside of the acceptable or expected operating range.

No.	Name	Description
130.	Incoming energy consumption meter	Install metering equipment capable of measuring the total energy use of the data centre, including all power conditioning, distribution and cooling systems. Again, the measured energy shall be separate from any non-data centre building loads. Note that this shall be required for an energy efficiency meter indicator.
131.	ICT energy consumption meter	Install metering equipment capable of measuring the total energy delivered to ICT systems, including power distribution units. This may also include other power feeds where non UPS protected power is delivered to the racks. Note that this should be required for an energy efficiency meter indicator.
132.	Room level metering of supply air temperature and humidity	Install metering equipment at room level, capable of indicating the supply air temperature and humidity for the ICT equipment.
133.	CRAC unit level metering of supply or return air temperature and humidity	Collect data from CRAC units on supply or return (dependent upon operating mode) air temperature and humidity.
134.	PDU level metering of ICT energy consumption	Improve visibility of ICT energy consumption by metering at the power distribution unit inputs or outputs.

No.	Name	Description
135.	PDU level metering of mechanical and electrical energy consumption	Improve visibility of data centre infrastructure overheads.
136.	Row or rack level metering of temperature and humidity	Improve visibility of air supply temperature and humidity.
137.	Device level metering of temperature	Improve granularity by using built-in device level metering of intake and/or exhaust air temperature as well as key internal component temperatures.

12.2 Energy use and environmental collection and logging

No.	Name	Description
138.	Periodic manual readings	Entry-level energy, temperature and humidity reporting can be performed with periodic manual readings of consumption meters, thermometers and hygrometers. This should occur at regular times, ideally at peak load.
139.	Automated daily readings	Automated daily readings enable more effective management of energy use. Supersedes periodic manual readings.
140.	Automated hourly readings	Automated hourly readings enable effective assessment of how ICT energy use varies with ICT workload. Supersedes periodic manual readings and automated daily readings.

12.3 Energy use and environmental reporting

Energy use and environmental (temperature and humidity) data need to be reported to be of use in managing the energy efficiency of the facility.

No.	Name	Description
141.	Written report	Entry-level reporting consists of periodic written reports on energy consumption and environmental ranges. This should include determining the averaged DCiE over the reporting period.
142.	Energy and environmental reporting console	An automated energy and environmental reporting console to allow M&E staff to monitor the energy use and efficiency of the facility provides enhanced capability. Averaged and instantaneous DCiE are reported. Supersedes written report.
143.	Integrated ICT energy and environmental reporting console	An integrated energy and environmental reporting capability in the main ICT reporting console allows integrated management of energy use and comparison of ICT workload with energy use. Averaged, instantaneous and working range DCiE are reported and related to ICT workload. Supersedes written report and energy and environmental reporting console. This reporting may be enhanced by the integration of effective physical and logical asset and configuration data.

12.4 ICT reporting

Utilization of the ICT equipment is a key factor in optimizing the energy efficiency of the data centre.

No.	Name	Description
144.	Server utilization	Reporting of the servers' processor utilization globally or grouped by service/location. Whilst effective metrics and reporting mechanisms are still under development, a basic level of reporting can be highly informative.
145.	Network utilization	Reporting of the network utilization globally or grouped by service/location. Whilst effective metrics and reporting mechanisms are still under development, a basic level of reporting can be highly informative.
146.	Storage utilization	Reporting of the storage utilization globally or grouped by service/location. Whilst effective metrics and reporting mechanisms are still under development, a basic level of reporting can be highly informative. The meaning of utilization can vary depending on what is considered available capacity (e.g., ports, raw versus usable data storage) and what is considered used (e.g., allocation versus active usage). Ensure the definition used in these reports is clear and consistent. Note that mixed incentives are possible here through the use of technologies such as de-duplication.

13 Design of network

This clause contains requirements on network design to connect equipment present in the data centre and the data centre with other data centres.

No.	Name	Description
147.	Equipment selection	Select network equipment (switches, routers, firewalls, etc.) with best energy efficiency.
148.	Network design	Consider the network design (topology, DC interconnection map and constituent network devices) to maximize egress bandwidth (effective cumulative throughput towards connected DC elements or external networks) relative to energy footprint. Minimize the number of "internal" network elements and interconnects ("grey ports") that are not delivering traffic towards data processing and storage equipment or external networks.
149.	Plan for run-time energy consumption profiling of the network	Consider installing power meters and/or using embedded energy monitoring tools to profile energy utilization within all network devices. In combination with the practices of clause 12, this gives data to assess the efficiency of a network in real-time and plan for extended energy conservation policies.
150.	Establish extended energy conservation policies for network devices	Using information derived from practices outlined in the EU Code of Conduct on data centres v2.0, consider analysis of productivity patterns and identify opportunities to enable extended energy conservation features within network devices (such as automatic capacity downgrade during certain times of the day).
151.	Use a network as medium to propagate energy conservation policies throughout DC	Consider integration of DC idling and sleep policies (such as best practice 28) within the network. For instance, implement on-demand reconfiguration of server clusters using "wake-on-LAN" technology.

Annex A

Possible methodology for cooling data centres by using renewable energy in cold regions

(This annex forms an integral part of this Recommendation.)

A.1 Data centres in cold regions

A.1.1 Conditions of data centre location

The location of a data centre should be selected with various factors in mind, including security from external forces such as earthquakes and floods, availability of a communication infrastructure, stable supply of electric power, convenience of transportation, and recruitment of people to work in the data centre. From the viewpoint of energy efficiency, it is also important to examine whether renewable energy can be used or not.

A.1.2 Use of renewable energy in cold regions

Renewable energy may be used in various ways, for example, in the generation of electric power and as a heat source. In cold weather regions, efficient cooling becomes possible by using low air temperature, or accumulated snow, as a cold heat source of air conditioning systems at data centres.

A.2 General matters relating to data centre cooling

A.2.1 Air conditioning systems for data centres

At data centres, floor-diffused air conditioning systems with raised floors are generally adopted. Figure A.1 shows an example of air conditioning system components. Cool supply air (SA) sent out of the air conditioner is heated by a server in the server room, and the heated return air (RA) returns to the air conditioner. The cycle is repeated. Equipment, such as chillers and water cooling towers, are required for producing cooling water using electric power, and cooling coils and fans for producing cool air using cooling water. The cooling operation takes place throughout the year at data centres because servers generate a large amount of heat.

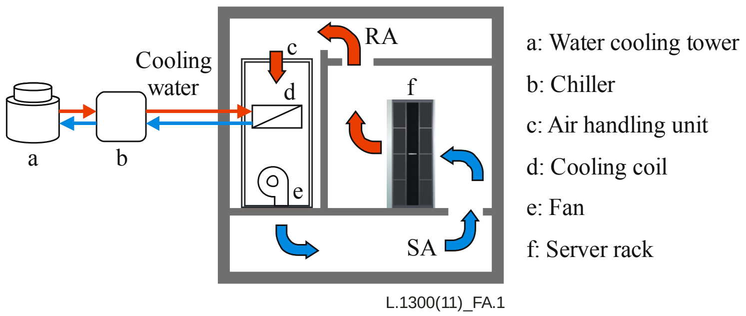


Figure A.1 – Air conditioning system components at a data centre

A.3 Outdoor air cooling

Data centres which require cooling throughout the year could use low temperature outdoor air in winter for cooling.

A.3.1 Outdoor air cooling systems

The modes of cooling systems using the cold heat of low temperature outdoor air are classified into the following categories.

(1) Direct use of cold heat

Low temperature outdoor air is taken directly into the server room for cooling. It is taken into the air conditioner and mixed with high temperature return air from the server room, or is directly taken into the server room.

(2) Indirect use of cold heat

Cold heat of low temperature outdoor air is used indirectly by performing heat exchange.

(3) Selection of the mode of use

In the mode of direct use, cold heat of outdoor air is directly used and high thermal efficiency is achieved. The mode of indirect use is applicable even in cases where no outdoor air can be taken directly because of conditions such as the quality of outdoor air, temperature and humidity. When planning a data centre, various conditions should be comparatively examined and an optimum mode should be selected. Both modes may be used interchangeably in different periods as outdoor air conditions vary.

A.3.2 Mechanism of outdoor air cooling and considerations

A.3.2.1 Mechanism of outdoor air cooling and temperature and humidity control

At data centres, conditions for supplying air to servers are held in a designated range, so air supply conditions should be held at a certain level when adopting the outdoor air direct use mode.

(1) Temperature control methods

Low temperature outdoor air (OA) is taken into the air conditioner and mixed with return air (RA) from the server room. The temperature of supply air (SA) can be kept constant by adjusting the OA/RA mix proportions according to the variation of OA temperature. Unnecessary exhaust heat from the server is discharged outdoors as exhaust air (EA) (Figure A.2).

(2) Humidity control methods

In cases where outdoor air is dry, as in winter, humidity should be controlled through humidification. Humidification is achieved by various methods, such as supplying steam, atomizing and vaporizing. Using humidifiers of the drip infiltration vaporization type enables humidification without using any electric power (Figure A.3).

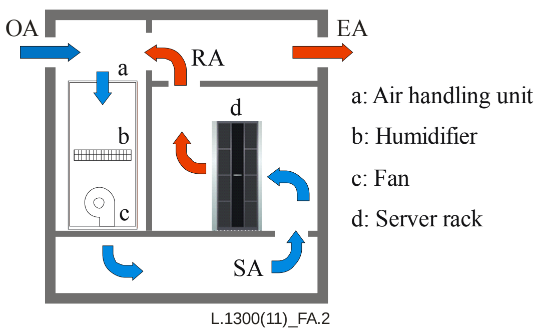


Figure A.2 – Direct use of outdoor air for cooling

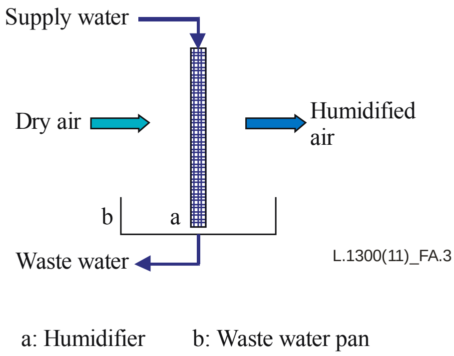


Figure A.3 – Humidifier of drip infiltration vaporization type

A.3.2.2 Cooling cycles and system installation conditions

Changes in air condition during outdoor air cooling, and the ranges of air conditions in which outdoor air cooling can be done, are shown on a psychometric chart (Figure A.4).

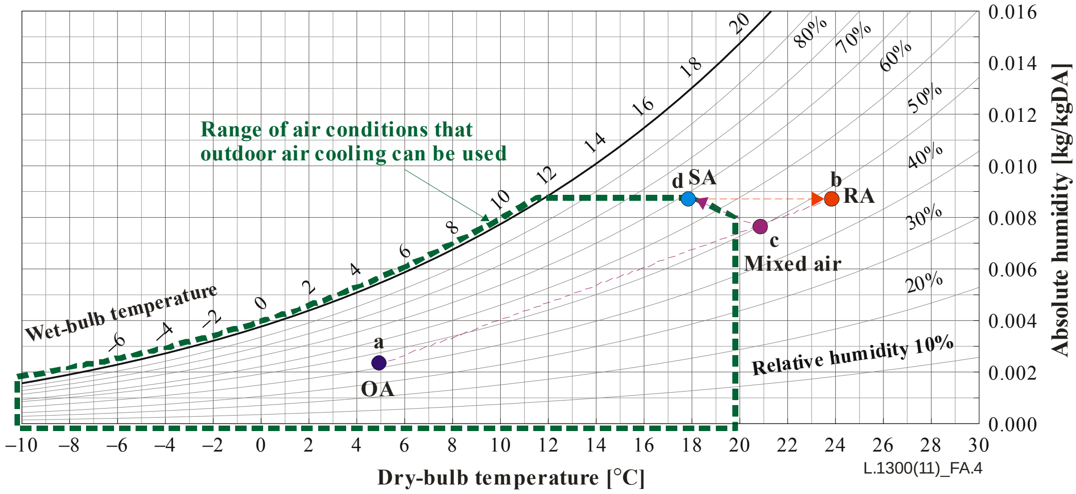


Figure A.4 – Changes in air condition during outdoor air cooling

OA (point a) and RA (point b) are mixed to create the state of mixed air (point c). Humidity is evaporated by the humidifier and the mixed air is cooled or humidified to create the state of server SA (point d). The temperature and humidity of outdoor air vary according to the season or time. An appropriate air condition can, however, be created through the adjustment of mix proportions and humidification. If the temperature and humidity of outdoor air meet certain requirements, outdoor air cooling becomes possible. For example, if temperature, relative humidity and absolute humidity are assumed to be 18°C, 65% and 0.0085 kg/kgDA respectively, as water supply conditions of the air conditioner, the range in which outdoor air cooling can be done is represented by the following parameters.

(1) Outdoor air temperature < 20°C (Note 1)

(2) Absolute humidity < Supply air humidity (0.0085 kg/kgDA)

(3) Wet bulb temperature < Wet bulb temperature of supply air (14°C)

NOTE 1 – Determined by the capacity of the humidifier.

Even in cases where the outdoor air condition does not meet the above requirements, cooling by using an electric heat source to compensate for the lack of cold heat enables the reduction of electric power consumption. The range in which outdoor air cooling (combined use) can be done, then expands.

A.3.2.3 Other considerations

(1) Removal of impurities

In areas where impure substances are mixed with the air, such as in coastal and volcanic areas, air purity should be kept at a certain level using filters and other equipment.

(2) Compatibility between construction and equipment planning

At data centres, a large amount of heat is generated and a large amount of cool air is required. Full consideration should, therefore, be made of construction planning such as creating openings on exterior walls of the building that are sufficiently large to taken in outdoor air.

A.4 Snow and ice cooling

In regions of heavy snowfall, high costs are incurred for ploughing, storing and melting snow in built-up areas and on arterial highways. However, in such regions, snow may be a source of renewable energy if, instead of being discarded as useless, it is stored in winter and used in summer, when no outdoor air cooling is possible, to cool data centres.

A.4.1 Snow and ice cooling systems

The cooling and snow storage methods of snow and ice cooling systems are classified into the following categories.

(1) Cooling methods

Use of air: air is chilled by means of direct contact between air and snow. The method is suitable in cases where a relatively small amount of air is handled. High power is required for conveying the heat, because gas is used as the heating medium.

Use of snowmelt water by performing heat exchange: the cold heat of snowmelt water is used by performing heat exchange. Heat can be conveyed easily, even over a long distance between the snow storage pit and the place to be cooled, because liquid is used as the heating medium.

(2) Snow storage methods

Indoor storage: a building is constructed exclusively for storing snow, or a part of an existing building (e.g., basement) is used as a snow storage facility.

Outdoor storage: a snow pile is constructed outdoors and the equipment and piping required for obtaining cold heat are installed.

(3) Selection of an appropriate method

At data centres, servers generate a large amount of heat and, therefore, a large amount of heat is also required for cooling. Using snowmelt water by performing heat exchange is considered more beneficial in view of the efficiency of heat exchange and the ease of heat conveyance. Outdoor storage that requires no building is more appropriate because a large snow pile needs to be constructed.

A.4.2 Mechanism of snow and ice cooling and considerations

A.4.2.1 Mechanism of snow and ice cooling

Snowmelt water obtained from snow and ice produces water for cooling via a heat exchanger. Warm water produced by the heat exchanger returns to the snow pile as circulating water and is used again for melting snow and ice (Figure A.5).

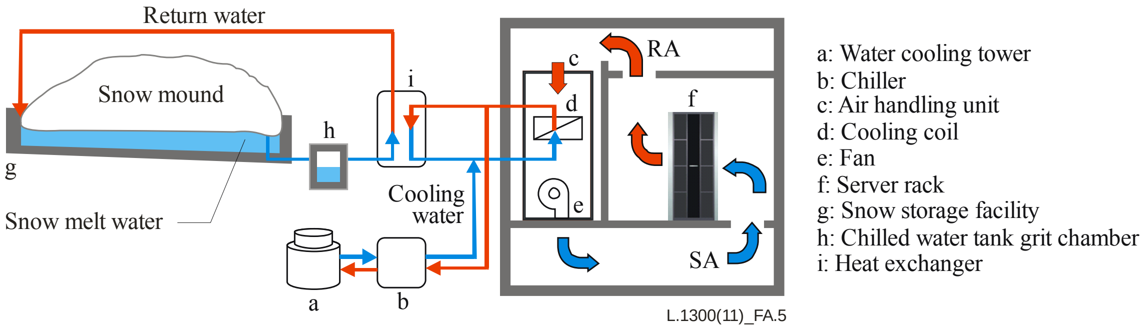


Figure A.5 – Systems for circulating snowmelt water and storing snow outdoors

A.4.2.2 Operation and management of snow and ice cooling systems

(1) Supplying snow and ice

Snow and ice cooling requires the collection of snow and ice that provide the amount of heat required for cooling data centres. Acquiring the cooperation of a local autonomous body, or other organization that manages snow removal in the vicinity, may reduce the running costs during the collection, transport and storage of snow. Securing a large space for snow storage facilities adjacent to the site of a data centre is also necessary.

(2) Securing necessary cold heat

As the snow melts, voids are formed between the snowmelt water and snow pile. If the voids become larger, the area of contact between the snowmelt water and snow pile is reduced and the amount of heat obtained is also reduced. If the voids become even larger, the snow pile collapses and the contact between the snowmelt water and snow pile is restored. In the cycle, the temperature of snowmelt water obtained from snow and ice varies. The amount of cold heat can, however, be kept at a certain level by adjusting the flow of cooling water sent to the air conditioner via a heat exchanger.

(3) Managing snow storage facilities

The snow collected on the streets contains mud and various types of impurities. Impurities should be removed completely via mud pits or filters. Applying heat insulating sheeting for storing snow and ice until summer, reduces natural thawing in outdoor snow storage facilities and enables efficient use of snow and ice. Regularly removing deposited impurities, and properly managing the level of snowmelt water, enable stable cooling.

A.5 Method of cooling data centres in cold regions

A.5.1 Cooling facilities for data centres in cold regions

At data centres, stable operation is required around the clock, all year round.. It is therefore preferable for data centres in cold regions to be equipped with hybrid cooling facilities that make the best use of renewable energy and also use an electric heating source as a backup (Figure A.6).

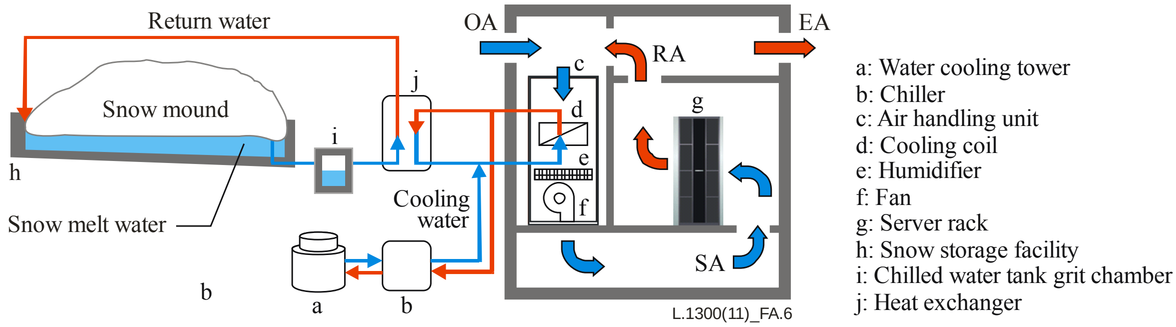


Figure A.6 – Equipment with hybrid cooling facilities

A.5.2 Energy efficiency and optimum operation control for respective cooling systems

Outdoor air cooling: cooling can be done only by fan drive power without using any electric heating source. Energy consumption can be greatly reduced.

Snow and ice cooling: electric power is used by pumps for circulating snowmelt water, but no electric cold heat source is used. Electric energy consumption can therefore be reduced.

For cooling, outdoor air, snow and ice and electric heat source cooling systems, are available in the descending order of energy efficiency for cooling. In cold regions, cooling systems can be operated most efficiently by making the best use of outdoor air cooling, and adopting snow and ice cooling, or electric heat source cooling, during the period in which no outdoor air cooling is possible.

A.5.3 Maximization of data centre cooling efficiency

In cold regions, using outdoor air or snow and ice for cooling data centres makes contributions to the reduction of power consumption. Cooling efficiency can be maximized by using outdoor air or snow and ice, in combination with solar radiation, wind power and other types of renewable energy, or with other methods for increasing cooling efficiency.

Annex B

Possible methodology for cooling data centres with high density ICT devices

(This annex forms an integral part of this Recommendation.)

B.1 Outline of air conditioning methods

B.1.1 Conventional air conditioning

B.1.1.1 Air conditioning system outline

Figure B.1 shows the conventional air conditioning system in a data centre. Floor supply air conditioning in which multiple floor supply air conditioners (CRAC: computer room air conditioner) are installed in the room. A large number of server devices are installed on the raised floor in the room, and arranged in a regular pattern, alternately facing the cold aisle (towards which the server device air inlets are directed) and the hot aisle (towards which the exhausts are directed).

Hot interior air, discharged from the hot aisle into the interior upper airspace, is drawn from the top of the floor supply air conditioning equipment, dehumidified and cooled to the specified temperature with chilled water inside the air conditioning equipment, and supplied to an under-floor chamber. This cold air is supplied to the cold aisle from outlets (gratings) in the cold aisle on the raised floor and, after passing through and removing the heat generated by the server devices, it is discharged to the hot aisle as high-temperature exhaust air.

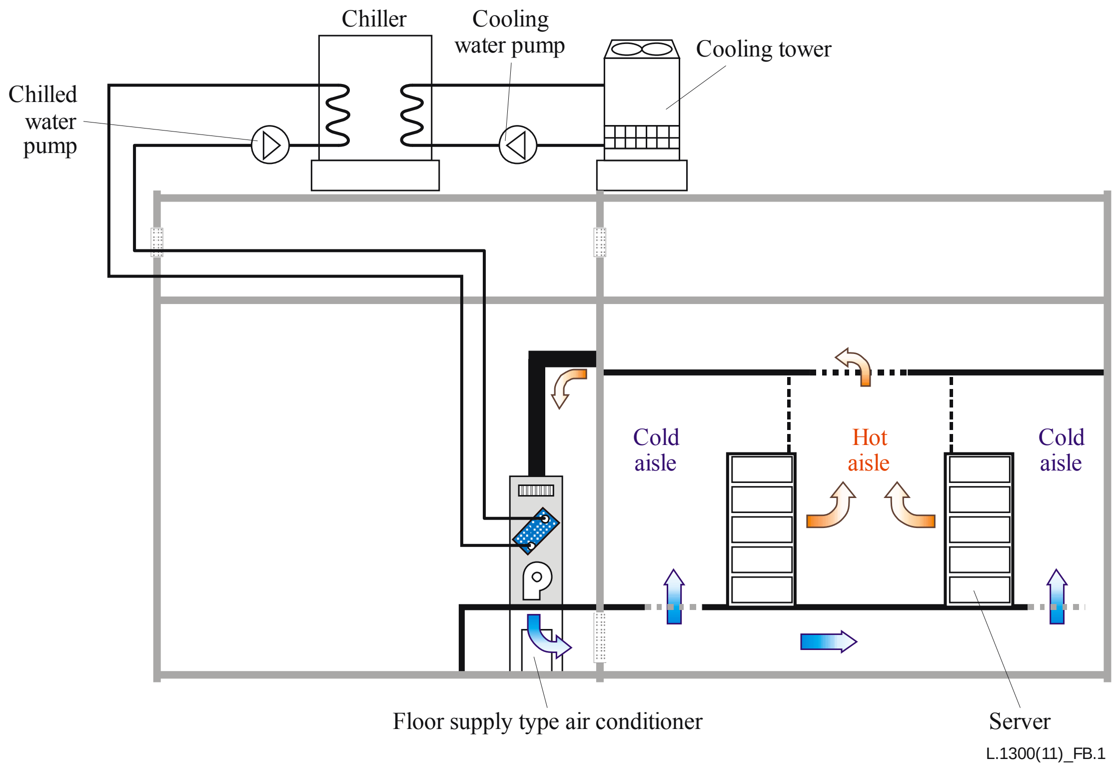


Figure B.1 – Conventional air conditioning system

B.1.1.2 Control system and operating status

With the floor supply conventional air conditioning system, the amount of chilled water passed through the cooling coils is controlled to maintain the air supplied to the room at a constant temperature. With this method, the cooled air is supplied from the outlets on the floor, mixed with the air in the room, and drawn into the server devices. In the typical server room, allowable server inlet air temperature is around 25°C, and supply air temperature necessary to keep the server inlet temperature lower than allowable temperature is generally approximately 18°C. Humidity is adjusted by dehumidifying with the cooling coils and by evaporative humidification.

B.1.1.3 Problems

Figure B.2 shows the problems associated with the conventional air conditioning system. This cold air is introduced from the server inlet side facing onto the cold aisle and, after cooling the devices, it is discharged from the rear side of the rack as hot air. If part of the high-temperature exhaust air is circulated into the inlet side, a hot spot occurs in which the temperature at the server rack inlet increases, with the associated risk of performance deterioration of the ICT devices and other damage due to high temperatures, and the ultimate danger of a halt to service.

Since low-temperature air is supplied from the under-floor chamber to the entire room with a conventional air conditioning system, the proportion of electric power required to distribute the large volume of air is considerable because of excessive operation of the air conditioning equipment to prevent hot spots happening. This may result in reduced efficiency of the air conditioning operation, and a consequent increase in air conditioning power consumption.

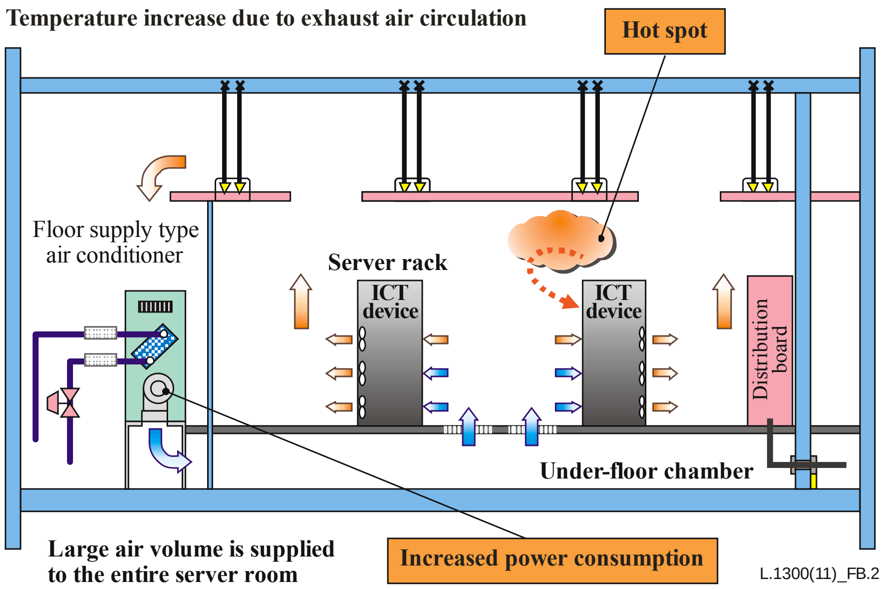


Figure B.2 – Problems with typical air conditioning

B.1.2 Outdoor air cooling system

B.1.2.1 Air conditioning system outline

Figure B.3 shows the configuration of the outdoor air cooling system. With outdoor cooling, in addition to floor-supply air conditioners supplying cooled air to the room as with conventional air conditioning, the air conditioning system incorporates exhaust fans discharging air from the room to the outside, and outdoor air ducting introducing outdoor air to the air conditioners.

A large number of server devices are installed in server racks on the raised floor in the room, arranged in a regular pattern alternately facing the cold aisle (towards which the server device air inlets are directed) and the hot aisle (towards which the exhausts are directed).

With this method, as with conventional air conditioning, air cooled with multiple floor supply air conditioners installed in the room (CRAC: computer room air conditioners) is supplied to the room for cooling. During the intermediate seasons, and in winter (during which outdoor air temperature is low), outdoor air is introduced directly to the air conditioner to reduce the amount of cooling required by the cooling coils, and water chilling unit energy consumption for generating chilled water is greatly reduced. Furthermore, the same amount of air is exhausted from the hot aisle as is introduced from outside.

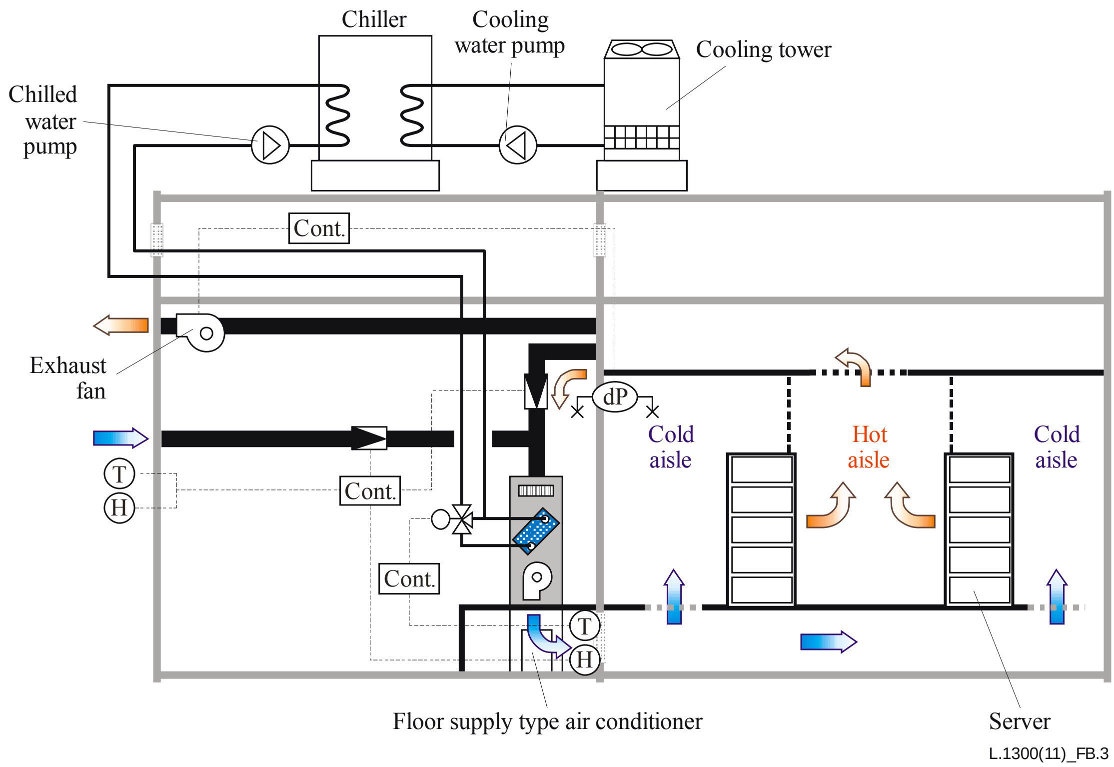


Figure B.3 – Outline of an outdoor air cooling system

B.1.2.2 Control system and operating status

Figure B.4 shows the operation control method and trends in the status of the air with outdoor air cooling. During the intermediate period, and winter, low-temperature air (2) is introduced into the air conditioner, mixed (3) with return air (1) in the room, and air cooled and humidified by a cooling coil and an evaporative humidifier and supplied to the room (4). When the temperature of the humidified air is lower than that of the supplied air, an electric heater is used to heat the air to the specified temperature (5) to prevent condensation.

Large amounts of ICT equipment are commonly installed in the room, and temperature and humidity are strictly controlled to prevent faults in, and deterioration of, equipment. With this method, the amount of outdoor air introduced is controlled to ensure that the low-temperature air supplied to the room is of the specified humidity. Furthermore, to ensure that the supplied air reaches the specified temperature, an electric heater is employed as necessary to heat the air before being supplied to the air conditioner. When temperature and humidity conditions are such that energy conservation through the introduction of outdoor air is not possible, the outdoor air intake duct is closed according to the measured outdoor air enthalpy value, and operation is the same as for conventional air conditioning. Furthermore, in order to introduce the large volumes of outdoor air required, the volume of air passed through the exhaust fan is controlled to ensure that air pressure in the room reaches the specified value.

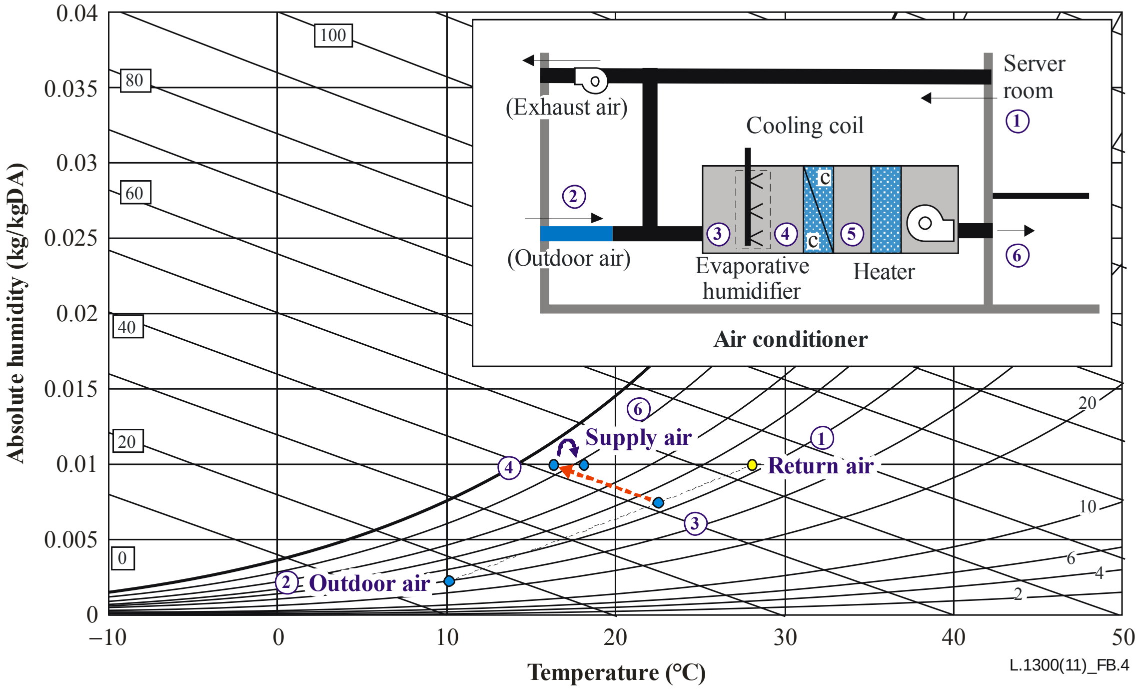


Figure B.4 – Air status in an outdoor air evaporative cooling system

B.1.2.3 Caution

With outdoor cooling, the status of the outdoor air is measured to determine whether or not outdoor air can be introduced, and control the operation mode. The operation mode changes frequently with changes in the status of the outdoor air, with the possibility of a deterioration in the ability to control the indoor environment. The control system is designed to minimize these frequent changes in the operation mode, and thus achieve stable environmental control. Furthermore, in regions where outdoor air temperature is low, low-temperature air and hot air are mixed and supplied to the room, and a design to prevent temperature irregularities and reduced temperatures is necessary.

With this method, low-temperature external air is introduced directly for cooling, thus reducing heat source power, however blower power is increased by installation of indoor discharge fans and increased ventilation resistance of outdoor air intake ducts. In order to determine the energy conservation within the entire system, it is important to introduce an operation control system able to determine the difference between the reductions in heat source power and blower power.

B.1.3 Evaporative cooling system

B.1.3.1 Air conditioning system outline

Figure B.5 shows the configuration of the evaporative cooling system. As with a conventional system, evaporative cooling employs floor supply air conditioners to supply cold air to the room. Furthermore, the equipment is made up of an evaporative cooling unit comprising an evaporative cooler to cool return air passed from the room to the air conditioner with outdoor cold air, and an indirect sensible heat exchanger, an outdoor air fan passing outdoor air through the evaporative cooling unit, and a circulation fan passing air through the evaporative cooling unit.

A large number of server devices are installed in server racks on the raised floor in the room, arranged in a regular pattern alternately facing the cold aisle (towards which the server device air inlets are directed) and the hot aisle (towards which the exhausts are directed). The high-temperature interior air discharged from the hot aisle into the space at the top of the room is drawn in from the top of the floor supply air conditioners, dehumidified and cooled to specifications using the cooling coils in the air conditioner, and supplied to the under-floor chamber. Part of the air circulated in the air conditioner from the hot aisle is introduced to the evaporative cooling unit.

Similarly, outdoor air is introduced into the evaporative cooling unit, and outdoor air humidified in the evaporative cooler, and the resulting cooled air and return air exchange heat indirectly so that humidity remains unchanged while the temperature is reduced. Thus, the interior return air cooled with the latent heat of evaporation of water is mixed with interior return air circulated directly in the air conditioner, dehumidified and cooled to the specified temperature using chilled water in the cooling coils in the air conditioner, and supplied to the under-floor chamber.

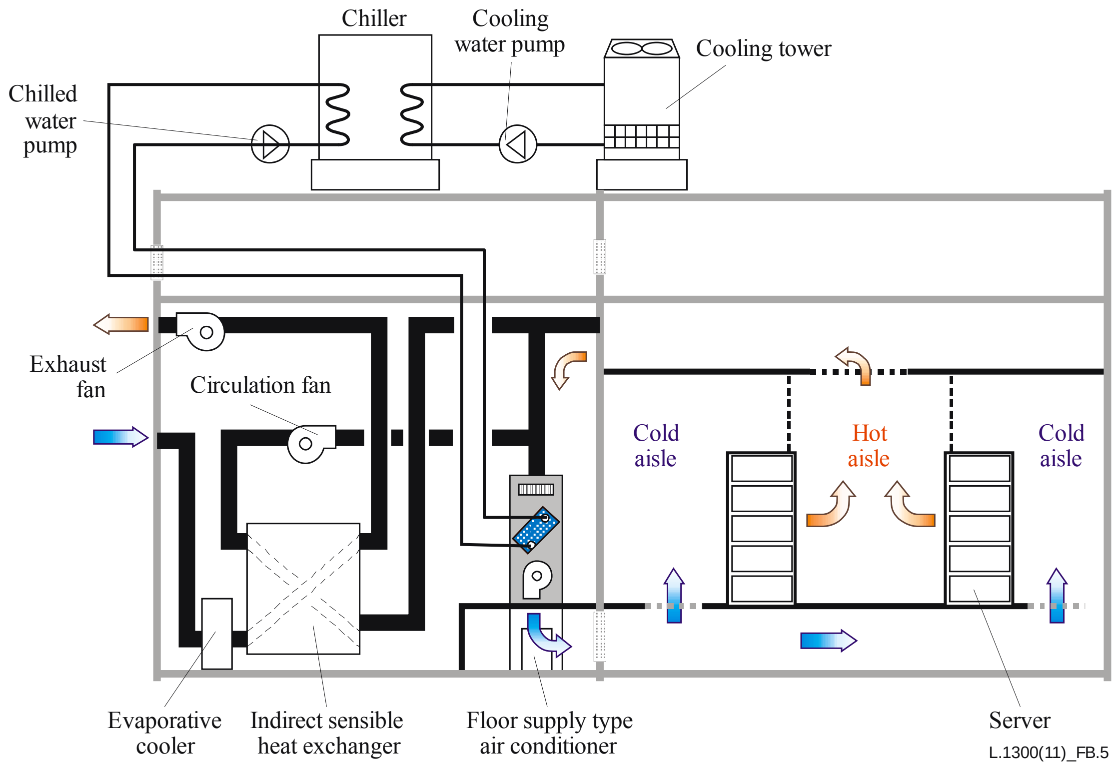


Figure B.5 – Outline of an evaporative cooling system

B.1.3.2 Control system and operating status

Figure B.6 shows the trend in the status of the air with this method. With the evaporative cooling method, the intermediate period and winter low-temperature outdoor air (5) is humidified with the evaporative cooler in the evaporative cooling unit, cooled further (6), heat exchanged indirectly with the interior return air (1) in the sensible heat exchanger, and the interior return air cooled(2). The cooled interior return air (2) is mixed (3) with the circulated interior return air, cooled (4) to the required temperature with the cooling coils in the air conditioner, and supplied to the room. Here, depending on the outdoor air conditions, the interior return air shall be dehumidified at the heat exchanger because of the low temperature of outdoor air. In this case, the evaporative humidifier is controlled by following measured outdoor air conditions. Also, under outdoor air conditions of temperature and humidity in which the cooling effect is reduced and energy conservation cannot be expected, the exhaust fan and circulation fan are halted and ducts are switched to prevent the waste of electric power.

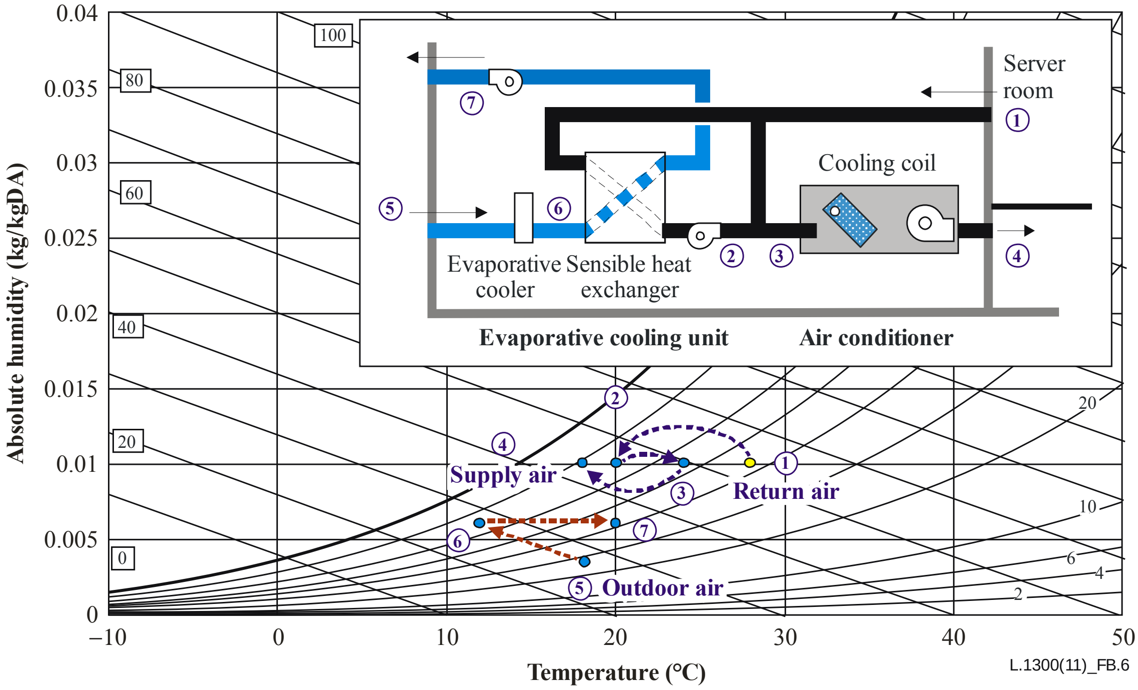


Figure B.6 – Air status in an evaporative cooling system

B.1.3.3 Caution

With the evaporative cooling method, the low-temperature outdoor air is humidified in the evaporative cooler to further cool its temperature. However, under conditions in which the outdoor air wet-bulb temperature is 0°C or lower, water used to humidify the air in the evaporative cooler may freeze. To prevent such freezing, control is implemented to prevent humidification, and air is passed through the equipment, in response to outdoor air conditions. Similarly, in the sensible heat exchanger, when the temperature of the outdoor air is low, it is possible that return air may be dehumidified in the sensible heat exchanger, and a method of control must be implemented to prevent dehumidification.

The evaporative cooling method uses cooling by the outdoor air to reduce the power required by the chilling unit. However, fan power required to pass outdoor air or return air through the evaporative cooling unit is increased. In order to determine the energy conservation within the entire system, it is important to introduce an operation control system able to determine the difference between the reductions in chilling system and distribution power, such as fans etc.

B.1.4 Spot cooling with a conventional air conditioning system

B.1.4.1 Air conditioning system outline

Figure B.7 shows the configuration of the spot cooling system used for natural circulation of the refrigerant. The combined spot cooling method and typical air conditioning method, and the spot cooling method alone, are possible for cooling. However, a system was configured using only the spot cooling method.

A large number of server racks incorporating server devices are installed on the free access floor in the room, and are arranged alternately facing the cold aisle (towards which the server rack air inlets are directed) and the hot aisle (towards which the exhausts are directed).

With the spot cooling method, a spot cooling unit cooling the air in the hot aisle and circulating it in the cold aisle, and a water-cooled condenser using chilled water to condense refrigerant gas evaporated with the spot cooling units, were installed. Suspended spot cooling units employing natural circulation of refrigerant were installed in the space between the server rack and the ceiling. These units draw in the high-temperature return air discharged from the hot aisle into the space above the room, and by evaporating the refrigerant in the cooling coils in the cooling units, cool the return air in the room to the specified temperature, and supply it to the cold aisle. The refrigerant evaporated in the cooling coils is circulated naturally using the liquid gas density difference and circulates through the water-cooled condenser naturally to transport heat to the exterior.

With this method, the spot cooling units cool the air locally, and are thus effective in preventing hot spots. Furthermore, by handling locally the entire amount of heat generated in the room, the blowers supplying large volumes of air to the entire room, as with the typical air conditioning method, are substituted by a small fan for localized air circulation, and a large reduction in heat transport power is possible.

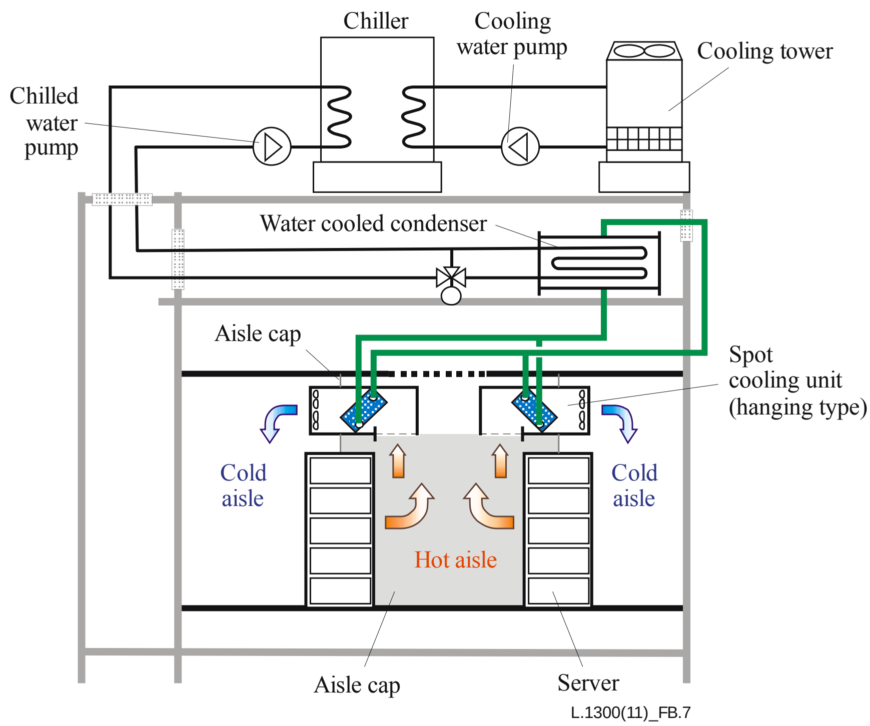


Figure B.7 – Outline of a spot cooling system

Figure B.8 shows an outline of the natural refrigerant circulation method. The high-temperature exhaust from the server rack is passed through the cooling coils by a small fan in the spot cooling unit. The refrigerant in the cooling coils absorbs heat from the high-temperature exhaust air and evaporates the refrigerant. The density of the gas is reduced, and it therefore circulates through the water-cooled condenser installed above the coils. In the water-cooled condenser, the refrigerant is condensed to a liquid by the chilled water, and falls under gravity and thus circulates through the cooling coils. This natural circulation of the refrigerant permits heat transport without motive power.

Heat generated in the server rack is transported to the exterior by the air and refrigerant. With this method, the refrigerant is transported without motive power using natural circulation, and the air is circulated locally, so that heat transport is possible with very low blower power. This permits a large reduction in heat transport power in comparison to the typical air conditioning method.

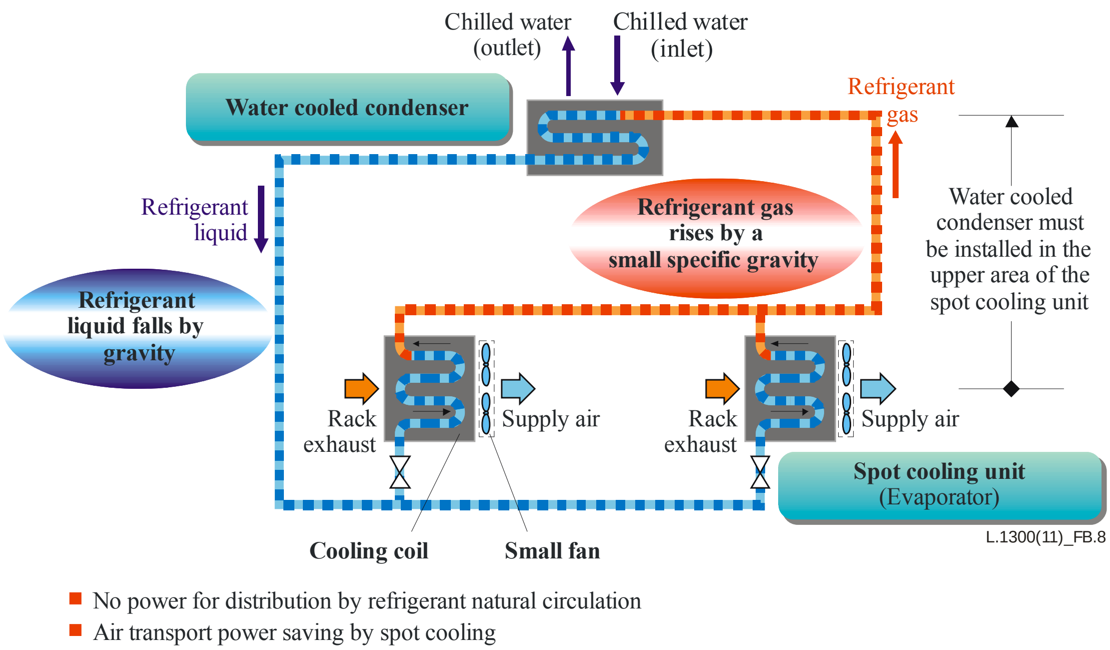


Figure B.8 – Principle of a refrigerant natural circulation system

B.1.4.2 Control system and operating status

With the spot cooling method, the refrigerant evaporated in the cooling units is condensed in the water-cooled condensers, and the flow of chilled water through the water-cooled condensers is controlled to maintain the refrigerant at the specified temperature. Furthermore, the high-temperature air in the hot aisle is drawn in, and the flow of refrigerant controlled to ensure that the cooling unit outlet air reaches the specified temperature.

B.1.4.3 Caution

This method involves a system in which multiple spot cooling units are installed at the top of the server racks, and differs from conventional air conditioning supplying chilled air to the room from the floor. Since the cooling unit layout affects the thermal environment, it is important to have an appropriate layout plan for the server rack arrangement and load distribution at the planning stage. The exhaust air from the server racks is introduced efficiently to the cooling units, thus improving the thermal environment, and highly efficient operation with improved cooling performance of the cooling unit is possible. Methods of preventing air dispersion in the hot aisle are therefore effective.

B.2 Selection of cooling systems suited to data centre specifications

When selecting air conditioning systems for data centres, improved efficiency of ICT equipment, and progress in cloud computing, require high levels of space efficiency to permit the installation of large amounts of ICT equipment in a limited space. Furthermore, from the point of view of preventing global warming and controlling running costs, high levels of energy conservation are required to increase air conditioning energy efficiency, and control energy consumption. The factors and effective air conditioning methods to ensure space efficiency and energy efficiency of the various air conditioning methods were therefore investigated.

B.2.1 Data centre power density and cooling methods with high space efficiency

Energy conservation is naturally a matter of importance in the construction of urban data centres. However, space efficiency in terms of the maximum number of server racks able to be installed is also important. With conventional air conditioning, outdoor air cooling, and evaporative cooling systems, air conditioning equipment is installed in the room to circulate air heated by the ICT equipment throughout the entire room. With these methods, increased power density of a data centre requires higher cooling performance and larger dimensions to the air conditioning equipment, with consequently greater floor area required for installation of air conditioning equipment. Here, power density indicates energy consumption of ICT equipment per unit floor area of data centre. On the other hand, with the spot cooling method using natural circulation of the refrigerant, spot cooling units are suspended from the ceiling above the server racks. Use of this space eliminates the need for floor area to accommodate a conventional floor supply air conditioning unit, and ensures that it is possible to accommodate an increased number of cooling units when power density increases, and thus allows a major reduction in the carbon footprint of cooling equipment. Furthermore, with conventional methods, cold air is supplied throughout the floor chamber, and increased floor chamber height is therefore required for cold air supply. With this method, under-floor chambers are not required, and floor height can be reduced.

B.2.2 Outdoor air conditions and high energy-efficiency cooling methods

Energy consumption of air conditioning systems is comprised of power consumed by water chilling units employed in the production of chilled water required to cool air, and power consumed by heat transport equipment such as fans and pumps used to transport heat inside and outside the room.

Outdoor air cooling systems and evaporative cooling systems are able to make effective use of low-temperature outdoor air, and permit a reduction in heat source power. However, the ventilation resistance of evaporative cooling units, air transport ducts, and under-floor chambers is considerable, and blower power is therefore increased. In cold regions, when outdoor air wet-bulb temperature is low, chilling system energy consumption is therefore considerably reduced, ensuring the most energy-efficient air conditioning method.

On the other hand, the spot cooling method employs the natural circulation of the refrigerant, and interior cooling is therefore possible by localized air circulation, so that blower power required for air circulation is greatly reduced in comparison with the typical air conditioning and outdoor air cooling, evaporative cooling methods. Furthermore, the spot cooling method employs the natural circulation of refrigerant, permitting heat transport without motive power, so that heat transport power can be greatly reduced in comparison with the typical air conditioning method. With this method, energy-efficiency is improved through reduced transport power, even outside cold regions, thus ensuring the most energy-efficient air conditioning method in temperate regions.

Based on this comparison, for the construction of data centres with a high power density, located in a temperate region, space efficiency of suspended spot cooling units employing the spot cooling method with natural circulation of refrigerant is highest, air conditioning efficiency is high, and spot cooling is therefore the most appropriate air conditioning method for high-power density data centres.

B.2.3 Further efficiency improvements

In addition to the large reduction in transport power through use of this spot cooling method, it is also effective to consider the reduction in heat source power (which accounts for a large proportion of cooling system energy), when determining the efficiency of a cooling system. In cold areas, heat source power can be reduced through effective use of low-temperature exterior air to produce chilled water with the free-clean method, and with large, high-efficiency refrigeration units.

Appropriate control of a cooling system for the amount of heat generated is effective in reducing its power consumption. Methods to control the operation of air conditioners in conjunction with the power information for ICT devices, and methods of controlling optimized operation of the entire cooling system while monitoring the energy consumption of the entire system, are effective.

Annex C

Practical solutions for correcting airflow direction for equipment

(This annex forms an integral part of this Recommendation.)

In the case where the airflow can be in different directions for equipment mounted in a rack/cabinet, it is necessary to install a plate or duct to achieve an efficient solution. This annex provides two requirements for this duct/plate installation and design.

C.1 Requirements for correcting airflow direction for equipment

C.1.1 Design

The shape of the plate or duct should be designed so as not to decrease the intake and exhaust capacity of the equipment once it is installed.

C.1.2 Description in the installation manual of the equipment

A description should be added to the installation manual of such equipment so that practical solutions can be easily implemented.

Annex D

Minimum data set for controlling data centre equipment for energy saving management in data centres

(This annex forms an integral part of this Recommendation.)

Table D.1 below, lists the minimum data set necessary for evaluating energy efficiency and for controlling data centre equipment in order to save power in data centres. The rationale for this minimum data set is described in Appendix V. "G" and "S" in the "Data flow direction" column respectively represent data which should be obtained from the equipment and data which should be set according to the equipment.

Table D.1 – Minimum data set controlling data centre equipment for energy saving management in data centres

Type of equipment		Data set	Data flow direction
ICT equipment		Input power	G
		Inlet temperature	G
		Power state (shutdown, sleep, active)	G
		Power state (shutdown, activate)	S
Facility equipment	Cooling equipment	Input power	G
		Inlet temperature of indoor unit	G
		Outside temperature	G
		On-off state	G/S
		Amount of refrigerant supplied from an indoor unit to ICT equipment	G/S(1)
		Temperature of refrigerant supplied from an indoor unit to ICT equipment	G/S(1)
	Power equipment (UPS, rectifier, PDU)	Output power	G
		Input power	G

(1) If data cannot be obtained from the equipment, data can be estimated by using alternative data which can be obtained from the equipment and static data of the equipment. An example of estimation is shown in Appendix V.

Appendix I

Validation test of a data centre cooling method using renewable energy in a cold region

(This appendix does not form an integral part of this Recommendation.)

I.1 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 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.

I.2 Overview of the test

I.2.1 Specifications of the test facility

Figure I.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.

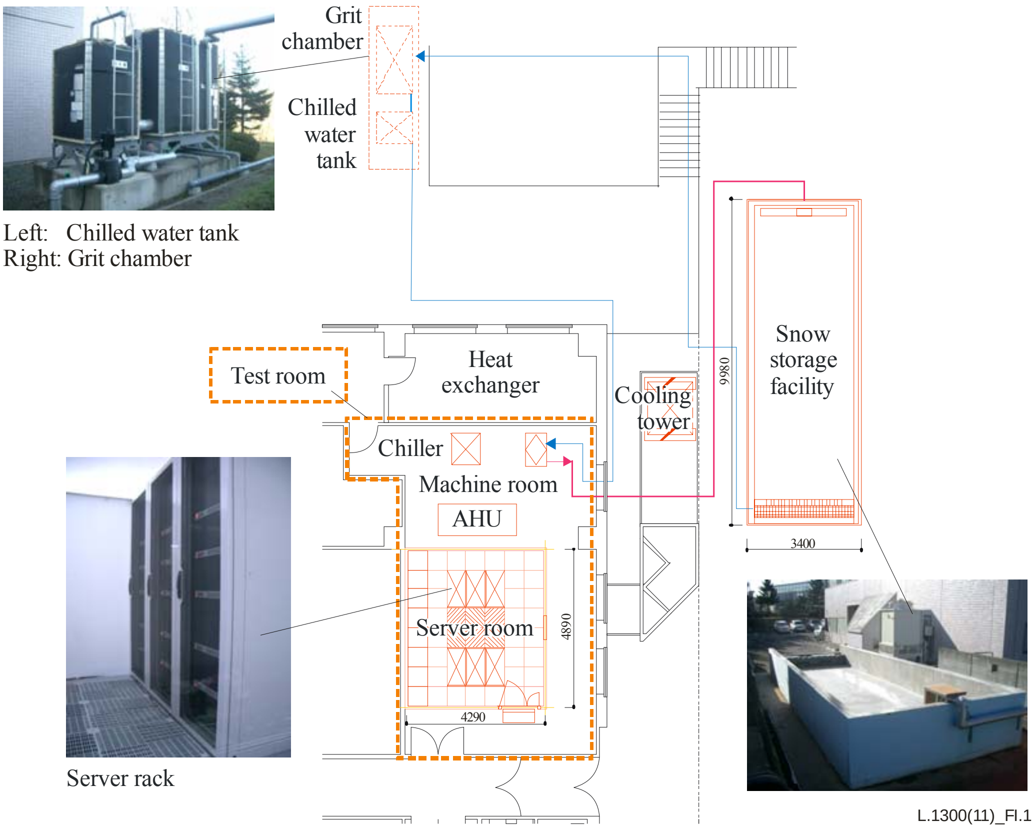


Figure I.1 – Layout of the test facility

I.2.2 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 temperature (RA) at 24°C ±2°C and return air humidity at 45% ±10%.

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

(1) Conventional air conditioning (Mode 1: ordinary heat source).

(2) Outdoor air cooling (Mode 2: OA and RA are mixed together by AHU, and the mixed air is humidified to achieve the target SA temperature and humidity).

(3) Snow and ice cooling (Mode 3: water, for which the temperature has been raised by heat exchange, is sent to the snow storage facility, and the water chilled by snow is stored in the chilled water tank. Then, chilled water to be sent to AHU's snow and ice cooling coils is chilled down by the heat exchanger, and 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).

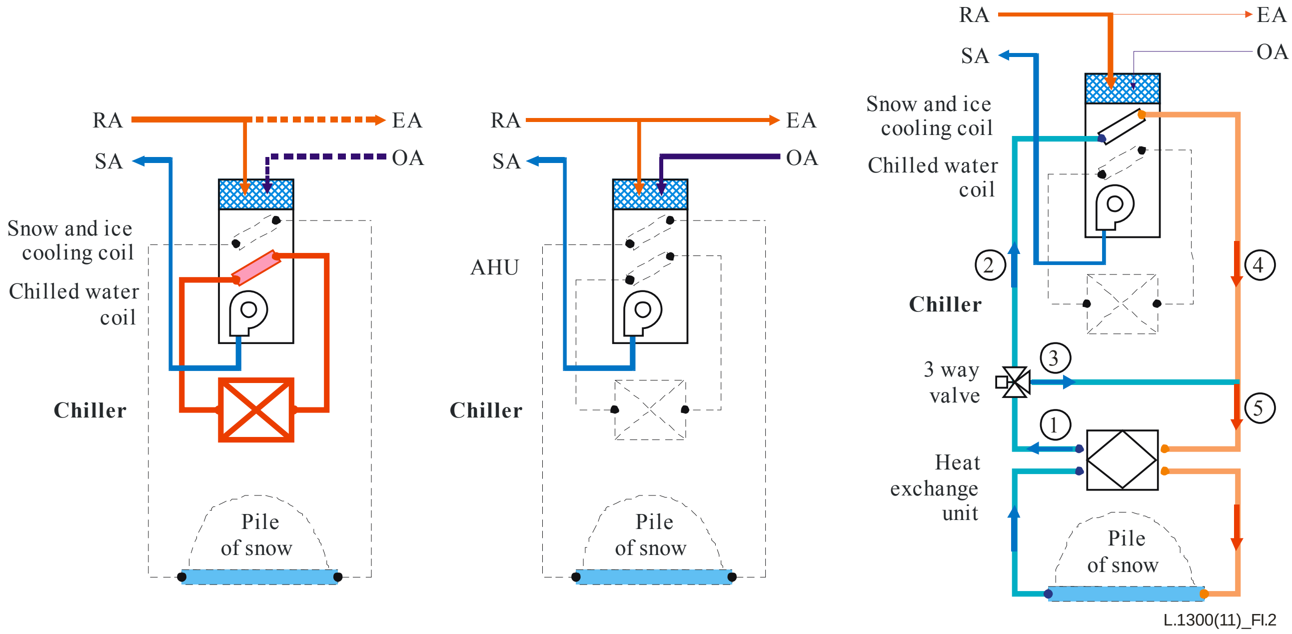


Figure I.2 – Image of each cooling mode

I.2.3 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 I.3 shows the air conditioning heat source diagram and measuring points. Table I.1 shows the specifications of the air conditioning equipment.

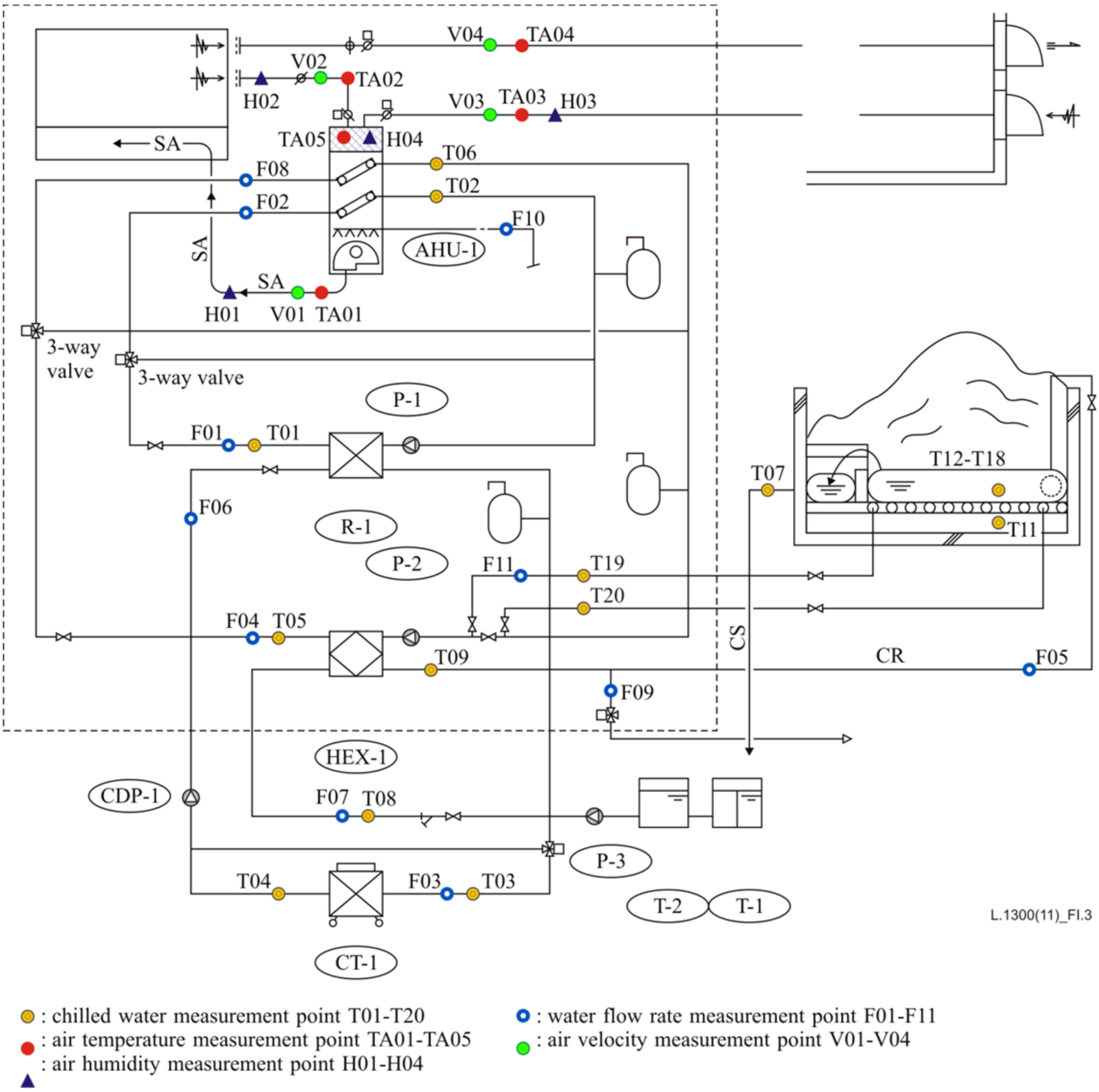


Figure I.3 – Air conditioning heat source diagram and measurement points

Table I.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)

I.3 Test results

I.3.1 Outdoor air cooling test results

Figure I.4 shows the outdoor air temperature. Figure I.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 and 8°C. The SA temperature was around 18°C, and the RA temperature was 25 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.

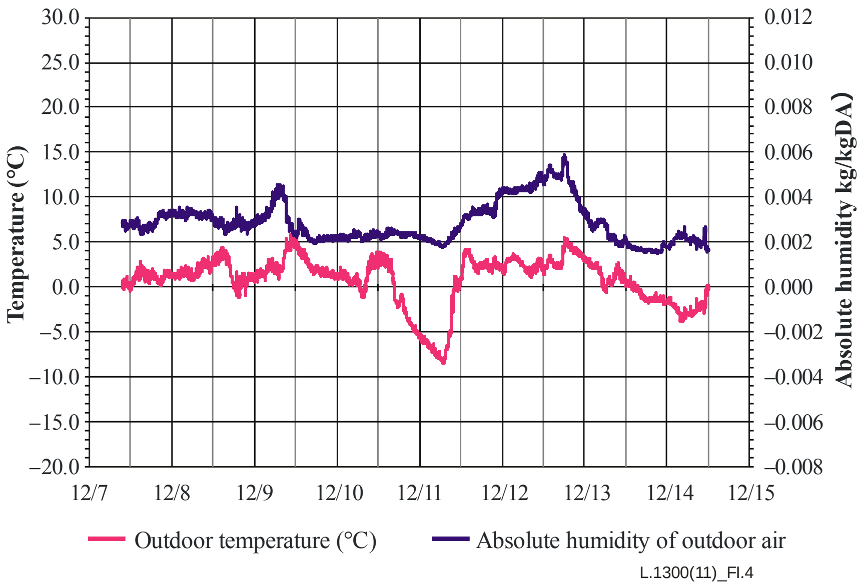


Figure I.4 – Outdoor air temperature and absolute humidity

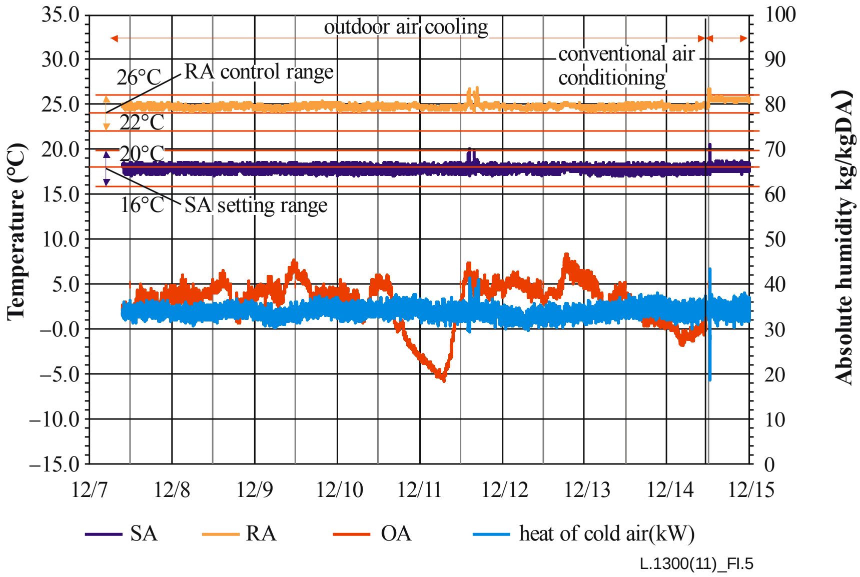


Figure I.5 – Air (SA, RA, OA) temperature and heat energy

To evaluate the state of outdoor air cooling operation, Figure I.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 I.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 I.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.

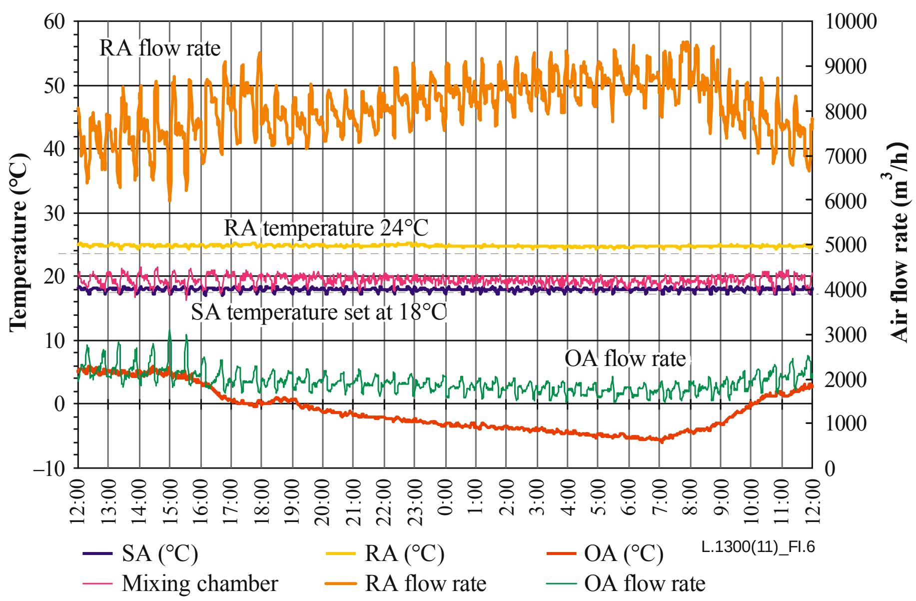


Figure I.6 – Air temperature and airflow rate

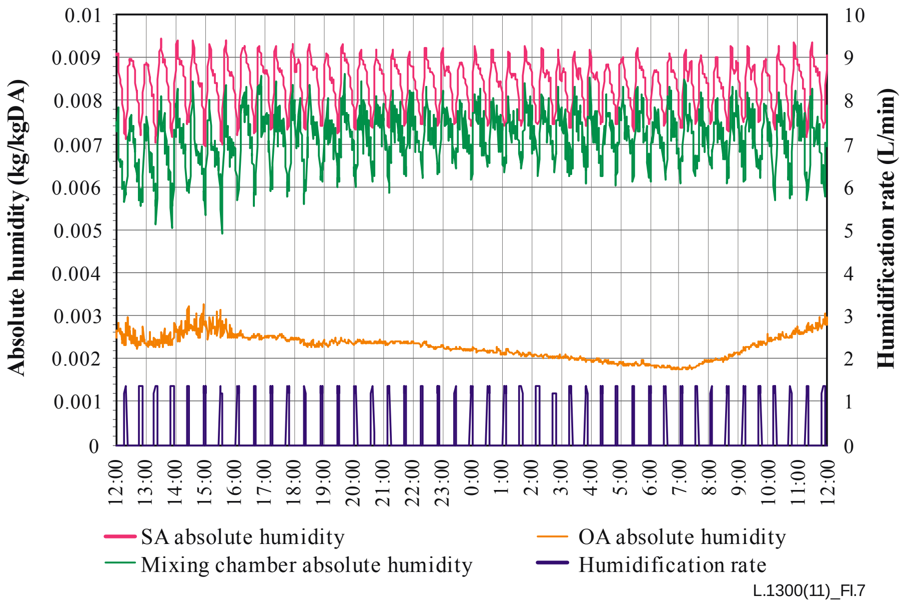


Figure I.7 – Absolute humidity of air and the humidification rate

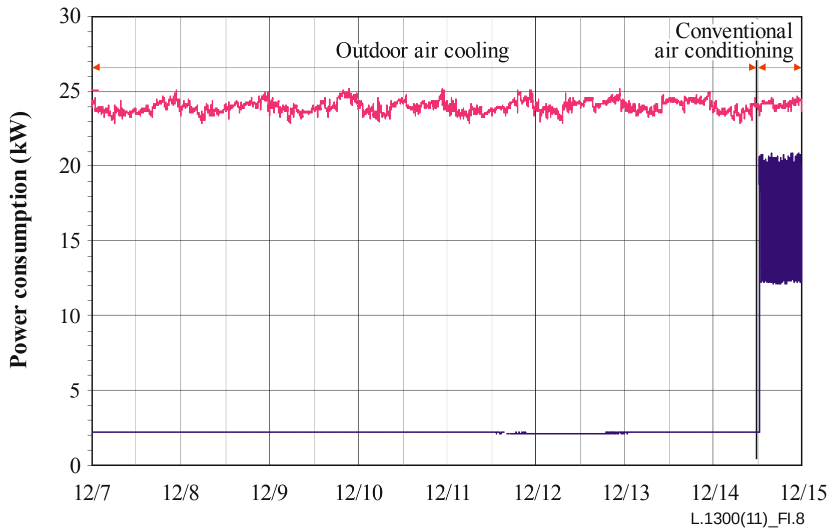


Figure I.8 – Power consumption of servers and air conditioning equipment

I.3.2 Snow and ice cooling test results

Figure I.9 shows the chilled water flow rate and the air conditioning heat load in the case where snowmelt water is used. Figure I.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 I.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 I.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 I.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 I.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.

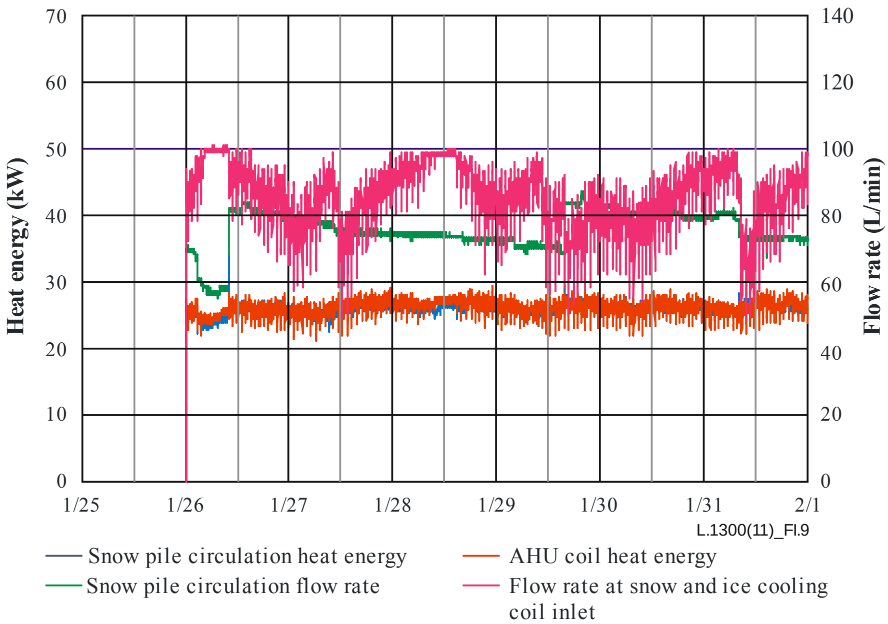


Figure I.9 – Chilled water flow rate in snow and ice cooling

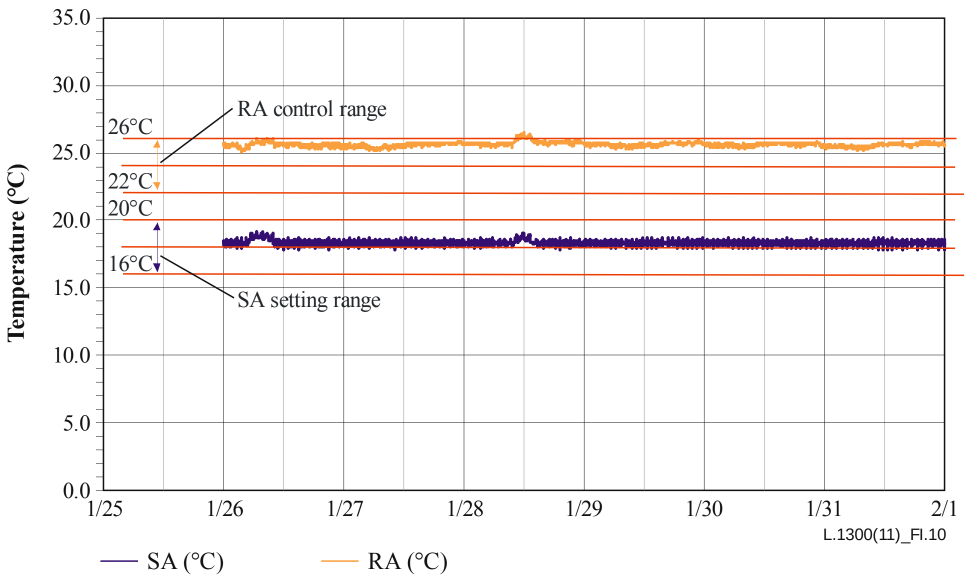


Figure I.10 – Air temperature in snow and ice cooling

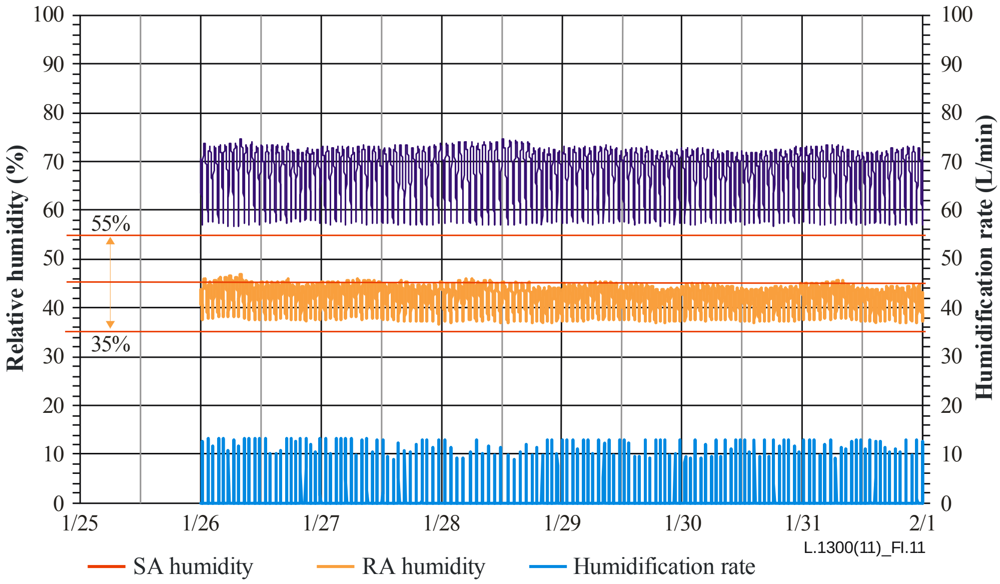


Figure I.11 – Relative humidity of air and the humidification rate

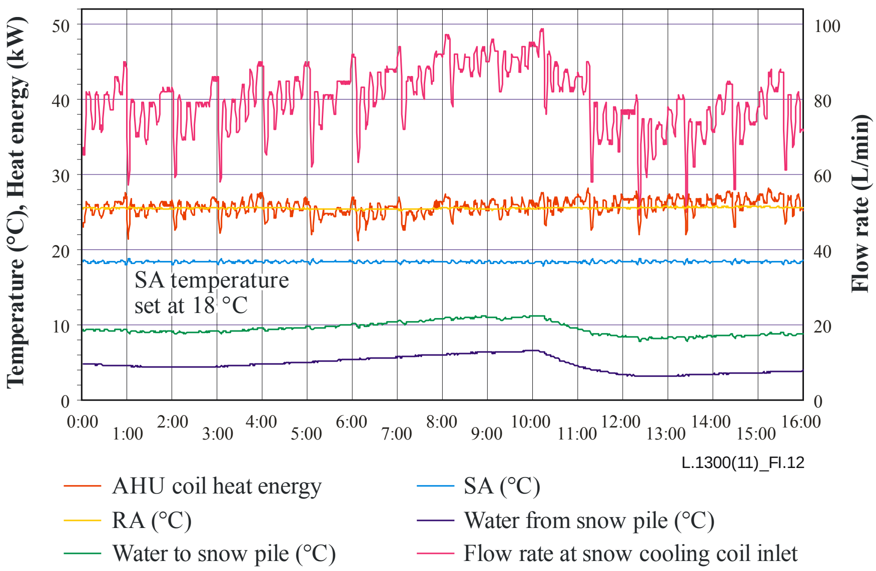


Figure I.12 – Air temperature in snow and ice cooling

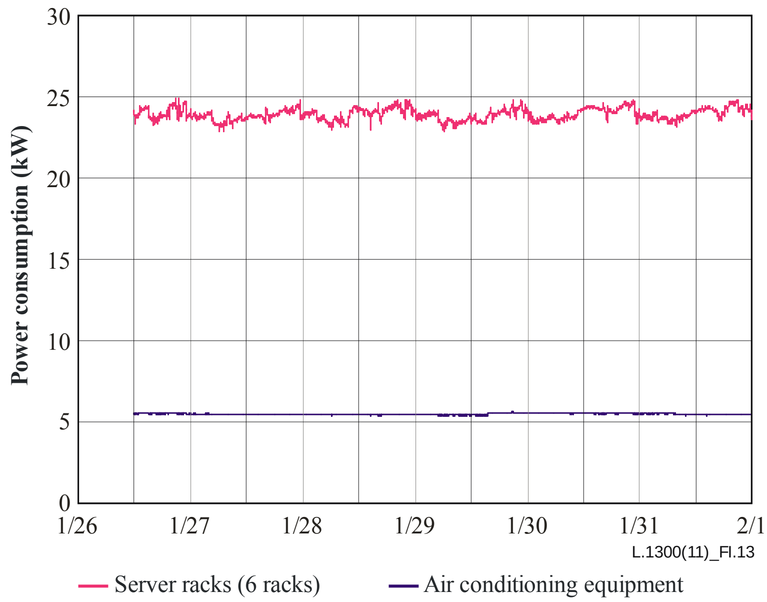


Figure I.13 – Power consumption of servers and air conditioning equipment (snow and ice cooling)

Table I.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 I.2 – 10-day power consumption

	Power consumption (kWh)		
	Outdoor air cooling	Conventional air conditioning	Percentage reduction (%)
Outdoor air cooling period	566.4	3864	85.3
	Snow and ice cooling	Conventional air conditioning	Percentage reduction (%)
Snow and ice cooling period	1308	4176	68.7

I.4 Prediction of annual energy consumption

I.4.1 Annual energy consumption estimation method

Figure I.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 I.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.

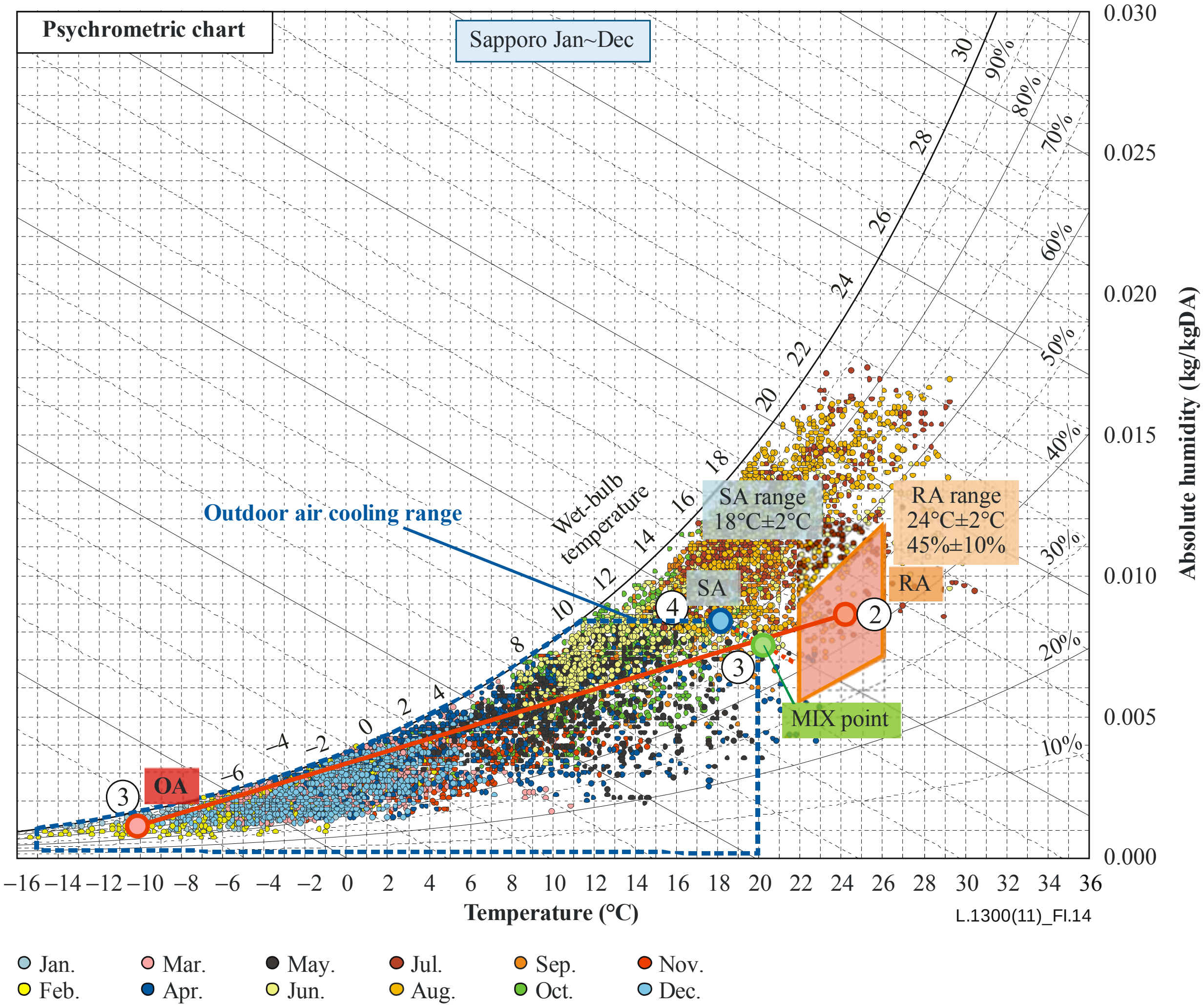


Figure I.14 – Psychometric chart: Sapporo weather data

Table I.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 I.4 shows the amount of time each air conditioning method is used, as the basis for the calculation of annual energy consumption.

Table I.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	6274	2486	0
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	6274	1865	621
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	6274	1243	1 243
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	6274	621	1 865
Pattern 5: outdoor air cooling + conventional air conditioning	6274	0	2 486
Pattern 6: conventional air conditioning	0	0	8 760

I.4.2 Estimation of annual energy consumption of the test facility

Table I.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 I.5 – Specifications of the air conditioning system

Element	**Test room**
number of rack	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 I.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

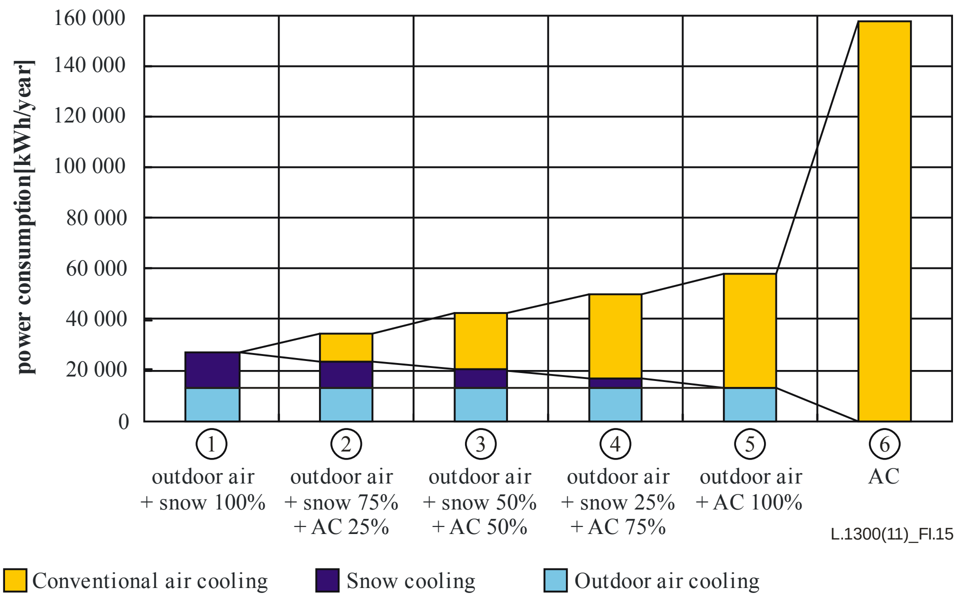
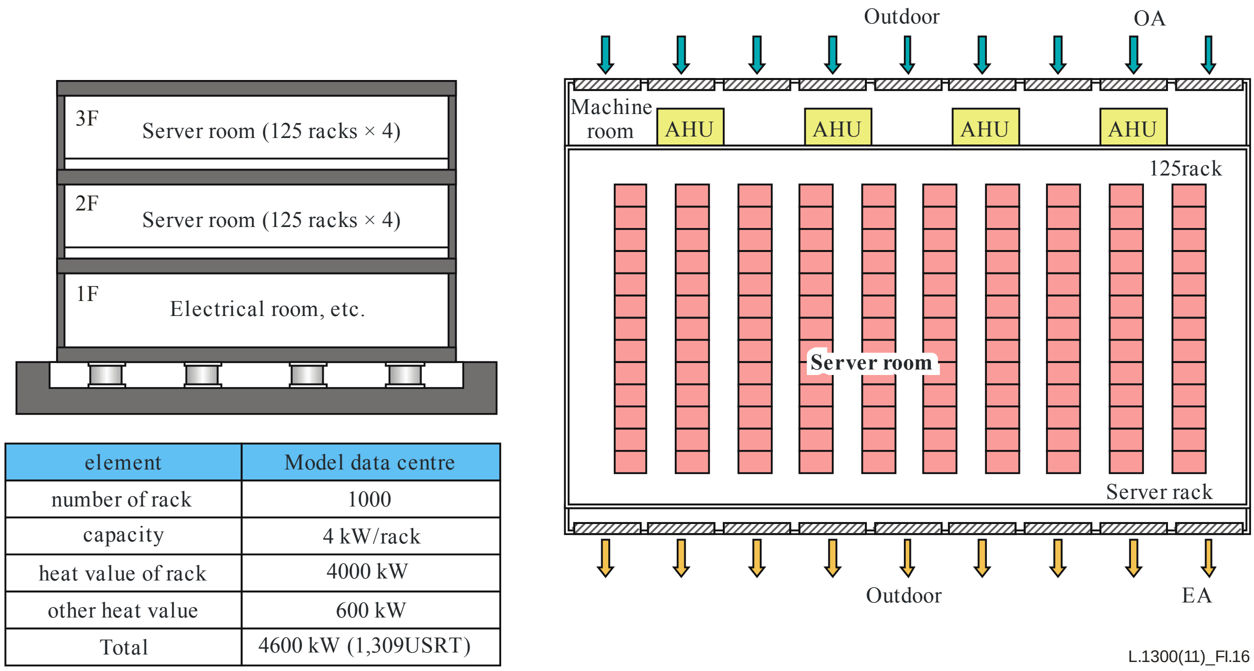


Figure I.15 – Calculated annual power consumption of the test facility

I.4.3 Calculation of energy consumption of the model data centre

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

Figure I.16 illustrates a 1000-rack data centre and the schematic diagram of the air conditioning system. Basically, the air conditioning system shown in Figure I.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 I.16 – 1000-rack model data centre

(2) Estimation of energy consumption by air conditioning pattern

Table I.7 and Figure I.17 show the calculated annual power consumptions 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 I.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 I.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

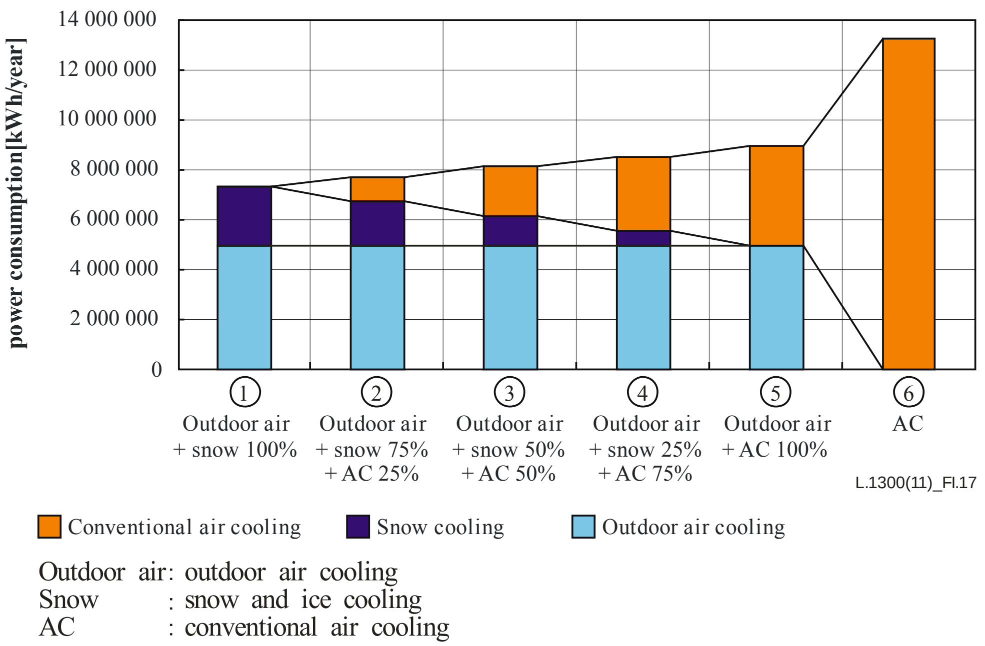


Figure I.17 – Calculated annual power consumption of the 1000-rack model data centre

(3) Calculation of running costs

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

Table I.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

Table I.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 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 I.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 I.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

(5) 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 I.10 shows the PUE calculation results.

Table I.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 I.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 I.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	4318.9	44.5
Pattern 2: outdoor air cooling + snow cooling 75% + conventional air conditioning 25%	7 734 300	4547.8	41.6
Pattern 3: outdoor air cooling + snow cooling 50% + conventional air conditioning 50%	8 144 500	4789.0	38.5
Pattern 4: outdoor air cooling + snow cooling 25% + conventional air conditioning 75%	8 549 300	5027.0	35.5
Pattern 5: outdoor air cooling + conventional air conditioning	8 943 500	5258.8	32.5
Pattern 6: conventional air conditioning	13 244 700	7787.9	0.0

I.5 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 to solve problem.

(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 in non-cold regions, also, energy efficiency can be improved by using similar methods if outdoor air conditions are met.

Appendix II

Potential for primary energy savings in TLC/ICT centres through free cooling

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

The growth of modern society is characterized by dynamism in communications, and in recent years the field of telecommunications has achieved great importance in the socio-economic development of many countries. Such a trend requires increased power installation in data centres that serve to allocate routers, switches, computers, and many other equipment that have high energy requirements. Such data centres generate heat that must be dissipated. To give an example, the mean value of electrical power density installed in Italian telecommunication plants is about 450 W/m^2 and all this electrical power is converted into endogenous power.

In 2007, electrical energy consumption for Italian telecommunications was 4000 GWh, which is 1.25% of global electrical energy consumption for that year. Moreover, data shows that the global demand for electrical energy has increased by 0.4% with respect to 2006 data, but that the increase in telecommunications was 1.5%. The most important Italian telecommunication company is the second national user for energy consumption, with 0.7% of total national energy demand (the largest user is the national railway transport company). More than half of the energy consumption is used for fixed network and mobile equipment, and approximately 16% of this part is used for cooling.

In total, electrical energy purchased or generated by the group in 2007 amounts to 2.15 TWh, i.e., about 2.3% more than energy used in 2006, and 7.36% more than energy used in 2005. Equipment in data centres have to operate within defined temperature and humidity conditions, because their internal circuits are sensitive to excessively high or low temperature and humidity. Furthermore, the equipment cannot be switched off because data must be transmitted from centre to centre 24 hours a day, 7 days per week. ETSI standard EN 300 019-1-3 establishes the upper and lower limits for temperature and humidity in which equipment must operate.

To maintain correct operating conditions, the cooling system must operate continuously, absorbing large amounts of electricity. To contribute to energy saving policies, such as the 20/20/20 objectives established by the European Commission, the use of alternative cooling systems for data centres conditioning is crucial. Free cooling consists of the direct use of external air to cool the environment. The temperature of external air can be reduced by injecting water spray, if the external humidity is lower than 100%. This is called adiabatic free cooling. Free cooling is a rational option for the telecommunication sector, as the temperature tolerated in data centres is usually above outdoor temperature and because of the non-stop operation of the equipment. Knowledge of typical external temperature and relative humidity is particularly important for a correct design of a free cooling system. Such information is available for various locations, and otherwise a model may be used. A possible model is presented in the next section. This is particularly useful because of the small number of parameters required for its application to a location. In addition, it provides a general behaviour that should be adopted for compact representation of the suitability of free cooling systems in a location.

This appendix describes a general approach to the energy analysis of free cooling systems and its application to telecommunication centres located in Italy. In the mid-period it could also be applied to data centres. First, a probabilistic model for ambient temperature and relative humidity is presented. This is the basis for predicting the air inlet condition. Then some theoretical and experimental data obtained from measurements in the Telecom Italia telecommunication laboratory are presented. These data allow one to relate the inlet air condition to the operating conditions of the equipment. Ultimately, the energy savings that can be achieved through use of free cooling systems in Italy is calculated. Italian locations are classified in terms of energy saving due to free cooling and adiabatic free cooling use, and the opportunity of using such a technique is highlighted through a pictorial representation on the Mollier diagram, where the limits of the ETSI standard are also drawn. With respect to the ETSI diagram, here the properties of the probabilistic model of temperature and relative humidity are used for a more compact representation.

II.2 Probabilistic model for the inlet conditions

External air temperature and relative humidity (RH) define the applicability of free cooling. If the temperature is too high, a large air mass flow rate may be necessary to keep the internal temperature within acceptable limits. However, it may be impossible if the external temperature is above the maximum internal temperature. A model that represents the daily temperature (and RH) trend, allows temperature distribution to be foreseen for an assigned geographical site on the basis of little data, generally available for most locations. This model is composed of two parts. The first part is an equation that makes it able to describe hourly temperature and RH in the average day of each month. Then a stochastic model is applied in order to account for expected deviations.

Temperature model

The model is aimed at obtaining an average daily temperature trend for an assigned site and an assigned time step; temperature distribution has been described by simplified mathematical functions that require the lowest number of independent variables. The model has been generated thanks to a large amount of meteorological data referred to over a period of seven years. It has been created on the basis of data available from Turin. First, hourly data have been averaged to obtain 24 mean temperature values for every month (e.g., the value corresponding to the average temperature in January at 1 a.m. is obtained from the mean 31·7 temperatures recorded at 1 a.m.). The average temperature of a typical day of January is shown in Figure II.1. Similar curves are obtained for the other months.

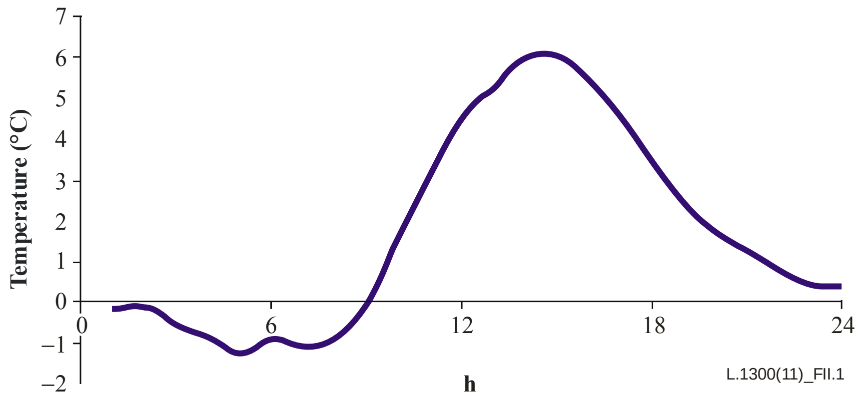


Figure II.1 – Temperature for an average day of January

The model has been obtained by considering two different periods: daytime and night-time. The sequence of the hours, during the day, has been modified and fictitious time units have been used: the day starts at sunrise (the first hour is the hour corresponding to sunrise) and finishes at the hours that come before sunset. The first hour will be different for different geographical areas and for different months. Night-time starts at sunset. Figure II.2 shows the shifted temperature curve and the two curves used for modelling daytime and night-time, which are described in the following.

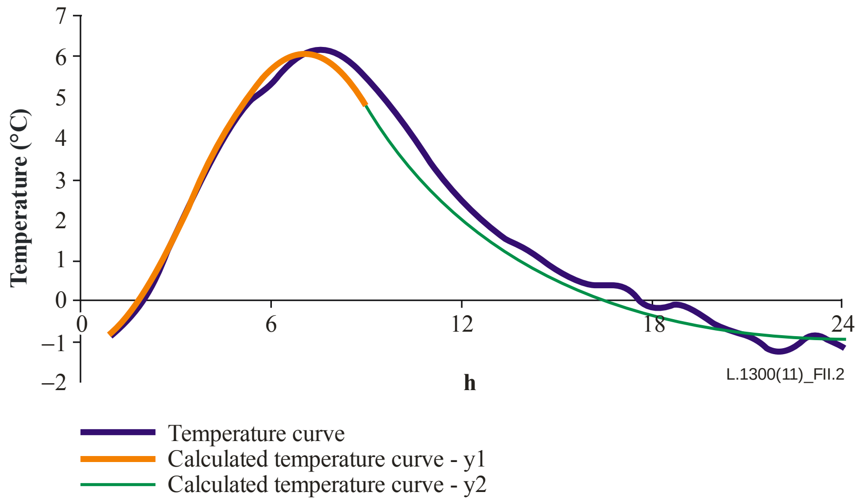


Figure II.2 – Temperature in a typical day of January and model curves

A harmonic function is used to model the daytime temperature:

$$y_1 = A + B \cdot \sin(\omega \times x - k) \qquad \text{(II-2.1)}$$

where A is the average between the maximum and minimum temperatures in an examined month; B is half of the difference between maximum and minimum temperatures; x is the current hour (sunrise ≤ x ≤ sunset); k is an empirical coefficient and its value is constant in every month; ω is the pulsation:

$$\omega = 2\,\pi/(H \times FF) \qquad \text{(II-2.2)}$$

where H refers to daylight time (from sunrise to sunset); FF is an empirical coefficient, that assumes two different values: in winter FF is equal to 1.6, otherwise it is equal to 1.45.

The curve corresponding to night-time is selected to describe the behaviour of a body that is losing heat, so it has been represented with an exponential function:

$$y_2 = b + (y_1(x_{SUNSET}) - b) \times \exp(h \times (x - x_{SUNSET})) \qquad \text{(II-2.3)}$$

where b is the minimum average value of the temperature Tmin, x_{SUNSET} is the actual sunset time, h is an empirical coefficient: its value is constant in every month and is equal to –0.231, x is the current hour (x > sunset). Only 4 parameters are required to obtain an average temperature daily trend for the chosen location:

1) highest monthly temperature (average value);
2) lowest monthly temperature (average value);
3) latitude;
4) longitude.

Latitude and longitude are capital to set location sunrise and sunset times.

Relative humidity model

Daily average distribution of the relative humidity has been obtained in the same way as described in the temperature model. Figure II.3 shows the relative humidity for an average day in January and the two curves are used to model the daytime portion and the night-time portion.

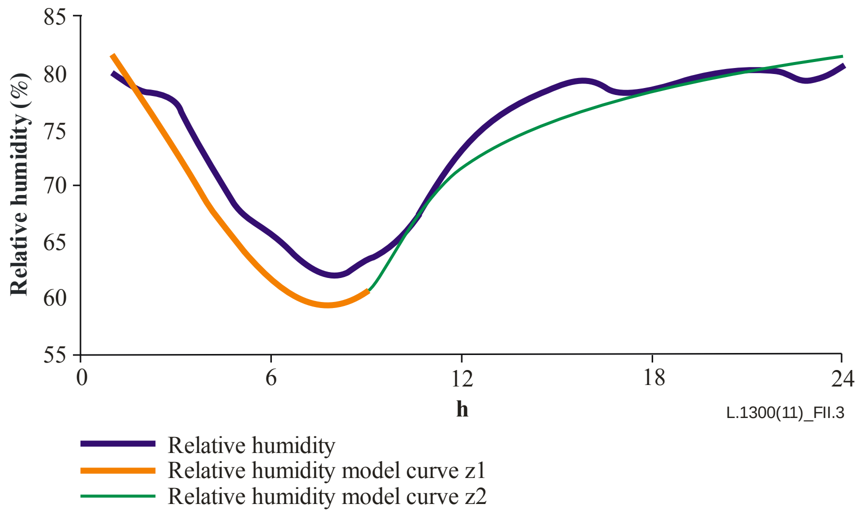


Figure II.3 – Relative humidity for a typical day in January, plus model curves

The daytime portion has been represented with a harmonic function:

$$Z_1 = C + D \times (-\sin(\omega \times x - q) \qquad \text{(II-2.4)}$$

where C is the mean between the lowest and the highest relative humidity (average value), D is obtained from half of the difference between the lowest and highest relative humidity (average value), q is an empirical coefficient, and its value is equal to 0.8. Compared to the previous model, this one differs due to the different way of calculating lowest and highest air relative humidity. Because of the difficulty in obtaining such information, data has been taken from the mean relative humidity value, lowest temperature (average value) and corresponding saturated steam pressure. On the basis of the average humidity value, corresponding water vapour ratio has been calculated using the well-known expression:

$$x_M = 0.622 \times (\phi_M \times p_{vs} (T_M)/(p_{atm} - \phi_M \times p_{vs}(T_M) \qquad \text{(II-2.5)}$$

where φ_M is the average relative humidity, pvs is the saturated steam pressure calculated at reference temperature, p_{atm} is the atmospheric pressure, x_M is the water vapour ratio. Lowest and highest relative humidity have been calculated with the hypothesis of keeping a constant water vapour ratio:

$$\phi_{min} = (p_{atm} \times x_M)/(0.622 \times p_{vs} (T_{max}) + x_M \times p_{vs} (T_{max}) \qquad \text{(II-2.6)}$$

$$\phi_{max} = (2 \times \phi_{mean}) - \phi_{min} \qquad \text{(II-2.7)}$$

The night-time portion has been modelled with a logarithmic function:

$$z_2 = z_1 (x_{SUNSET}) + M \times \ln(x - x_{SUNSET}) + G \qquad \text{(II-2.8)}$$

where G is an empirical coefficient equal to 4.5, while M is:

$$(z_1(x_{SUNRISE}) - z_1(x_{SUNSET}) - G)/\ln(24 - H) \qquad \text{(II-2.9)}$$

Deviation analysis

The aim of this part of the model is to introduce deviations with respect to the average hourly temperature and the relative humidity trend.

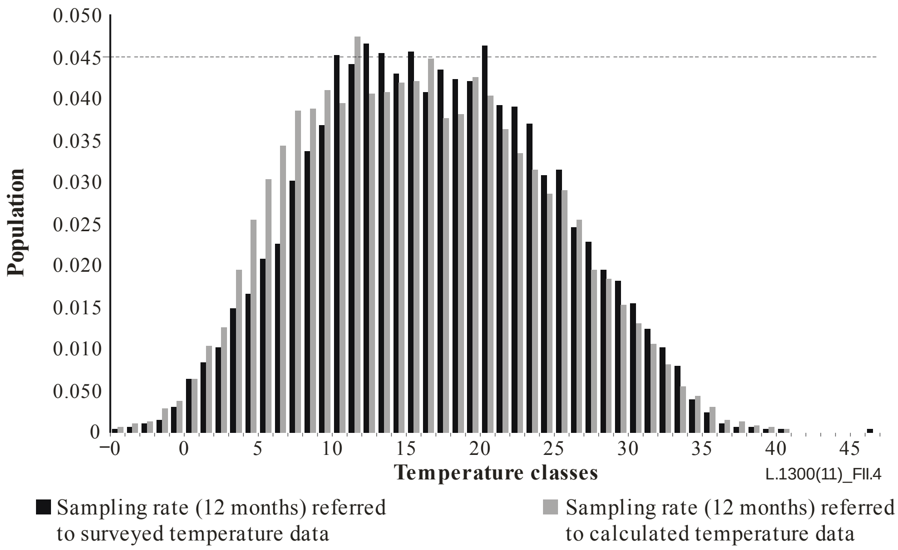


Figure II.4 – Comparison between calculated and surveyed yearly temperature distributions

The relative frequency distribution of the differences has been approximated as a normal distribution. The standard deviation on difference between calculated mean values and real temperature and relative humidity values has been determined for Turin. The deviation for temperature is 3.5°C, while for humidity it is 15.5%. The model has been the validated comparison of calculated distribution with available data for Rome and Palermo. Figure II.4 shows a comparison between calculated temperature and modelled temperature for a year.

II.3 Room temperature

Cooling of data centre rooms depends on two different factors: external conditions and internal conditions. Meteorological models allow the forecasting of external factors in order to class location on the basis of operative conditions of equipment. When external air goes into areas, it exchanges heat with the air of the rooms that benefit from the exchange in different ways, according to different room configurations. For this reason, it is vital to know how external parameters need to be modified by referring to equipment suction conditions. A second model has been created to reproduce machine work modalities in Telecom Italia data centre rooms, located in Turin. Room pressure is less than outside pressure because external air has to enter and to cool the environment. The testing laboratory is divided into two contiguous parts (Room 1 and Room 2) divided by a watertight door. Room 1 is about three times wider than Room 2, and has seven rows of racks containing equipment that differ for power. Room 2 is characterized by a large power density but, compared to Room 1, air entrance is penalized because of larger friction losses in the inlet air ducts. In Room 2, there are four rows of racks and four air ducts for external air inlet. The layout is not optimum, because in the same passage there is equipment that expels air utilized for circuit cooling and also equipment that takes in air to cool the circuit, so the second one takes in high temperature air. Room 2 has been selected for the analysis shown hereafter. The results of such an analysis are used as the reference for further considerations.

Four operating scenarios of the room are considered:

1) Ideal condition obtained by installing equipment of the same type with inlet vents all facing a cold aisle, and the outlet vents facing a hot aisle. Fresh air enters from the ceiling above the cold aisle and exhaust air is extracted from the ceiling above the hot aisle. Figure 5 shows a schema of this configuration, which theoretically allows one to feed the racks with fresh air at the same temperature as the inlet temperature of the room. This scenario is the best one, but is not always applicable in real data centres, especially if there is equipment with the inlet vent on the same side as the outlet vent.

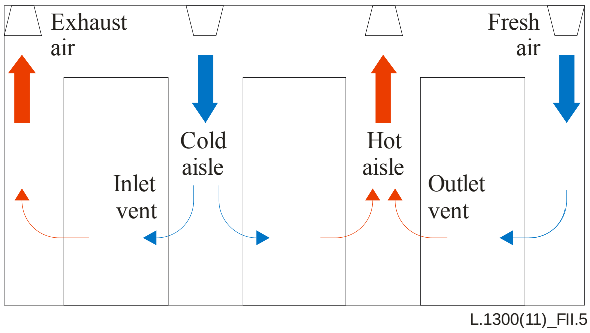


Figure II.5 – Schema of air distribution according to configuration 1

2) Ideal condition corresponding to perfect air mixing in the room. This means that the inlet temperature in the racks is equal to the exhaust air temperature (i.e., the temperature of air exiting the room). This temperature can be calculated as follows:

$$\Phi = m \times c \times (T_{ex} - T_{in}) \qquad \text{(II-2.10)}$$

where Φ is the heat generation in the room (corresponding to the installed power capacity), m is the air mass flow rate, c is the air specific heat, T_{ex} is the exhaust air temperature and T_{in} is the fresh air temperature. If the system is sized with regards to a fresh airflow of 400 Nm^3/h per kW of installed power, the temperature of air entering the racks is about 7.4°C higher than fresh air temperature.

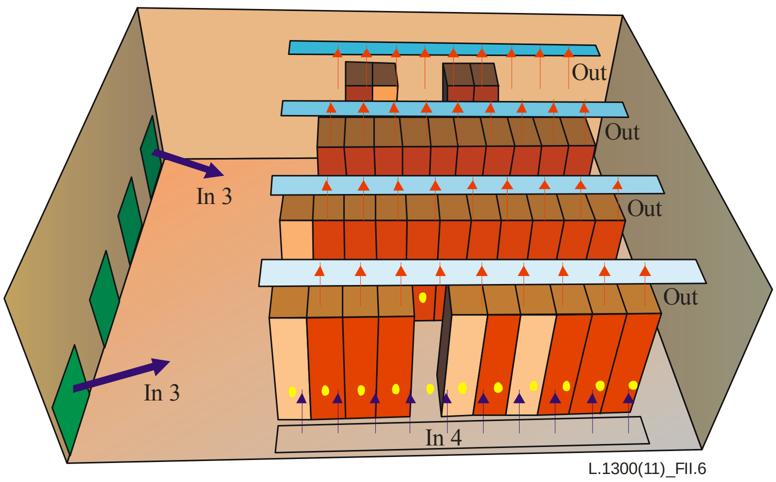


Figure II.6 – Schema of air distribution in scenarios 3 and 4

3) Real conditions obtained by distributing fresh air from four large vents on the side wall. Two of these vents are indicated as in 3 in Figure II.6. These two vents supply about 13 500 Nm^3/h of fresh air, which corresponds to 300 $Nm^3/h/kW$. The other two vents, one of which is shown in Figure II.7, are located on the opposite wall. These two vents supply about 1500 Nm^3/h of fresh air, which corresponds to 33 $Nm^3/h/kW$. Exhaust air is extracted from 36 vents on the ceiling (indicated as out in Figures II.6 and II.7). Temperature distribution corresponding to this scenario is shown in Figure II.8. Temperatures have been measured in the aisles (10 measurements for each aisle) at 1 metre from the floor and then the distribution is obtained through interpolation. The maximum temperature is about 8.5°C higher than fresh air temperature. This scenario is interesting as such a configuration may be easily obtained in a data centre.

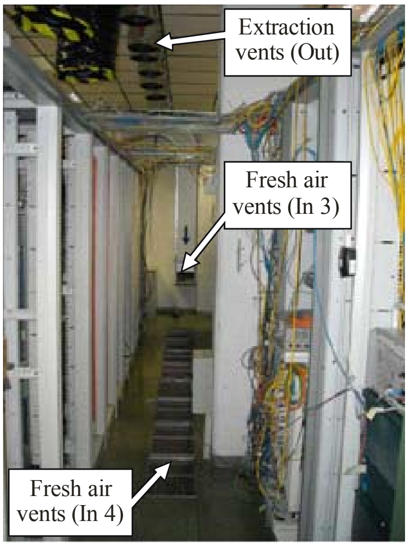


Figure II.7 – Rack aisle and air distribution system

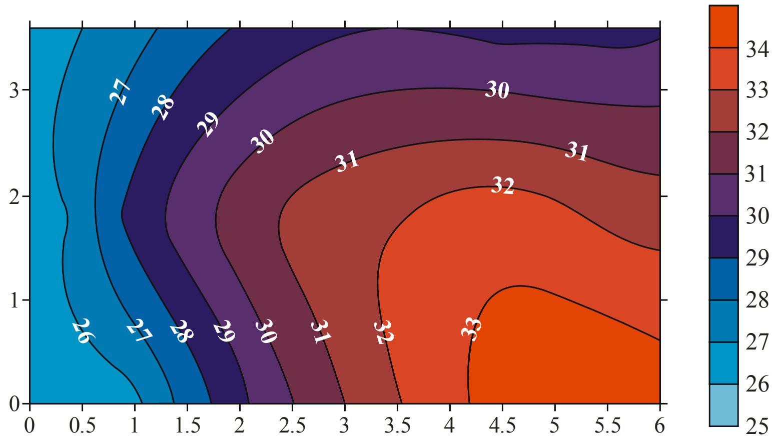


Figure II.8 – Air temperature in scenario 3

4) Real condition obtained by distributing fresh air from distribution vents on the floor. These vents are indicated as in Figures II.6 and II.7. The total amount of fresh air is the same as in scenario 3. Exhaust air is extracted from the vents on the ceiling as in scenario 3. Temperature distribution obtained from measurements at 1 metre from the floor, is shown in Figure II.9. The maximum temperature is about 4.5°C higher than fresh air temperature. This scenario is not always applicable in data centres, as it requires distribution ducts below the floor.

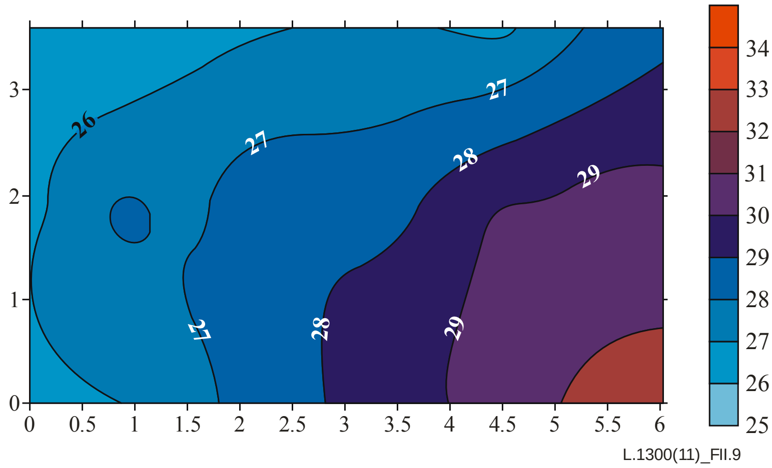


Figure II.9 – Air temperature in scenario 4

II.4 Energy analysis

Energy analysis of free cooling systems is conducted considering the difference between fresh air temperature and inlet vent temperature as a parameter. Three cases are considered: $\Delta T=0°C$, $\Delta T=4.5°C$, $\Delta T=8.5°C$. Air temperature on the inlet vent of the racks is therefore calculated starting from the external temperature obtained through the probabilistic model and adding the ΔT corresponding with the examined scenario. Relative humidity is calculated starting from the ambient value and considering the effect due to ΔT. If the condition is within the limits of the ETSI diagram, only the fans of the free cooling system are used. On the basis of measurements conducted during tests, the electric power required by the fans at full load is about 1.9 kW. Clearly this value depends on the installation. For usual installations, ventilation power per installed power of the TLC equipment is expected to be smaller. When the point is outside the limits and it is possible to obtain acceptable operating conditions through adiabatic saturation, the humidification section (see Figure II.10) is turned on. The measured electric power required by the water pumps is about 0.8 kW. Should such a process prove insufficient, the chillers are turned on. Chillers are characterized by an average COP equal to 4.

Figure II.10 – Filtration and humidification section

The results obtained for seven Italian towns are presented in Tables II.1-3 for the various values of ΔT. In the case of ΔT=0°C and ΔT=4.5°C, the free cooling system allows the equipment to comply with the ETSI standard [b-ETSI EN 300 019-1-3]. In fact, more than 90% of the inlet conditions are within the limits. In the case of ΔT=8.5°C only for Turin (located in northern Italy) the free cooling system is able to comply with the standard. For plants installed in Parma, Rome and Florence (all in central Italy) the standard is complied with, without using the chillers, as the combination of free cooling and adiabatic free cooling is sufficient to have more than 90% of the inlet conditions within the limits. For the last three towns, chillers are required.

Table II.1 – System operation with ΔT=0°C

Town	Free cooling	Adiabatic free cooling	Chillers
Turin	99.0%	0.0%	1.0%
Parma	99.0%	0.0%	1.0%
Rome	99.1%	0.0%	0.9%
Florence	98.2%	0.0%	1.7%
Foggia	97.9%	0.1%	2.0%
Olbia	98.2%	0.1%	1.7%
Catania	96.1%	0.0%	3.9%

Table II.2 – System operation with ΔT=4.5°C

Town	Free cooling	Adiabatic free cooling	Chillers
Turin	97.9%	0.1%	1.9%
Parma	96.3%	0.9%	2.8%
Rome	95.3%	1.3%	3.4%
Florence	94.4%	1.2%	4.4%
Foggia	93.5%	1.4%	5.1%
Olbia	94.3%	1.3%	4.5%
Catania	91.5%	1.1%	7.4%

Table II.3 – System operation with ΔT=8.5°C

Town	Free cooling	Adiabatic free cooling	Chillers
Turin	92.8%	1.7%	5.5%
Parma	87.7%	4.2%	8.1%
Rome	85.3%	5.3%	9.4%
Florence	86.6%	3.8%	9.7%
Foggia	84.3%	4.6%	11.2%
Olbia	85.0%	4.5%	10.5%
Catania	82.1%	4.1%	13.8%

A pictorial representation can be used to represent the opportunity of using free cooling and adiabatic free cooling in a data centre located in a specific place. This representation makes use of the temperature and relative humidity limits of the ETSI standard [b-ETSI EN 300 019-1-3] drawn on the Mollier diagram. In addition, the properties of the Gaussian distribution are considered. In this way a point corresponding to the average annual temperature and relative humidity guarantees that 90% of the points are within the limits, so that the standard is complied with. Figure II.11 shows this representation for 106 Italian towns.

Circles refer to ΔT=0°C, crosses to ΔT=4.5°C and triangles to ΔT=8.5°C. Points within the curves marked in red mean that the free cooling system is able to comply with the limits. All towns except one (Lampedusa, which is an island in the middle of the Mediterranean sea) are within the limits, with ΔT=0°C. If a ΔT=4.5°C is considered, about half the towns require additional cooling systems, while considering ΔT=8.5°C most towns need them. The farther the point is from the curve, the larger is the additional cooling to be supplied with chillers.

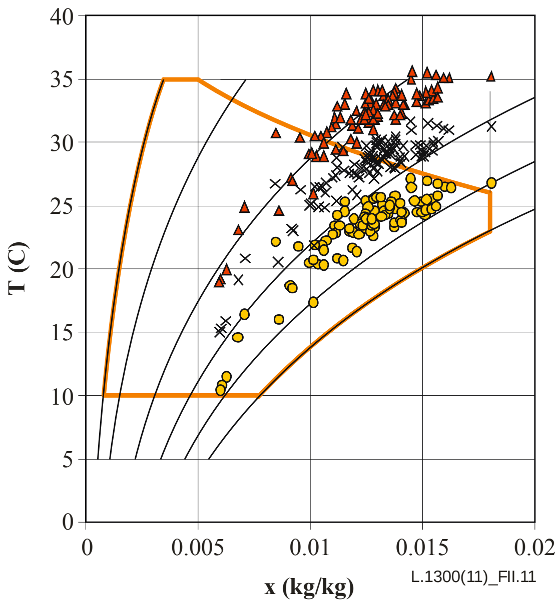


Figure II.11 – Italian towns on the modified ETSI diagram

Table 4 shows the energy savings obtained for the seven towns using the free cooling and the adiabatic free cooling systems as much as possible. Calculations have been performed, considering the goal of 90% of the points within the limits of allowed operating conditions. The cooling load Q is obtained as:

$$Q = Q_{en} - k \cdot V \cdot \sum_{i=1}^{365} (T_{room} - T_{ext})_i \cdot 24$$

where Q_{en} is the endogenous heat generation (a constant power of 45 kW is considered in calculations), k is the volumetric heat transfer coefficient (0.9·10-3 kW/(m^{3}K), V is the room volume, T_{room} is the daily average internal temperature and T_{ext} is the daily average ambient temperature. This model has been used with the intention of creating a simple reference for calculating the energy savings. While designing a specific system, a detailed analysis is required.

Primary energy consumptions and savings are calculated considering the average efficiency of power plants installed in Italy, (about 0.46). Energy saving is the same with ΔT=0°C and ΔT=4.5°C as only the free cooling system is used. This amount is larger for towns in the south part as the cooling load is larger. In the case of ΔT=8.5°C energy savings reduce for all towns except Turin, where the free cooling system is sufficient to comply with the standards. In the case of Catania for instance, a reduction of about 29 MWh occurs.

Table II.4 – Energy saving obtained with the free cooling + the adiabatic free cooling system

Town	Primary energy consumption with chillers (kWh)	Primary energy saving (kWh)		
		ΔT=0°C	ΔT=4.5°C	ΔT=8.5°C
Turin	174157	140942	140942	140942
Parma	175409	142195	142195	140889
Rome	177439	144224	144224	143241
Florence	176835	143620	143620	142925
Foggia	177655	144440	144440	120190
Olbia	178562	145347	145347	122389
Catania	178994	145779	145779	117027

Appendix III

Verification test and feasibility study of energy and space efficient cooling systems for data centres with high density ICT devices

(This appendix does not form an integral part of this Recommendation.)

III.1 Introduction

III.1.1 Background

In his speech to the General Assembly of the United Nations in September 2009, Prime Minister Hatoyama stated Japan's international pledge to reduce CO2 emissions by 25% of 1990 levels by the year 2020, as a mid-term target. As a contribution to this target, a "world-leading reduction in environmental impact" was also proposed for the "Haraguchi Vision". At the same time, there is no method for measuring the reduction in CO2 emissions within the internationally recognized field of ICT. With 2010 as the first target period, work on providing advice on methods of evaluating the effects of CO2 reductions commenced for ICT at the International Telecommunication Union (ITU), and international standardization for ICT on climate change has been strengthened.

Within the context of information and communications, the importance of data centres, which form the foundation of information and communications, has increased with the development of cloud computing and the rapid progress in ICT. Furthermore, in business activities as well, in terms of improving the efficiency of operations, rapid progress has been achieved in ICT, and the demand for data centres, the foundation of the ICT infrastructure, is growing rapidly. Data centres house large numbers of ICT devices (e.g., server storage network devices) for the processing and storage of a wide variety of data, and have air conditioning equipment to cool the interiors of the buildings. Accordingly, the consumption of power, in association with this rapid expansion of demand for data centres, is itself growing rapidly.

The proportion of power required by air conditioning equipment for such cooling is high in comparison with the power consumed by the ICT devices, and a reduction in the power consumption of data centres is a matter of considerable importance in improving the efficiency of air conditioning equipment, and in improving energy conservation. Furthermore, in Japan, the majority of data centres of telecommunication operators are located on sites in the suburbs of the capital and other large cities, and the construction of space-efficient data centres is therefore a matter of importance.

Equipment for the verification and testing of the various cooling methods used for data centres was therefore constructed, and cooling efficiency measured and verified. Energy consumed with the various cooling methods was calculated, usage of energy and space included, and a high-efficiency method of air conditioning determined.

III.1.2 Objective

Air conditioning used in data centres involves blowing chilled air from the server room floor to supply chilled air to the inlets of the server racks, and thus remove the heat generated by the ICT devices. This system is often referred to as 'floor supply air conditioning'. For data centres located in cold areas, power consumption for air conditioning can be reduced by using natural energy from exterior air and snow. This has considerable possibilities, and examples are in use, and planned, both in Japan and overseas.

On the other hand, in Japan, the majority of data centres of telecommunication operators are located on sites in the suburbs of the capital and other large cities, and efficient use of the limited space available at these sites, and the need for high energy efficiency data centre equipment is of clear importance.

In existing server rooms with high-load and high-density racks, air conditioning power consumption of various cooling methods was therefore tested and verified to investigate the optimum specifications and energy conservation benefits of air conditioning equipment in high power density data centres.

III.2 Outline of verification and testing

III.2.1 Experimental equipment

Figure III.1 shows an outline of the equipment employed in verification and testing. This testing was conducted at the Hitachi Plant Technologies Ltd, Matsudo Research Laboratories (Matsudo City, Chiba Prefecture), using a simulated server room and test air conditioning equipment.

The simulated server room contained simulated server equipment with built-in heaters, and was mounted on a free-access floor. The facilities comprised a cold aisle supplying chilled air from the air conditioning equipment, and a hot aisle facing the server rack exhaust.

Test air conditioning equipment comprised a floor supply air conditioner employing conventional air conditioning and outdoor air cooling, an evaporative cooling unit employing evaporative cooling, and a spot cooling unit employing spot cooling.

The test equipment comprised eight simulated servers generating 8 kW of heat per rack. The floor supply air conditioner had a cooling capacity of 64 kW for an airflow of 20 000 m^3/hr, and the evaporative cooling unit had a cooling capacity of 32 kW for an airflow of 10 000 m^3/hr. One of each was installed. Four spot cooling units, each with a cooling capacity of 15 kW/unit, were also installed.

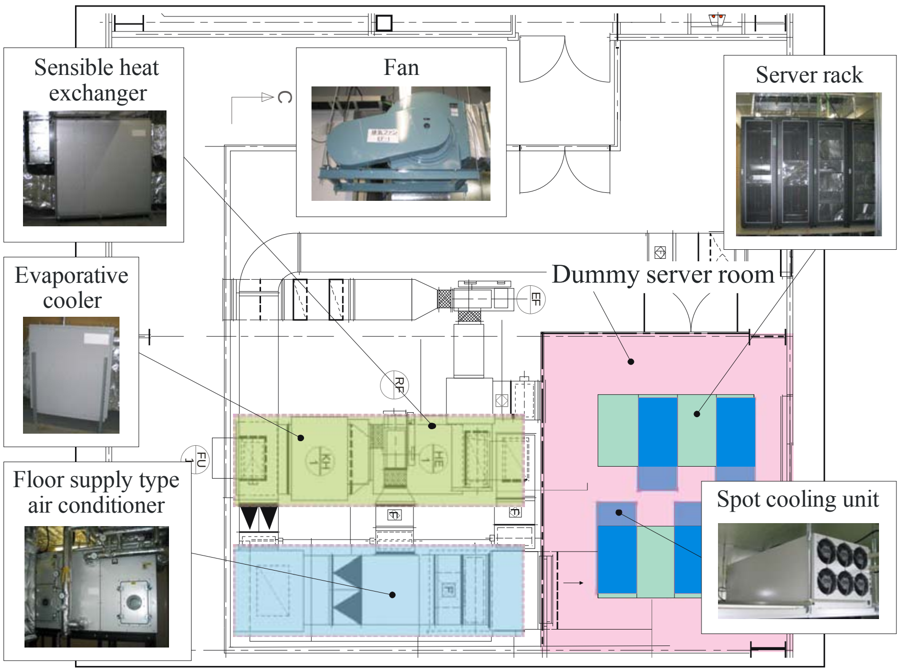


Figure III.1 – Outline of a verification test facility

The typical floor supply air conditioning method was of the under-floor type in which cooling is achieved by supplying cooled air from multiple floor outlets. Hot interior air discharged from the hot aisle into the interior upper airspace is drawn from the top of the floor supply air conditioning equipment, dehumidified and cooled to the specified temperature with chilled water inside the air conditioning equipment, and supplied to an under-floor chamber. During testing, the temperature of the air supplied from the floor supply air conditioning equipment was maintained at 18°C ±2°C.

Outdoor air cooling employs a floor supply air conditioner supplying cold air to the room, outdoor air ducts passing outdoor air to the air conditioner, and an exhaust fan discharging this air to the outside. As with conventional air conditioning, this method cools by supplying air conditioned air from multiple perforated tiles on the floor in the room. When the temperature of the outdoor air is low, it is passed to an air conditioner, mixed with high-temperature return air from the room, cooled and the humidity is adjusted as necessary, and supplied to the under-floor chamber. During testing, the temperature of the air supplied from the floor supply air conditioning equipment was maintained at 18°C ±2°C.

In addition to floor supply air conditioning equipment which supplies cold air to the room, the evaporative cooling methods employs an evaporative cooling unit comprised of an evaporative cooler and direct sensible heat exchanger, an external fan to pass exterior air over the unit, and a circulating fan to circulate return air. This interior return air is cooled by humidified outdoor air that is cooled by humidification using an evaporative cooling unit, mixed directly with air circulated internally, and introduced into the air conditioning equipment. Chilled water is then used to dehumidify and cool the air to the specified temperature via cooling coils within the air conditioning equipment, and the air is then supplied to the room via the under-floor chamber. During testing, the temperature of the air supplied from the floor supply air conditioning equipment was maintained at 18°C ±2°C.

In addition to floor supply air conditioning equipment to supply chilled air to the room, the spot cooling method employs a spot cooling unit using the natural circulation of a refrigerant for heat transport, and a water-cooled condenser to condense the refrigerant evaporated in the spot cooling unit. The spot cooling unit using the natural circulation of a refrigerant is installed between the server racks and the ceiling, and draws in the hot return air discharged from the hot aisle into the space below the ceiling, evaporating the refrigerant in the cooling coils in the cooling unit, and cooling the return air to the specified temperature, and supplying it to the cold aisle. The refrigerant evaporated in the cooling coils employs the natural circulation of the refrigerant occurring with the difference in density at the vapour-liquid interface. Heat is transported outside the room by circulating the refrigerant through the water-cooled condenser. During testing, the temperature of air supplied to the floor supply air conditioning equipment was maintained at 18°C ±2°C, and the temperature of the air from the spot cooling unit was maintained at 23°C ±2°C. Testing was also conducted using only spot cooling, without floor supply air conditioning equipment.

Figure III.2 shows an outline of measurement in verification and testing. Sensors to measure a range of data were installed in the test room, and in the vicinity of the air conditioning equipment. The data was recorded with a data logger.

In order to evaluate the air conditioning efficiency of each type of air conditioning equipment, this testing measured power consumption not only of IT devices, but also of floor supply air conditioning equipment, refrigerators, chilled water pumps, blowers used in evaporative cooling systems, and spot cooling units. Furthermore, chilled water return temperature, temperature of the return air from the floor supply air conditioner, evaporative cooling unit return air temperature, outdoor air temperature and humidity, chilled water flow, and supply and discharge water flows, were also measured.

Furthermore, in order to evaluate the interior temperature and thermal environment, inlet and discharge temperature for the server racks, air conditioning equipment supply and discharge temperatures, and spot cooling unit supply and discharge temperatures, were measured with temperature and humidity sensors. This data was measured continuously at intervals of five minutes or less.

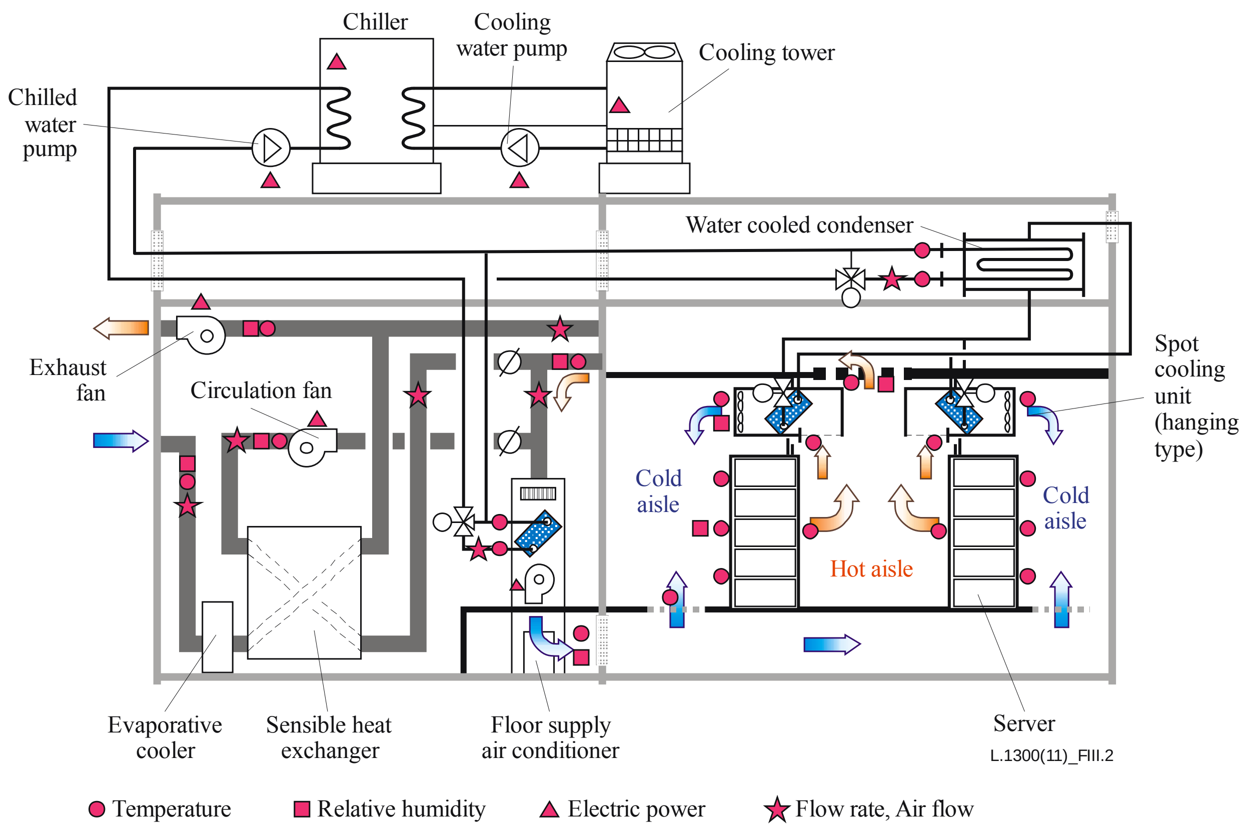


Figure III.2 – Outline of measurement points

III.2.2 Points investigated

The following investigations of air conditioning energy efficiency were conducted for each air conditioning method to evaluate the characteristics and energy conservation properties of each.

(1) Cooling characteristics of outdoor air cooling

(2) Cooling characteristics of evaporative cooling

(3) Cooling characteristics of spot cooling

(4) Air conditioning methods and power consumption

To evaluate space efficiency and air conditioning efficiency when applied to an actual data centre, a data centre with 500 server racks was assumed when developing the basic equipment plan and calculating annual power consumption.

III.3 Verification testing and results

III.3.1 Cooling characteristics of outdoor air cooling

Figure III.3 shows an example of trends in server rack intake temperature and air conditioner supply temperature under the average outdoor air conditions (outdoor air enthalpy approximately 13 kJ/kg) for Tokyo in January. It shows data measured at 64 kW (load ratio 100%) of heat generated by the ICT equipment with outdoor air cooling.

With combined outdoor air cooling and conventional air conditioning, low-temperature outdoor air is mixed with room return air, the mixture humidified to the specified humidity with the evaporative humidifier in the air conditioner, its temperature adjusted to the required supply temperature, and then supplied to the room. The air conditioner supply temperature status is controlled to a stable 18°C ±0.5°C. Furthermore, the maximum server rack inlet temperature was verified to be approximately 20°C to maintain a similar environment to that of typical air conditioning.

Air conditioning method	: Outdoor air cooling method
ICT device utilization rate	: 100%
Outdoor air enthalpy	: 13.12 kJ/kg
Outdoor air flow rate	: 7400 m^3/h
AHU supply air flow rate	: 19300 m^3/h
AHU supply air temperature set value	: 18°C

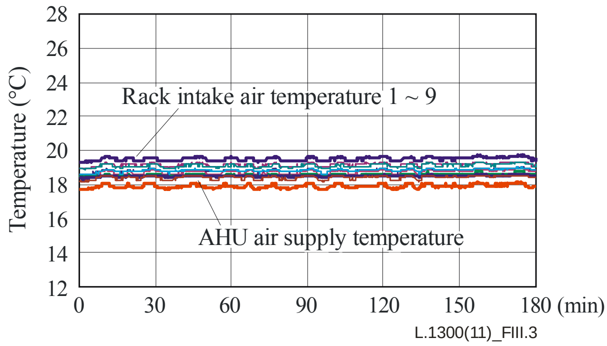


Figure III.3 – Example of air conditioning in an outdoor air cooling system

Figure III.4 shows outdoor air enthalpy and power consumption (single chilling system, chilling system, transport). When outdoor air enthalpy is increased, the amount of outdoor air required to handle the heat generated in the room increases. This is apparent in the trend towards increased transport power with increased outdoor air enthalpy. With this method, exhaust fans are installed to discharge the same amount of room air to the outside. In comparison with conventional air conditioning, power consumption of distribution equipment increases, however power consumption of a chilling system can be halted completely, thus saving large amounts of energy. Testing showed that, under the average outdoor air conditions prevailing in Tokyo in January (temperature 7.0°C, relative humidity 41%, enthalpy 13 kJ/kg), a 47% reduction in air conditioning power consumption is possible in comparison with conventional air conditioning.

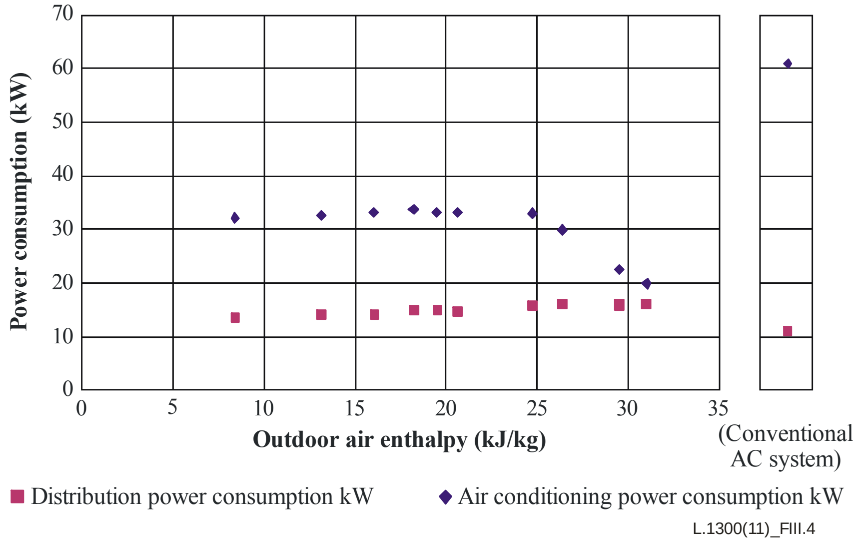


Figure III.4 – Outdoor air enthalpy and distribution power consumption

III.3.2 Cooling characteristics of evaporative cooling

Figure III.5 shows an example of trends for inlet temperature of an evaporative-cooled server rack, and air conditioning air supply temperature under outdoor air conditions prevailing in Tokyo in January (outdoor air enthalpy 13 kJ/kg). The graphs show actual data recorded for a combination of evaporative cooling and typical air conditioning, with 64 kW of heat generated by ICT devices.

Air conditioning method	: evaporative cooling + typical air conditioning
ICT equipment utilization	: 100%
Exterior air enthalpy	: 12.68 kJ/kg
Exterior air flow	: 9500 m^3/h

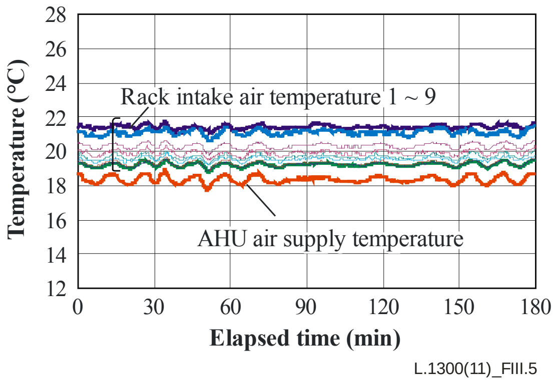


Figure III.5 – Evaporative cooling operational state (example)

With the combination of evaporative cooling and typical air conditioning, air was cooled with exterior air, and further cooled to the necessary supply temperature with air conditioning equipment before its supply to the room. Temperature was controlled in a stable manner during testing, and the supply temperature was maintained at 18°C ±2°C. Furthermore, maximum server rack inlet temperature was verified to be approximately 22°C to maintain a similar environment to that of typical air conditioning.

Figure III.6 shows outdoor air enthalpy and heat processed. It was confirmed that cooling performance improves as outdoor air enthalpy decreases, with cooling performance able to handle 38 kW, or approximately 60% of indoor heat generated, at outdoor air enthalpy of around 13 kJ/kg under average outdoor air conditions in Tokyo in January (temperature 7.0°C, relative humidity 41%).

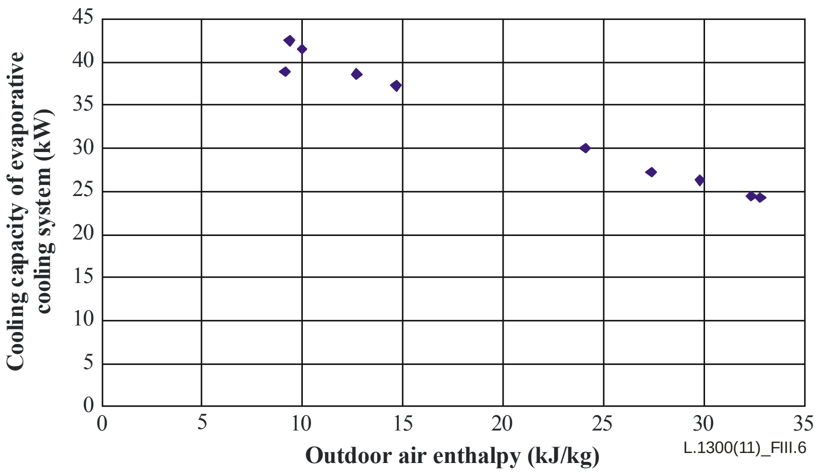


Figure III.6 – Outdoor air enthalpy and cooling capacity of evaporative cooling system

III.3.3 Cooling characteristics of spot cooling

Figure III.7 shows trends in server rack inlet temperature and air conditioning equipment temperature when using the spot cooling method. A combination of spot cooling and typical air conditioning was employed, with 64 kW of heat (100% load) generated by the ICT devices. With the combination of spot cooling and typical air conditioning, it was verified that the air supplied by the spot cooling unit was able to be maintained at a maximum stable temperature of 23°C ±0.5°C, and rack inlet temperature was able to be maintained at a maximum of 22°C, approximately the temperature obtained with typical air conditioning.

Air conditioning method	: spot cooling + typical air conditioning
Typical air conditioning	: 100%
Air conditionning air flow	: 10592 m^3/h

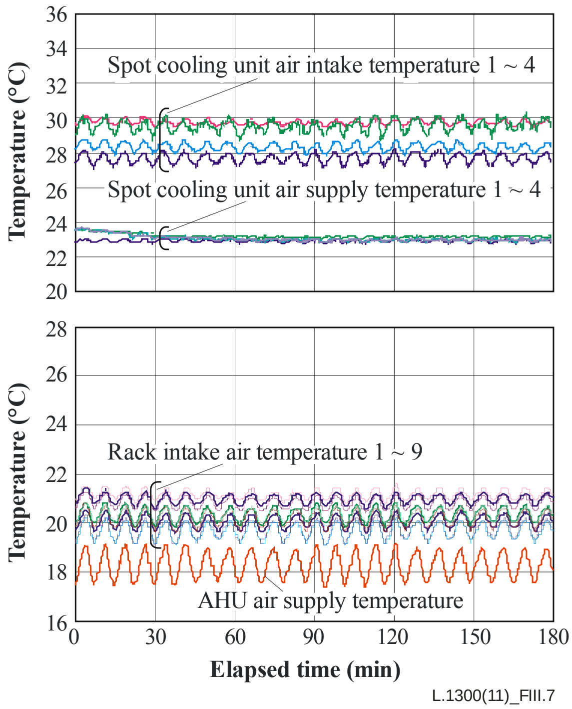


Figure III.7 – Spot cooling method operational state (example)

Figure III.8 shows the intake air temperature and spot cooling unit cooling performance. With the spot cooling unit, supply air was maintained at a constant temperature and, as intake air temperature increased, cooling performance increased, until at an intake temperature of 40°C, a cooling performance of 15 kW/unit was achieved.

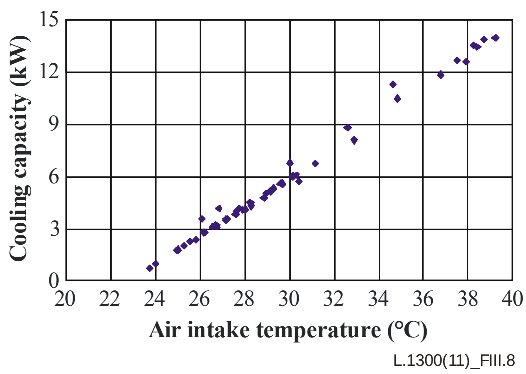


Figure III.8 – Air intake temperature and cooling performance

III.3.4 Comparison of the cooling performance of various air conditioning methods

Figure III.9 shows power consumption (single chilling system, chilling system, transport). While spot cooling consumes nearly the same chilling system power as the chilling system power in a conventional air conditioning system, no chilling system power was required for outdoor air cooling at 13 kJ/kg outdoor air enthalpy under average outdoor air conditions in January in Tokyo. It was also found that, with evaporative cooling, chilling system power could be reduced by 50% at 13 kJ/kg outdoor air enthalpy under average outdoor air conditions in January in Tokyo, and major reductions in chilling system power could be achieved by effectively exploiting outdoor air heat with outdoor air cooling and evaporative cooling.

Meanwhile, with outdoor air cooling, exhaust fan power increases with the introduction of outdoor air, increasing the distribution power by 25% over the distribution power in a conventional air conditioning system. In addition, blower power increased in an evaporative cooling system since outdoor air is indirectly used, increasing distribution power by 97%. On the other hand, with spot cooling, heat generated by the server devices can be handled by air circulation in the vicinity of the server racks, and thus the power required for air transport is much reduced. If all heat is handled with direct air conditioning, power required for transport can be reduced by 75% or more.

Testing showed that reductions of 46%, 5%, and 15% in total air conditioning power consumption, compared with the conventional air conditioning system, could be achieved with outdoor air cooling, evaporative cooling, and spot cooling systems respectively.

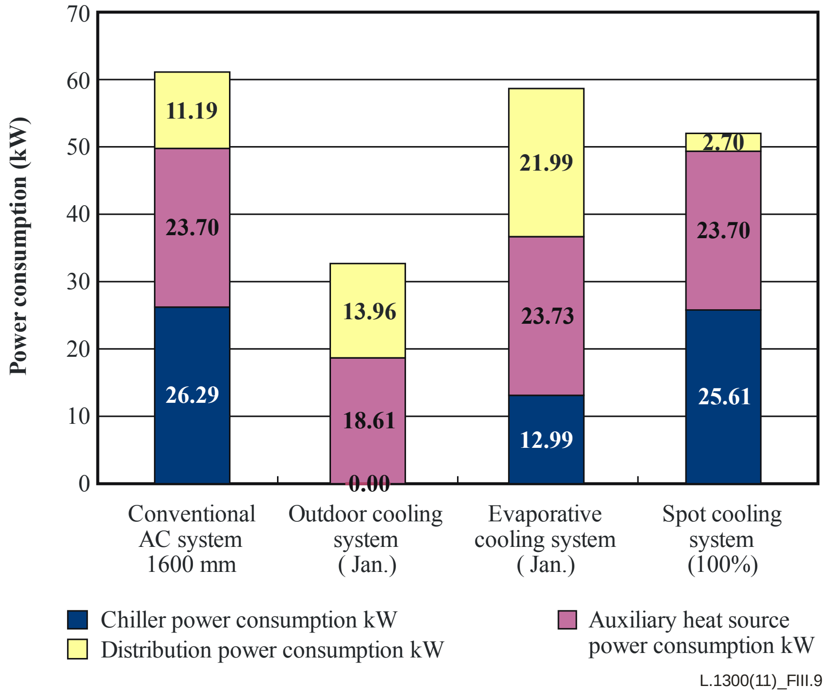


Figure III.9 – Comparison of power consumption

III.4 Trial calculations of energy conservation benefits in application to a full-scale data centre

III.4.1 Trial calculation model

Figure III.10 shows an outline of the trial calculation model, and trial calculation conditions. The trial calculation assumes a data centre comprised of 500 server racks, installed on two floors, with server racks spaced 1 600 mm apart.

Trial calculations covered air conditioner layout, air conditioning equipment room space, and annual power consumption for conventional air conditioning, as well as for outdoor air cooling, evaporative cooling (evaporative cooling and air conditioner, each handling 50% of the heat), and spot cooling. Calculations assumed all chilling systems as shared, and an air-cooled chiller with primary and secondary pump systems.

Calculations were made while varying the amount of heat generated by the server rack between 3 kW and 12 kW in order to evaluate the correlation between server room power density (power consumption by ICT equipment per unit floor space is same as heat generated by ICT equipment per unit floor space) and dedicated air conditioning area. In order to determine the effect on air conditioning power consumption in outdoor air wet-bulb temperature conditions, air conditioning power consumption was calculated in increments of 1°C between –10°C and 30°C for outdoor air wet-bulb temperature, and annual power consumption calculated for six representative cities (Tokyo, London, Singapore, Los Angeles, Dubai, and Moscow).

Outdoor air temperature and humidity data for 2010 was obtained from the NCDC National Climatic Data Centre) and used in the calculation of power consumption under the daily average representative air temperature and humidity conditions. Annual power consumption was calculated assuming a server load ratio of 100%.

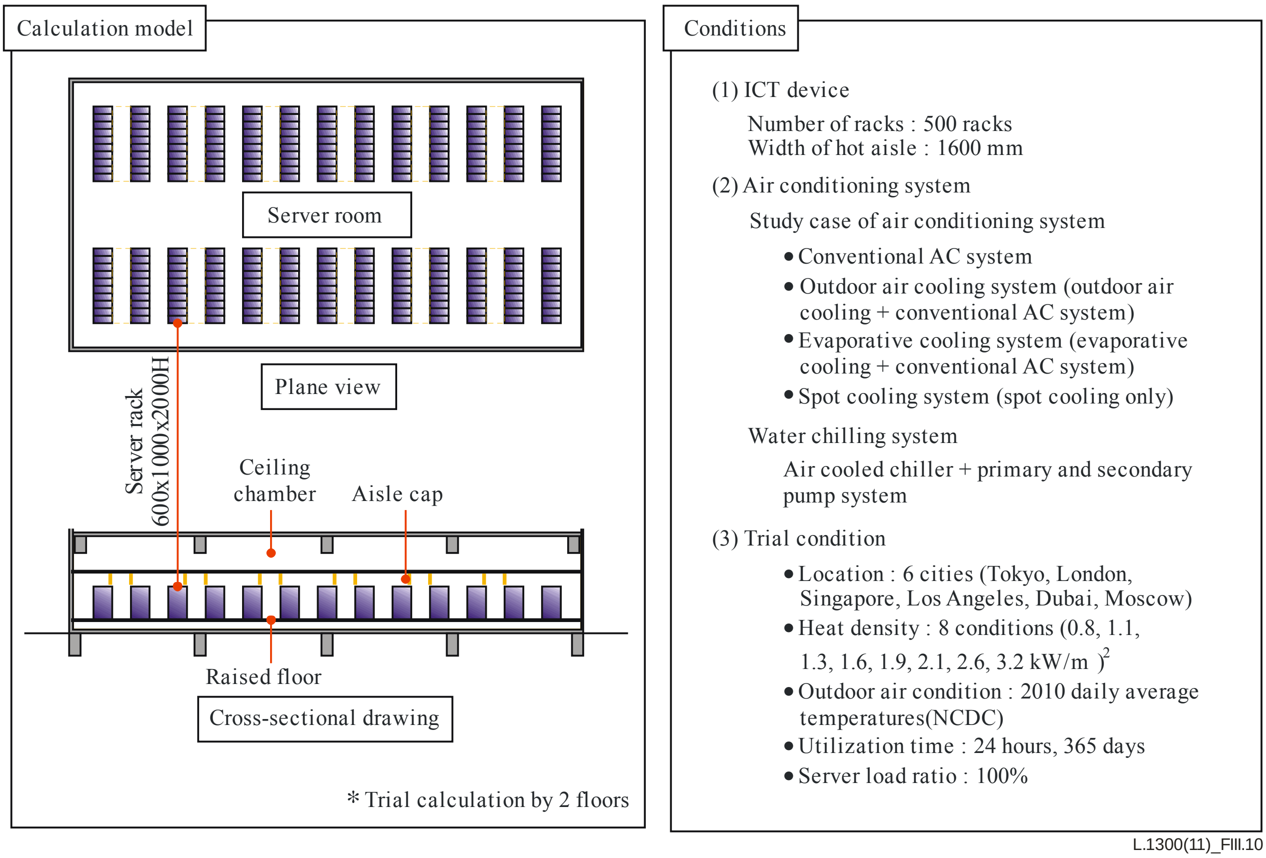


Figure III.10 – Calculation model and condition

III.4.2 Trial calculation method

III.4.2.1 Typical air conditioning method

An air conditioner was comprised of cooling coils, a humidifier, and a blower. The air conditioner controlled the flow of chilled water to ensure that the air supplied reached the specified temperature. The humidifier was assumed to be controlled so that humidity reached the specified value.

Static pressure for the air conditioner fan was set at 450 Pa, fan efficiency at 60%, and air temperature at 18°C, and chilled water flow was controlled with a two-way valve.

III.4.2.2 Outdoor air cooling method

An air conditioner for outdoor air cooling comprises a cooler coil, as well as an evaporative humidifier, electrical heater for heating, and a blower.

During the outdoor air cooling operation, a mixture of outdoor air and indoor return air is humidified by the evaporative humidifier, reducing its temperature adjusting its humidity to a specified value, then, after adjusting its temperature as needed with the electric heater, the air-conditioned air is supplied to the indoor space.

The chilling equipment was an air-cooled chiller, the air conditioner fan was set to a static pressure of 850 Pa, the fan was assumed to be running at 60% efficiency, and the evaporative humidifier was assumed to be running at 80% saturation efficiency. The exhaust fan was set to a static pressure of 300 Pa and was assumed to be running at 60% fan efficiency. In addition, the maximum outdoor air utilization during outdoor air cooling operation was set to one-half of the return air volume.

III.4.2.3 Evaporative cooling method

The air conditioner comprised cooling coils, a humidifier, and a blower. The evaporative cooling unit comprised an evaporative cooler, a sensible heat exchanger, a circulation fan, and an exhaust fan.

Static pressure for the air conditioner fan was set at 450 Pa, fan efficiency at 60%, circulation fan efficiency static pressure at 300 Pa, circulation fan efficiency at 60%, exhaust fan efficiency static pressure at 600 Pa, exhaust fan efficiency at 60%, and evaporative humidifier unit humidification efficiency at 80%. Chilled water flow was controlled with a two-way valve.

The volume of exterior air used by the evaporative cooling unit was half the air conditioning flow. The interior return air in this half of the air conditioning flow was cooled with exterior air and mixed with the remaining half of the return air for supply to the room. The rated cooling capacity for the evaporative cooling unit was equivalent to 50% of the interior heat load.

III.4.2.4 Spot cooling method

An air conditioner comprised of cooling coils, a humidifier, and a blower. The spot cooling system comprised a water-cooled condenser to condense the refrigerant and a spot cooling unit. The spot cooling method employed the natural circulation of the refrigerant. The flow of chilled water for the air conditioner was controlled to ensure that air was supplied to the room at the required temperature. The flow of refrigerant in the spot cooling unit is controlled to ensure that the temperature of the air supplied to the cold aisle reaches the specified value.

III.4.3 Power density and space efficiency

III.4.2.1 shows a comparison of power density and space efficiency by the air conditioning method. Power density is the amount of heat generated by the ICT equipment per m^2 of floor area. The greater this value, the greater the installed density of ICT equipment, ensuring a high density data centre. Space efficiency is the proportion of the total floor area occupied by ICT equipment. The greater this value, the more effectively the floor area is used for ICT equipment.

For conventional air-conditioning systems, the outdoor air cooling and evaporative cooling methods, the space efficiency is reduced as the power density is increased. This is because the required cooling capacity of the air-conditioning system increases as the power density increases, so the air conditioner size increases and the required area of the air conditioning equipment room increases. Also, the space efficiency is dramatically reduced when the power density exceeds 1.6 kW/m^2 for the outdoor air cooling method and 1.3 kW/m for the evaporative cooling method, reducing to less than 0.5. This is because in both methods, the air conditioner is installed on the wall side, but as the heat generation increases the cooling capacity of air conditioners on one wall side only becomes insufficient, and it becomes necessary to increase the space to install air conditioners on both wall sides.

On the other hand, with the spot cooling method, the space efficiency is virtually unaffected by increases in the power density. Even at high heat densities, the space efficiency is at a very high value of 0.95 or higher. Also, for all the heat densities calculated, the spot cooling system had the highest space efficiency. This is because the cooling unit that processes the heat generated from the ICT equipment is installed in the space above the server rack, so the floor area occupied by the cooling unit is virtually zero, and it is possible to greatly reduce the floor area required for installation of the air conditioners.

This investigation has shown that, particularly at high power densities, the area of the air conditioning equipment room as required with spot cooling is the smallest, and that space efficiency is high.

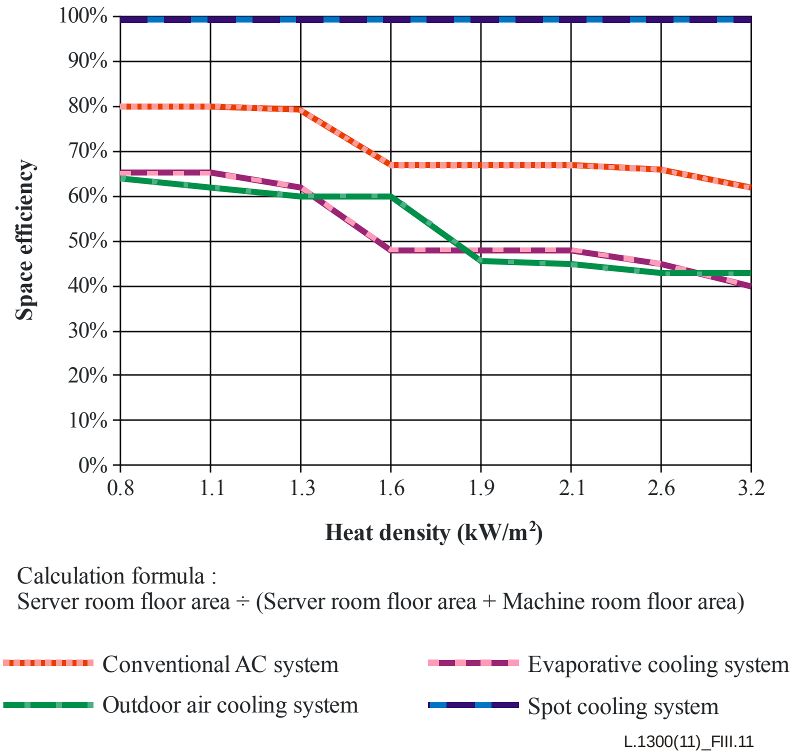


Figure III.11 – Heat density and space efficiency (location Tokyo)

III.4.4 Outdoor air conditions and air conditioning energy efficiency

Figure III.12 shows the results of the calculation of outdoor air wet-bulb temperature conditions and power consumption for conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling. This calculation shows the power consumption over a period of one hour at the required outdoor air wet-bulb temperature conditions.

When the outdoor air wet-bulb temperature is at −17C WB or less, the evaporative cooling method has the lowest electrical power consumption, and when the outdoor air wet-bulb temperature is between −17C WB and +15C WB, the outdoor air cooling method has the lowest electrical power consumption. This is because in these temperature ranges, outdoor air can be used for indoor cooling, so in both methods it is possible to greatly reduce the electrical power consumption. However, when the outdoor air wet-bulb temperature is greater than +15C WB, indoor cooling using outdoor air is not possible, and it has been found that the spot cooling method, which has a high reduction effect of transport power, has the lowest electrical power consumption.

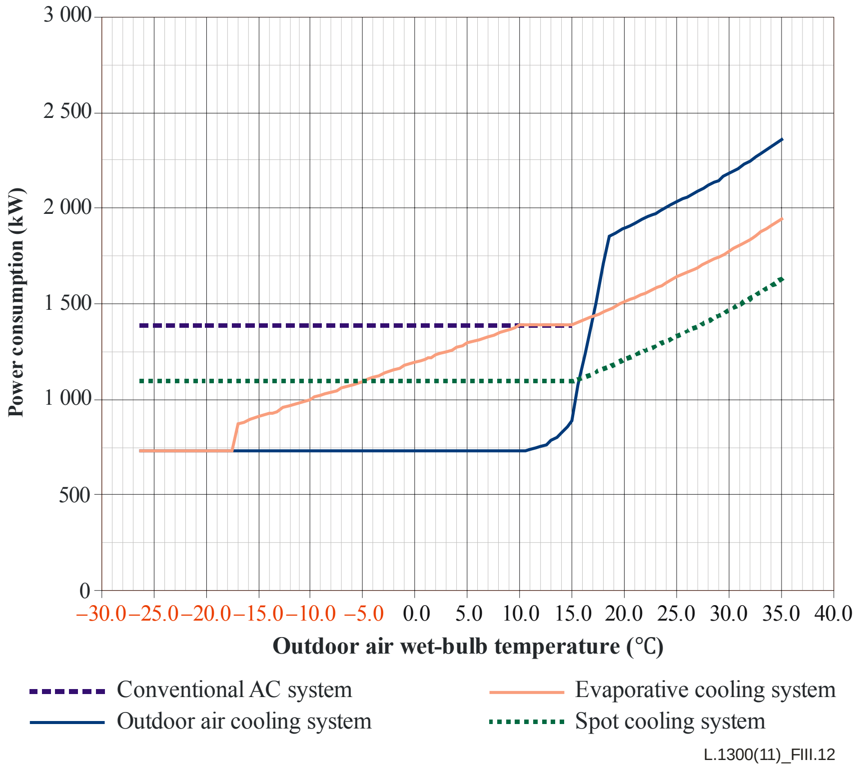


Figure III.12 – Comparison of power consumption with outdoor air conditions (Heat density 2 lkW/m²)

Figure III.13 shows the results of the calculation of outdoor air wet-bulb temperature conditions and energy efficiency for conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling. Energy efficiency indicates the amount of heat generated by the ICT equipment which can be handled with 1 kW of air conditioning power. The greater this value the greater the air conditioning energy efficiency.

When the outdoor air wet-bulb temperature is at −17C WB or less, the energy efficiency of the evaporative cooling method is highest at about 5.5, and when the outdoor air wet-bulb temperature was between −17C WB and +15C WB, the energy efficiency of the outdoor air cooling method is highest at 5.0. This is because in these temperature ranges, external air can be used for indoor cooling, so in both methods it is possible to greatly reduce the electrical power consumption. However, when the outdoor air wet-bulb temperature is greater than +15C WB, indoor cooling using external air is not possible, and the spot cooling method, which has a high reduction in transport power effect, has the highest energy efficiency. Also, when the outdoor air wet-bulb temperature is greater than +15C WB, it is found that the chilling system efficiency is reduced with the external air temperature, so the energy efficiency is reduced with an increase in wet-bulb temperature.

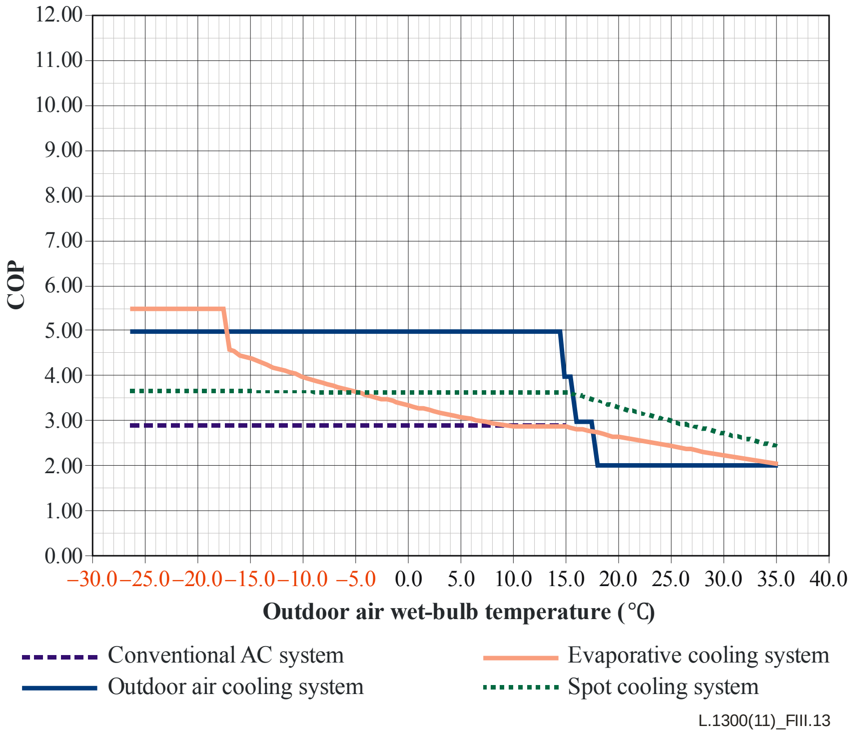


Figure III.13 – Comparison of COP with outdoor air conditions (Heat density 2 lkW/m²)

III.4.5 Annual air conditioning power consumption calculation results by city

Figure III.14 shows a comparison of the annual cooling load ratio in conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling.

With outdoor air cooling directly drawing in cold outdoor air, indoor air can be cooled with outdoor air even during the winter in Tokyo and the intermediate period. In comparison with conventional air conditioning, the amount of heat handled can therefore be reduced by 64%. Similarly, even with evaporative cooling using the direct cooling of cold outdoor air, indoor heat can be handled with exterior air cooling during the winter and the intermediate period. In comparison with conventional air conditioning, therefore, the amount of heat handled can be reduced by 13%.

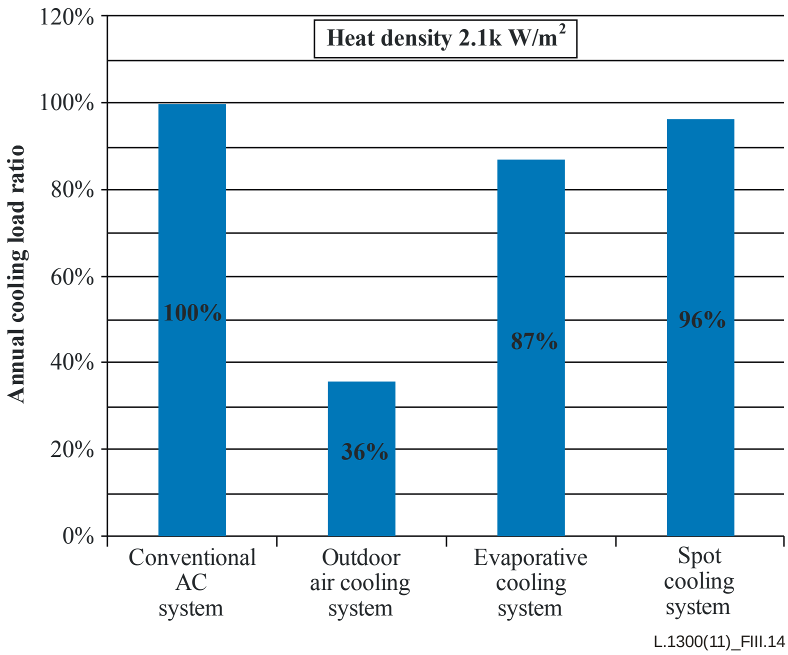


Figure III.14 – Comparison of annual cooling load ratio with air conditioning methods in Tokyo

Figure III.15 shows the results of the calculation of annual power consumption with conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling. With the evaporative cooling method, cooling with outdoor air reduces chilling system power consumption by 57% in comparison with conventional air conditioning. However, the increased power required for the exhaust fan increases transport power, and total air conditioning power consumption is therefore reduced by 15% in comparison with conventional air conditioning. With the evaporative cooling method, the use of cooling with exterior air reduces chilling system power consumption by 11% in comparison with the typical air conditioning method, however the increased power required for the blower to pass air through the evaporative cooling unit greatly increases transport power, and total air conditioning power consumption is therefore reduced by 2% in comparison with the typical air conditioning method.

With the spot cooling method, the use of the natural circulation of refrigerant, and the localized handling of heat with a spot cooling unit, reduced the power necessary for heat transport by 54% in comparison with conventional air conditioning. With this method, the reduction in transport power is considerable, and total air conditioning power consumption can be reduced by 22%.

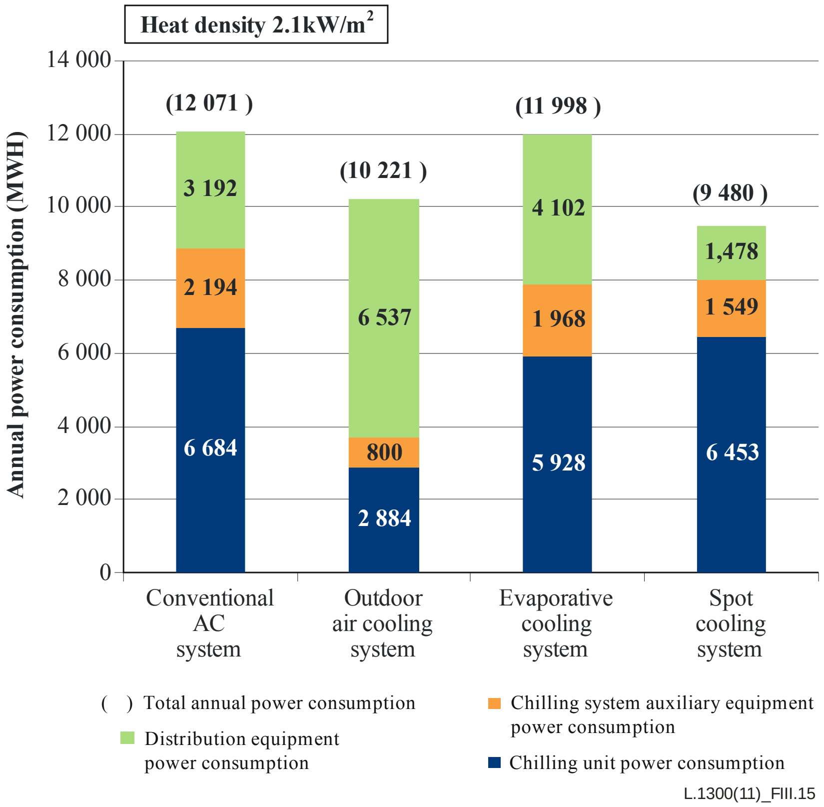
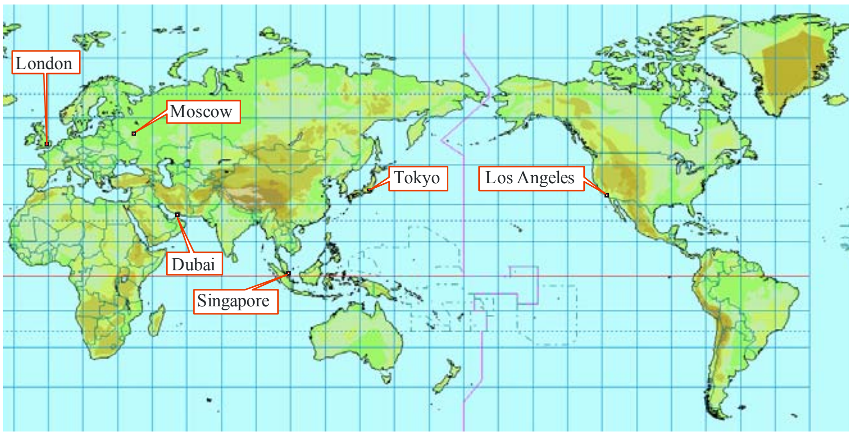


Figure III.15 – Comparison of annual power consumption with air conditioning methods in Tokyo

Figure III.17 shows the amount of heat handled in six cities with conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling. A comparison of the chilling system handling load for each city and each system is shown with the chilling system handling load by a conventional air conditioning system in Tokyo as 100.

It was considered that it would be impossible for outdoor air cooling systems and evaporative cooling systems (which utilize chilled outdoor air), to use the outdoor air in places like Dubai and Singapore, etc., which are in the tropical zone, where air temperature and humidity are high year-round. The decrease in chilling system handling loads due to evaporative cooling, which directly uses outdoor air, was found to be considerably broader in outdoor air cooling systems, where the chilling system handling loads in temperate and frigid locations were decreased by 64% in Tokyo, 82% in Moscow, and 98% in London.

Location



Outdoor air temperature

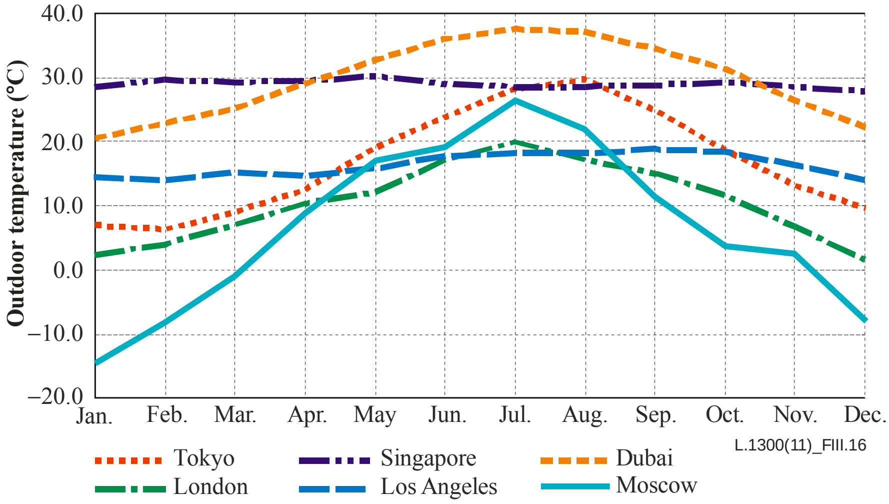


Figure III.16 – Calculation of location and outdoor air temperature

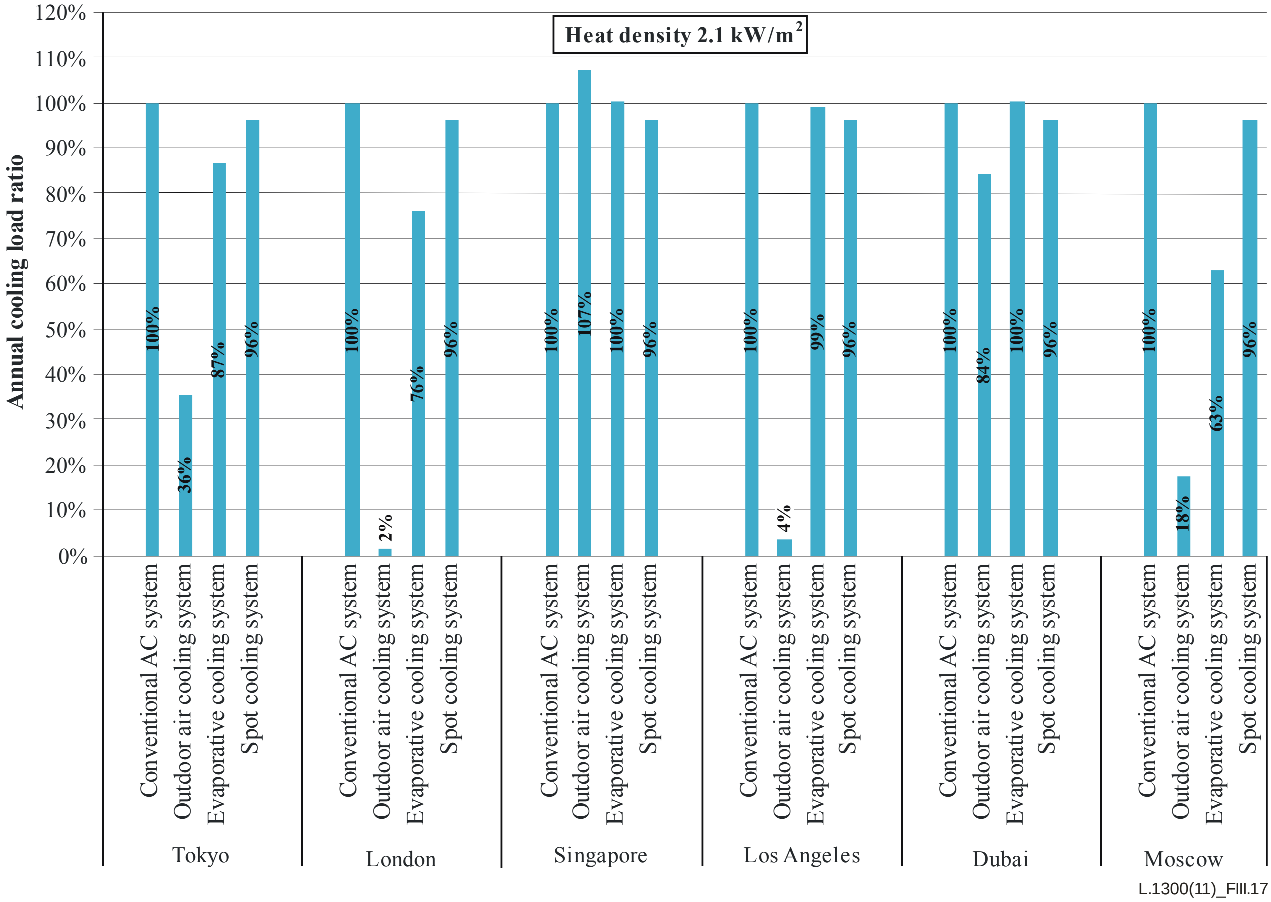


Figure III.17 – Comparison of calculating results of annual cooling load ratio with air condition methods in six cities

Figure III.18 shows the results of the calculation of annual power consumption for six cities with conventional air conditioning, outdoor air cooling, evaporative cooling, and spot cooling.

Results showed increased power consumption with outdoor air cooling systems and evaporative cooling systems, by chilling outdoor air, in tropical cities such as Dubai and Singapore, where air temperature and humidity are high throughout the year, and outdoor air cannot be used. On the other hand, chilling system power was greatly reduced by effective use of outdoor air with outdoor air cooling in temperate and cold regions, with a reduction in chilling system power of approximately 57% in Tokyo, 78% in Moscow, and 98% in London. However, with nearly double the transport power over conventional air conditioning due to increased air conditioner resistance and the installation of exhaust fans, the reduction in total conditioning power consumption was 28% in Moscow, and 39% in London.

Chilling system power was also reduced with the evaporative cooling system by effective use of outdoor air, and while energy conservation was slightly inferior to that with outdoor air cooling, since only indirect heat exchange is used, the reduction in chilling system power consumption was 35% for a cold location like Moscow and 23% in London. However, since the transport power of the ventilation fan in evaporative cooling units is greater than with conventional air conditioning, the reduction in total air conditioning power consumption was 3% in London, and 8% in Moscow.

With spot cooling, the use of the natural circulation of refrigerant, and the localized handling of heat with a spot cooling unit, reduced the transport power necessary for heat transport dramatically in comparison with conventional air conditioning, and power consumption was able to be reduced to a stable level without being affected by outdoor air conditions. With this method, considerable benefits were obtained through reduction of transport power, even where outdoor air is not effective (e.g., temperate regions). Reductions of 22% were obtained in tropical Singapore, 21% in London, and 22% in Moscow.

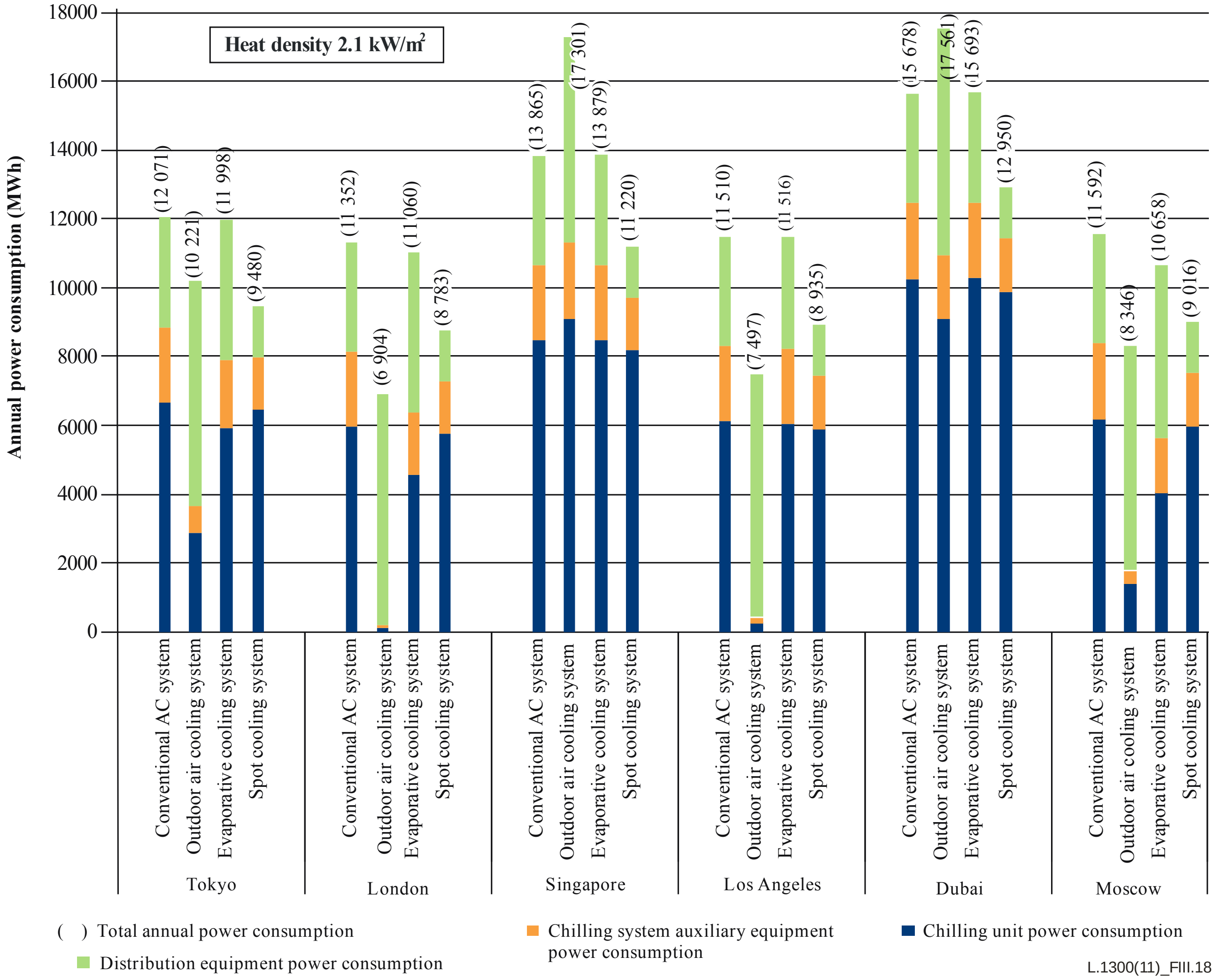


Figure III.18 – Comparison of annual power consumption with air conditioning methods in six cities

In this test, it was found that the reduction in power consumption compared with the conventional air conditioning system could be realized with outdoor air cooling, evaporative cooling, and spot cooling.

With outdoor air cooling, benefits were demonstrated in cold regions with low outdoor temperatures, with the greatest energy conservation effects being achieved in London, Los Angeles, and Moscow.

Additionally, with spot cooling, energy conservation benefits were demonstrated irrespective of the region, and were greatest in Tokyo, Singapore, and Dubai.

Appendix IV

Experimental studies on plates and ducts installed at equipment inlets and outlets

(This appendix does not form an integral part of this Recommendation.)

IV.1 Problem description of practical solutions for correcting airflow direction for equipment

This appendix describes examples of practical solutions for airflow correction. It will enable the recognition of the practical solutions to be taken for equipment in which airflow correction is necessary.

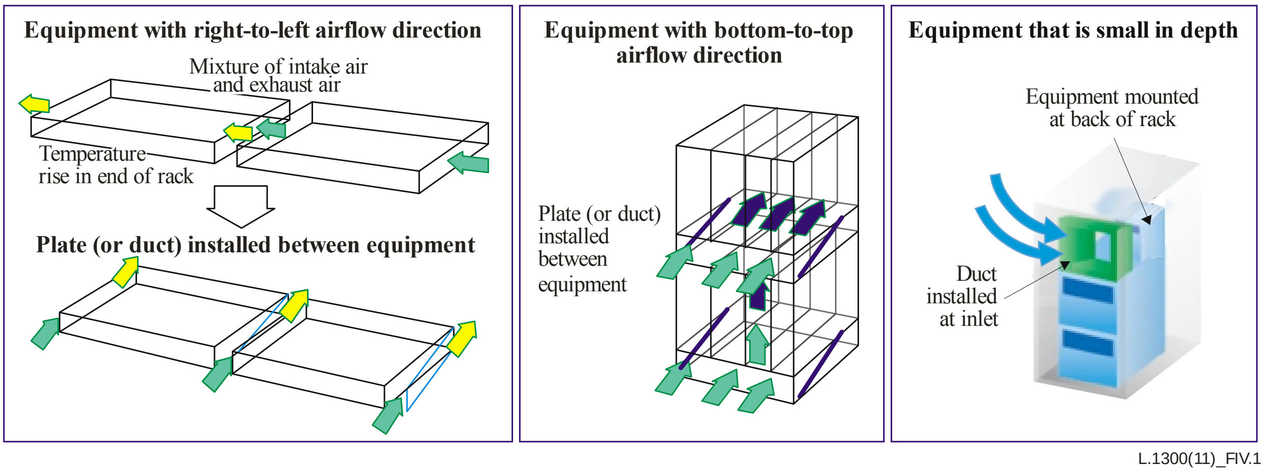


Figure IV.1 – Examples of types of rack mount equipment in which airflow correction is necessary

IV.2 Examples of practical solutions

The installation of a plate or duct at the inlet and outlet of the equipment is a practical solution to correct the airflow direction of the equipment.

An example of ducts installed in equipment with bottom-to-top airflow direction is shown in Figure IV.1. Installation of such ducts corrects the airflow direction to front-to-rear and separates the intake air and the exhaust air. Such separation prevents the equipment from sucking in the exhaust air of adjacent equipment and prevents increases in its temperature. Experimental studies on plates and ducts installed at the inlets and outlets of equipment with bottom-to-top airflow direction and with right-to-left airflow direction are shown below.

An example of a duct installed at the inlet of equipment that is small in depth is shown in Figures IV.2 and IV.3. Such a duct directs the cold air in front of the rack to the inlet of the equipment and enables cold air to be supplied to the equipment sufficiently.

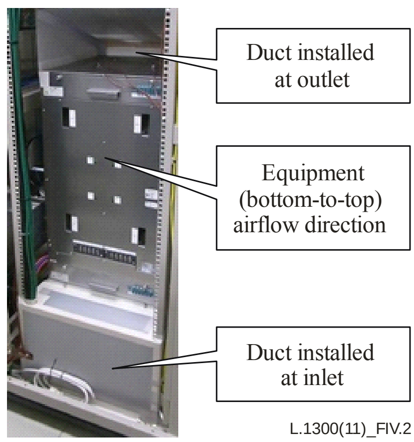


Figure IV.2 – Example of duct installation in equipment with bottom-to-top airflow direction

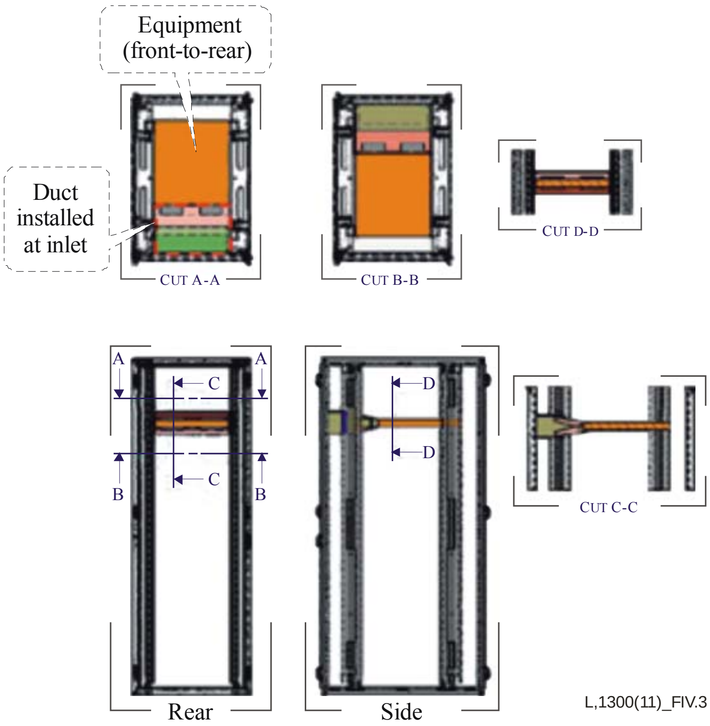
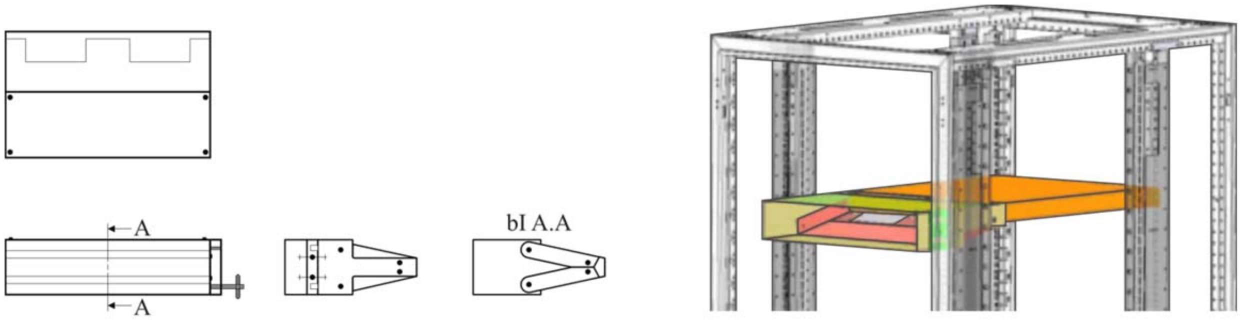


Figure IV.3 – Example of duct installation in equipment that is small in depth

An example of the description in an installation manual is shown in Figure IV.4.



Design of the duct (left) and image of duct installation to the equipment (right)

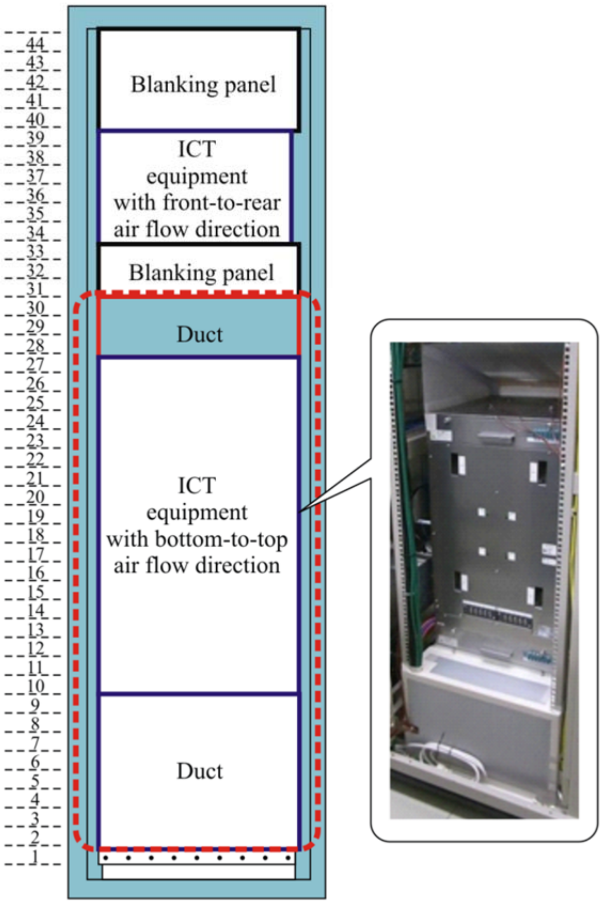


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Image of equipment mounted on the rack (left) and of duct installation attached to the equipment (right)

Figure IV.4 – Example of a description given in an installation manual

IV.3 Experimental result

The purpose of the experimental studies was to evaluate the effectiveness of the plates and ducts installed at the inlets and outlets of equipment with different airflow direction from the data centre airflow design.

IV.3.1 Outline of experiment

The layout of the experiment room, and equipment used for the experiment are illustrated in Figures IV.5 and IV.6 respectively. Four types of equipment and power distribution units (PDUs) were mounted on two open racks. A plate or a duct were installed at the inlet and the outlet of two types of rack mount equipment, whose airflow direction was bottom-to-top (Type BT) and right-to-left (Type RL).

The temperature was measured at 100, 500, 1 000, 1 500, and 2 100 mm above floor level, at the front and the rear of the rack. It was also measured inside the raised floor, at the inlet and the outlet of the adjacent equipment. The room temperature setting and the outlet temperature setting of the computer room air conditioning (CRAC) were 24 and 19°C, respectively. The CRAC was set to keep the air supply temperature constant and to operate in variable air volume (VAV) mode.

The figure on the left in Figure IV.7 depicts the airflow in Rack 1. Equipment Type RL, mounted in Rack 1, sucks in the exhaust air from equipment Type BT, mounted under equipment Type RL, and from equipment Type RL, mounted in Rack 2. This causes an increase in the temperature of the intake air of equipment Type RL in Rack 1.

As a measure to avoid this phenomenon, the following three cases were investigated, as shown in the figure on the right, in Figure IV.7.

(1) Install a duct at the outlet of equipment Type BT mounted in Rack 1.

(2) Install a duct at the inlet of equipment Type BT mounted in Rack 1, in addition to (1).

(3) Install a plate at the inlet and the outlet of equipment Type RL mounted in Racks 1 and 2, in addition to (1) and (2).

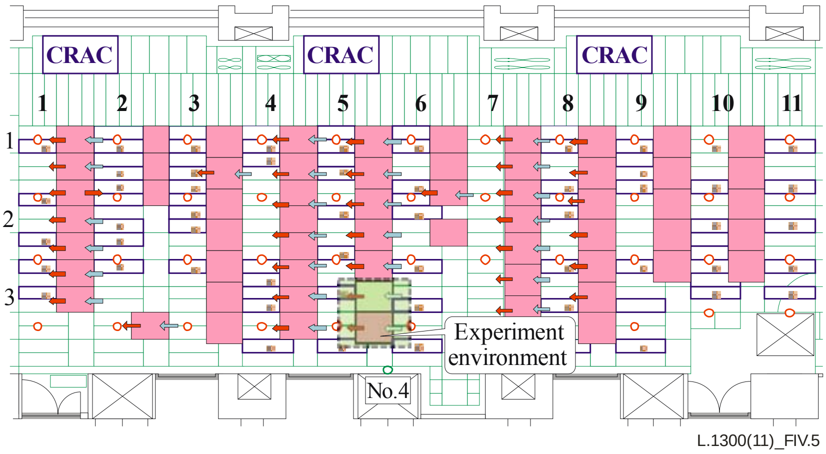

Figure IV.5 – Layout of experiment room

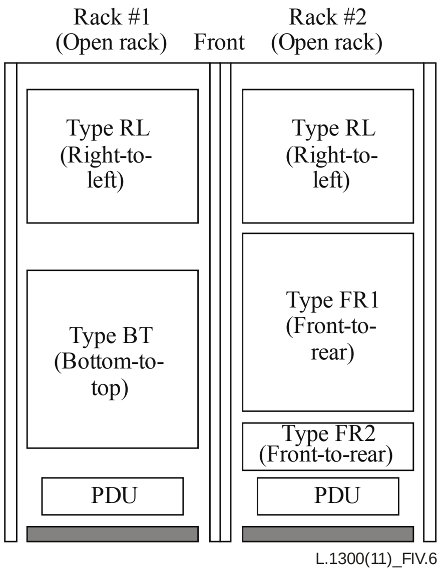

Figure IV.6 – Experiment environment

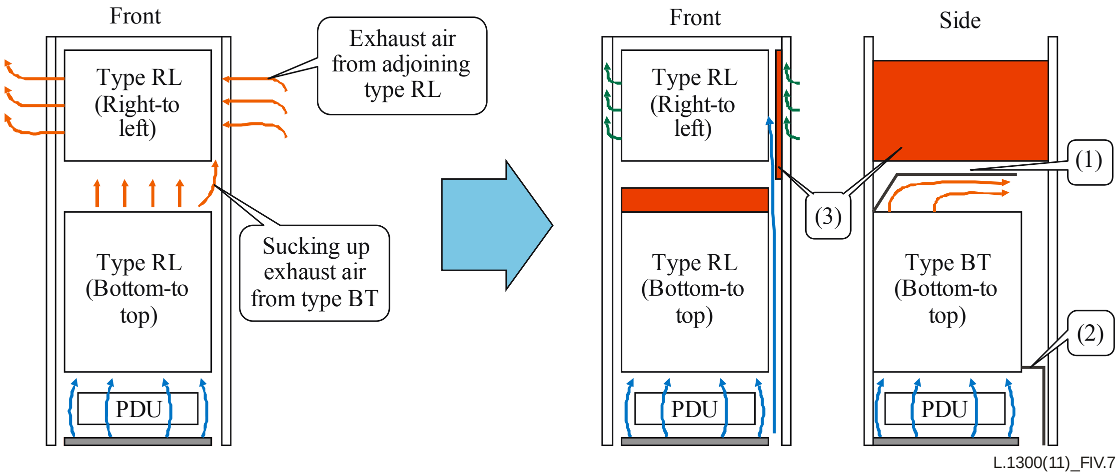

Figure IV.7 – Cases investigated

IV.3.2 Results

(1) Figure IV.8 reports the results obtained by installing a duct at the outlet of equipment Type BT mounted on Rack 1.

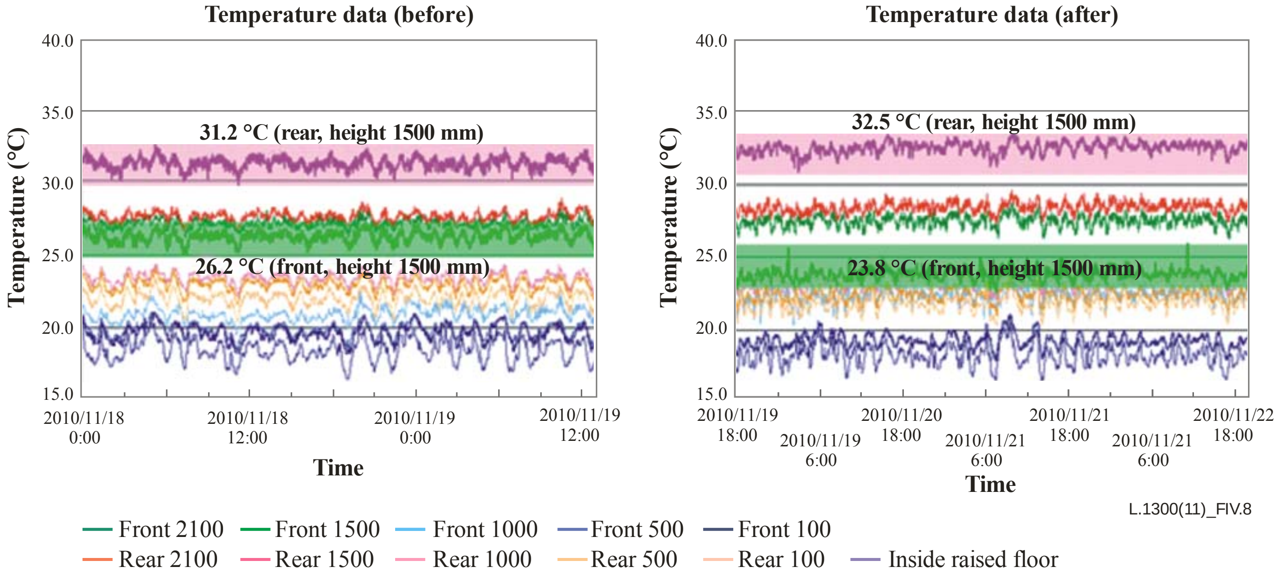

Figure IV.8 – Results of Rack 1 after installing a duct at the outlet

Temperature decrease was observed at 1500 mm above floor level at the front of the rack (26.2°C→23.8°C). This shows that the duct prevented the exhaust air from circulating to the front of the rack.

Temperature increase was observed at 1500 mm above floor level at the rear of the rack (31.2°C→32.5°C). This shows that the duct led the exhaust air to the rear of the rack.

(2) Figure IV.9 reports the result obtained by installing a duct at the inlet of the equipment Type BT mounted in Rack 1, in addition to (1).

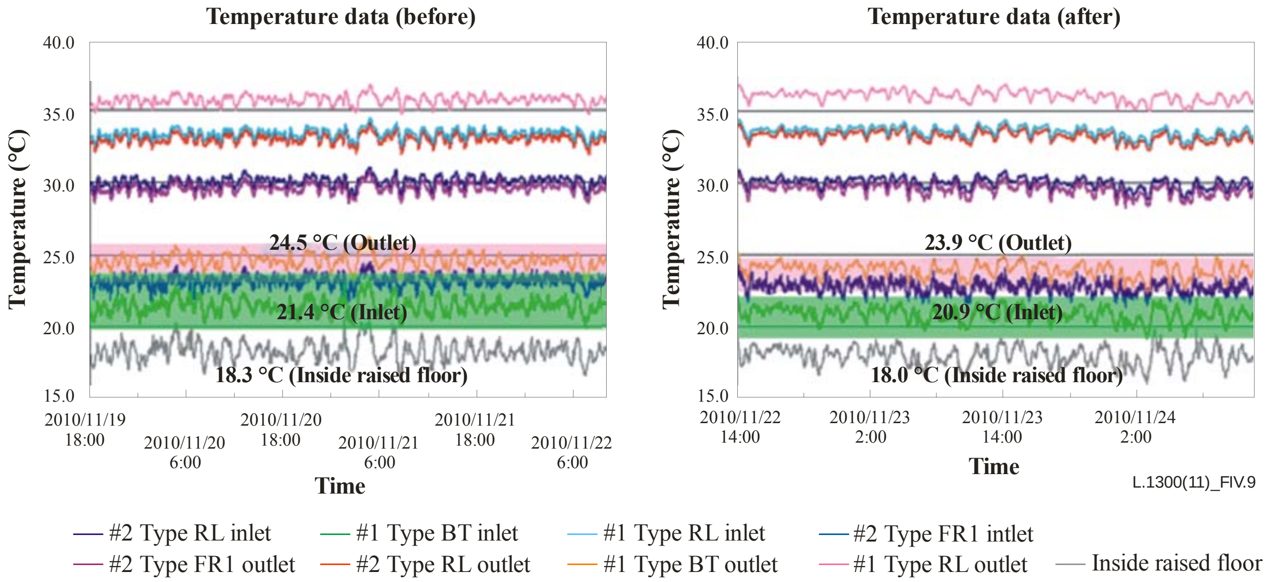

Figure IV.9 – Results of Rack 1 after installing a duct at the outlet and at the inlet

A marked difference in the inlet and the outlet temperature of equipment Type BT was not observed, but the difference from the temperature inside the raised floor became slightly smaller.

A marked temperature difference was not observed at other measurement points.

(3) Figure IV.10 reports the result obtained by installing a plate at the inlet and the outlet of equipment Type RL mounted in Racks 1 and 2, in addition to (1) and (2).

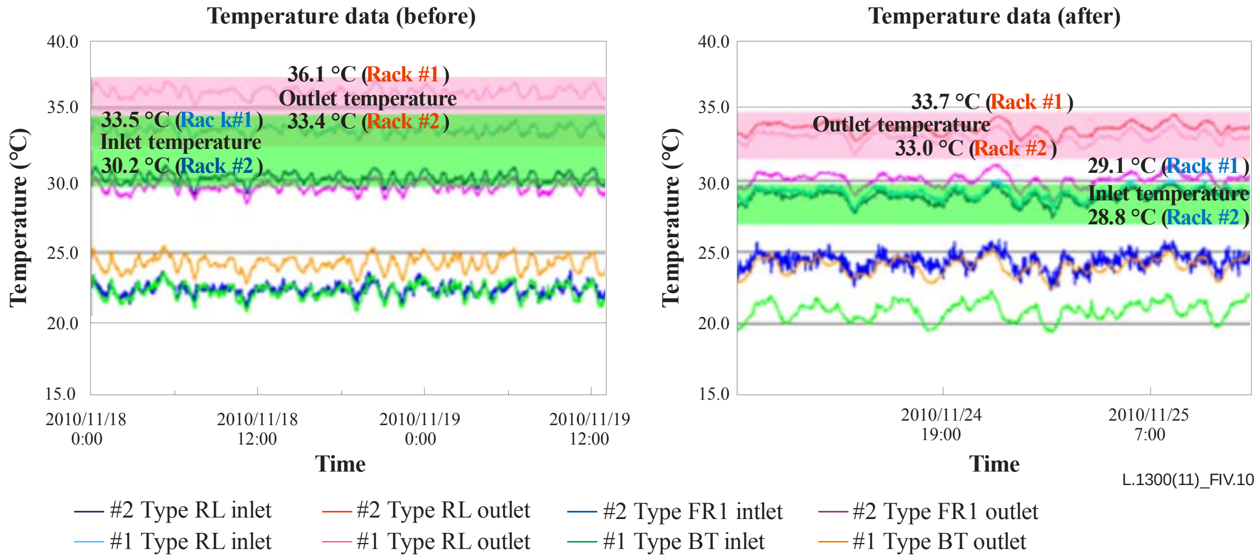

Figure IV.10 – Results of Rack 1 after installing a plate at the outlet and at the inlet

- Inlet and outlet temperatures of equipment Type RL mounted in Rack 1 were in the same temperature range as those of the adjacent equipment mounted in Rack 2.
- The plate prevented the equipment from sucking in the exhaust air from the adjoining equipment, and the outlet temperature became stable.

VI.3.3 Conclusions

For equipment whose airflow direction is bottom-to-top, the following results were obtained.

The duct installed at the outlet prevents the exhaust air from circulating to the front of the rack.

The duct installed at the inlet is likely to prevent exhaust air being sucked in, as with the blanking plate.

For equipment whose airflow direction is right-to-left, the following result was obtained.

Installation of the plate separates the intake air and the exhaust air, and prevents the equipment from sucking in the exhaust air from the adjoining equipment.

Appendix V

Rationale for minimum data set for evaluating energy efficiency and for controlling data centre equipment in view of power saving

(This appendix does not form an integral part of this Recommendation.)

V.1 Introduction

Energy consumption in data centres is increasing year by year with the growth in the data centre market. In order to mitigate global warming, it is an urgent task to reduce power consumption in data centres. Generally, ICT equipment (e.g., servers, routers, switches, storage units) and facility equipment (e.g., power delivery components, heating ventilation and air conditioning (HVAC) system components) account for a large percentage of energy consumption in data centres. Thus, power-saving measures for these components are necessary to reduce overall power consumption.

Evaluation of energy efficiency in data centres is necessary to know how green the data centre is and to investigate the effect of power-saving measures. To evaluate whether the data centre is power efficient, it is necessary to continuously trace metrics which represent the energy efficiency of the data centre. An example of such a metric is power usage efficiency (PUE) or its reciprocal, data centre infrastructure efficiency (DCiE), both of which express the energy efficiency of facility equipment.

In addition to power-saving measures for each component, energy consumption in data centres can be further reduced by implementing "coordinated control" of ICT equipment and facility equipment. In general, ICT equipment and facility equipment are separately controlled. If facility equipment is controlled in a coordinated way according to the arrangement of the workload of ICT equipment, further power reduction can be achieved.

To evaluate energy efficiency in data centres and to control data centre equipment to achieve power saving, necessary data needs to be collected from the data centre equipment. Nowadays, sensors can be installed to collect necessary data, but the installation cost can be very high. It is also possible to obtain monitoring information directly from data centre equipment by using, for example, a management information base (MIB) for ICT equipment. However, it is difficult to collect necessary data in an integrated fashion because a data centre is generally a multivendor environment, and each vendor defines its own measurement point and allocation address.

Based on this situation, this document describes the minimum data set necessary for evaluating energy efficiency and for controlling data centre equipment to save power in data centres. The data set includes two types of data:

- data that should be obtained from data centre equipment periodically (dynamic data);
- data that should be treated statically (static data).

The definition of such a minimum data set is intended to facilitate the evaluation and control of equipment under a multivendor environment. The means of collecting the data from data centre equipment is outside the scope of this Recommendation and should be addressed as a future task.

V.2 Definitions

Dynamic data: Data that should be obtained from data centre equipment periodically.

Static data: Data that should be treated statically.

V.3 Data set necessary for evaluation of energy efficiency in data centres

This clause describes the minimum data set necessary for evaluating energy efficiency in data centres. The necessary data set is described, based on the analysis of the following metrics for evaluating energy efficiency of data centres.

Table V.1 lists examples of metrics which represent the energy efficiency of a data centre. Table V.2 shows the relation between the metrics and the parameters.

Table V.1 – Examples of metrics representing energy efficiency of data centres

Metrics	Definitional identity	Notes
PUE: power usage effectiveness	Total energy consumption of data centre/Energy consumption of ICT equipment.	PUE is proposed by the Green Grid, and determines the energy efficiency of a data centre infrastructure. The reciprocal of PUE is DCiE.
ITEU: IT equipment utilization	Energy consumption of ICT equipment/total rated power of ICT equipment.	ITEU is proposed by the Green IT Promotion Council, and represents the degree of energy saving by virtual and operational techniques using the potential ICT equipment capacity without waste. A reduction in equipment to be installed is promoted by using only the number of devices needed to meet the required ICT capacity without waste.
ITEE: IT equipment energy efficiency	(Total server capacity + Total storage capacity + Total NW equipment capacity)/Total rated power of ICT equipment	ITEE is proposed by the Green IT Promotion Council, and aims to promote energy saving by encouraging the installation of equipment with high processing capacity per unit of electric power.
GEC: Green energy coefficient	Green (natural energy) energy/total energy consumption of data centre.	GEC is proposed by the Green IT Promotion Council, and is a value obtained by dividing green energy produced and used in a data centre by the total power consumption. It is introduced to promote the use of green energy.
DPPE: Datacentre performance per energy	Function of the four metrics PUE, ITEU, ITEE, GEC.	DPPE is proposed by the Green IT Promotion Council, and indicates the energy efficiency of data centres as a whole. It may be expressed as the product of the other four metrics.

Table V.2 – Relation between metrics and parameters

Parameters used in the metrics	Type of information	PUE	ITEU	ITEE	GEC	DPPE
Total energy consumption of data centre	Dynamic	✓			✓	✓
Energy consumption of ICT equipment	Dynamic	✓	✓			✓
Green energy produced and used in data centre	Dynamic				✓	✓
Rated power of ICT equipment	Static		✓	✓		✓
Server capacity	Static			✓		✓
NW equipment capacity	Static			✓		✓
Storage capacity	Static			✓		✓

Here, energy consumption of ICT equipment includes all of the ICT equipment, i.e., computing, storage, and network equipment, along with supplemental equipment, i.e., KVM switches, monitors, and workstations/laptops used to monitor or otherwise control the data centre. On the other hand, total data centre energy consumption includes all of the ICT equipment power plus everything that supports the ICT equipment, such as power delivery components, HVAC system components, and other miscellaneous component loads, such as physical security and building management systems. Table V.3 gives examples of components quoted from [b-TGG WP14].

Table V.3 – Examples of components of facility and ICT equipment

Facility	
	Power
	Transfer switch
	UPS
	DC batteries/rectifiers (non-UPS – telco nodes)
	Generator
	Transformer (step down)
	Power distribution unit (PDU)
	Rack distribution unit (RDU)
	Breaker panels
	Distribution wiring
	Lighting
	Heating, ventilation and air conditioning (HVAC)
	Cooling tower
	Condenser water pumps
	Chillers
	Chilled water pumps
	Computer room air conditioners (CRACs)
	Computer room air handlers (CRAHs)
	Dry cooler
	Supply fans
	Return fans
	Air economizer
	Water-side economizer
	Humidifier
	In-row, in-rack and in-chassis cooling solutions
	Physical security
	Fire suppression
	Water detection
	Physical security servers/devices
	Building management system
	Servers/devices used to control management of data centre
	Probes/sensors

Table V.3 – Examples of components of facility and ICT equipment

IT equipment	
	Computer devices
	Servers
	Network devices
	Switches
	Routers
	IT support systems
	Printers
	PCs/workstations
	Remote management (KVM/console/etc.)
	Miscellaneous devices
	Security encryption, storage encryption, appliances, etc.
	Storage
	Storage devices – switches, storage array
	Backup devices – media libraries, virtual media libraries
	Telecommunications
	All telco devices

source [b-TGG WP14]

Table V.2 indicates that the dynamic data necessary for calculating these metrics are the total energy consumption of the data centre and the energy consumption of ICT equipment, both of which are used in the calculation of PUE. Green energy produced and used in the data centre is also dynamic data, but does not need to be included in the data set because the scope of this Recommendation is a data set for evaluating power efficiency, not energy efficiency. Thus, consideration of the source of power is beyond the scope of this paper. Other parameters in Table V.2 are static data which can be obtained from equipment specifications.

To determine the total energy consumption of the data centre and the energy consumption of ICT equipment, some approaches to measuring PUE are described in [b-TGG WP14], as shown in Table V.4. PUE calculation is more precise at higher levels, and locations to measure annual energy consumption of the data centre and of ICT equipment, as well as the minimum measurement interval, are defined for each level. Figure V.1 shows an example of a power feeding system in a data centre with the measurement locations indicated. The higher the level, the shorter measurement interval is recommended, and thus, it would be easier to obtain energy consumption of ICT equipment if the input power of ICT equipment and the output power of power equipment (i.e., UPS, rectifier, PDU) could be collected as dynamic data from the equipment. On the other hand, for total power consumption, it is recommended that input power be measured in the utility meter when calculating PUE.

In addition, cooling equipment accounts for a large percentage of energy consumption in data centres, thus input power of cooling equipment should be collected as well.

Therefore, inclusion of the input power of ICT equipment and cooling equipment and the output power of the UPS, rectifier, and PDU to the data set, is necessary to evaluate the power efficiency.

Table V.4 – Measurement approaches of PUE

	Level 1 (basic)	Level 2 (intermediate)	Level 3 (advanced)
IT equipment power Total facility power where:	UPS Data centre input power	PDU Data centre input power less shared HVAC	Server… Data centre input power less shared HVAC plus building lighting, security
Minimum measurement interval	1 month/1 week	Daily	Continuous (XX min)

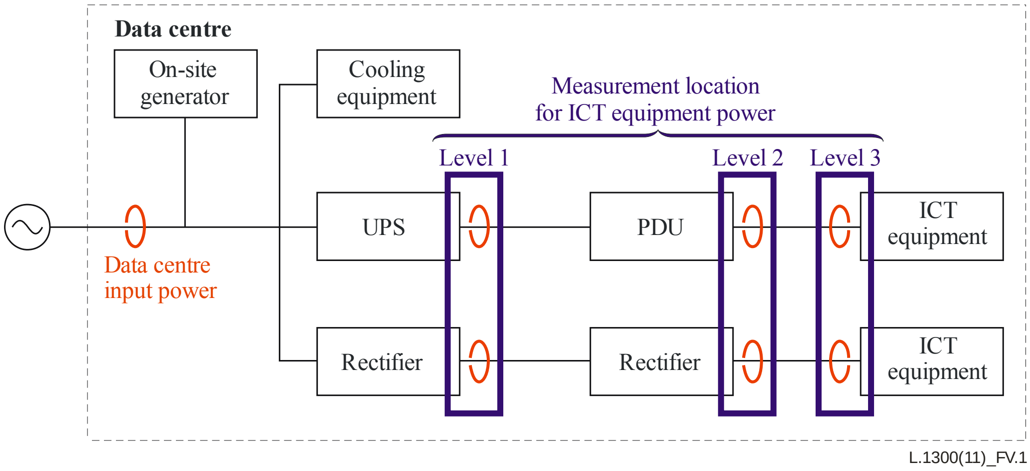

Figure V.1 – Example of a power feeding system of a data centre

V.4 Data set necessary for coordinated control to save power in data centres

This clause describes the minimum data set necessary for coordinated control to reduce the total energy consumption of data centres. First, the effect of coordinated control is explained in clause V.4.1. The description of the control architecture and the scope of the data set follow in clause V.4.2. Then, clause V.4.3 describes the details of the data set on ICT equipment, cooling equipment, power equipment, and the equipment configuration.

V.4.1 Power saving due to coordinated control

The effects of controlling multiple pieces of cooling equipment in a coordinated way are described here.

The efficiency of a computer room air conditioner (CRAC) varies with the load factor and operation mode. When each CRAC is controlled to satisfy its own temperature setting, the overall efficiency of all CRACs is not necessarily high. As shown in Figure V.2, when one of the CRACs in variable air volume (VAV) mode has a disproportionate load and the thermostats of adjacent CRACs remain switched off, the overall efficiency may be low.

An experiment was conducted to see if the total energy consumption could be reduced by adjusting the load balance among the CRACs. The temperature setting of each CRAC was adjusted so they would operate at higher efficiency.

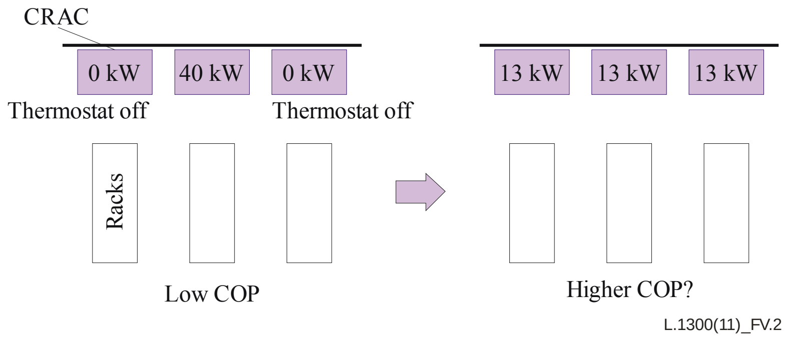

Figure V.2 – Illustration of a server room (COP: coefficient of performance)

The correlation between the outside temperature and the energy consumption of CRACs is shown in Figure V.3. This shows that the energy consumption of CRACs can be reduced by adjusting the load balance. For example, when the outside temperature is 15°C, the reduction in energy consumption of CRACs is estimated to be 17.5%. Note that this estimated value is only valid for the experimental environment, but the result indicates that coordinated control among CRACs makes it possible to save a large amount of power. For power saving, it is important to control multiple CRACs by optimally responding to the heat generation due to the operation of ICT equipment.

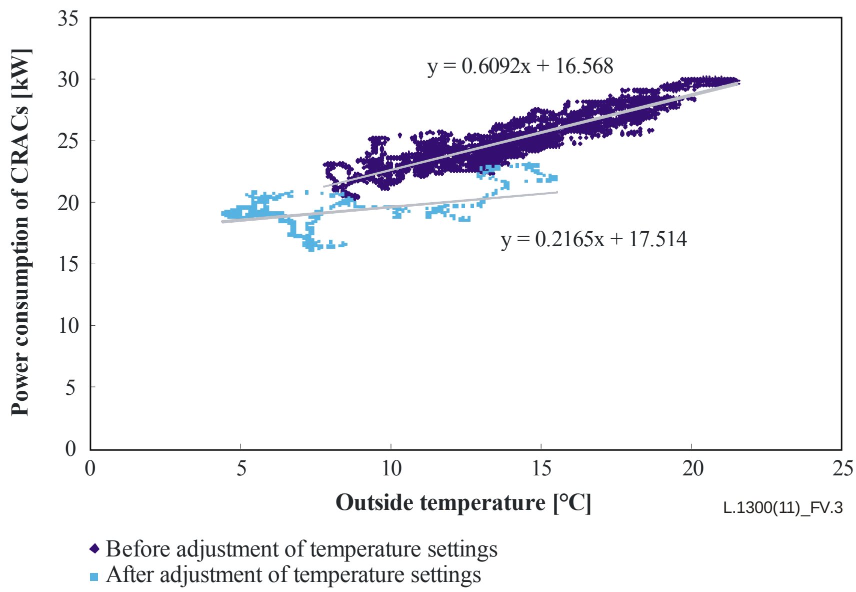

Figure V.3 – Correlation of outside temperature and energy consumption of CRACs

V.4.2 Control architecture

Figure V.4 illustrates an example of control architecture for power saving in data centres. A facility controller collects the dynamic data and sets the control parameters of ICT equipment and facility equipment. The facility controller also manages static data of ICT and facility equipment, such as equipment ID, equipment characteristics, server room configuration, and rack configuration. An ICT task controller manages and controls the work load of ICT equipment.

This document focuses on the control parameters of ICT equipment and facility equipment that directly contribute to power saving, and on the dynamic data which should be collected from ICT and facility equipment in order to set the control parameters. It also describes examples of the static data the facility controller should manage. However, data managed in the ICT task controller are outside the scope of this Recommendation because the arrangement of work load does not directly contribute to power saving.

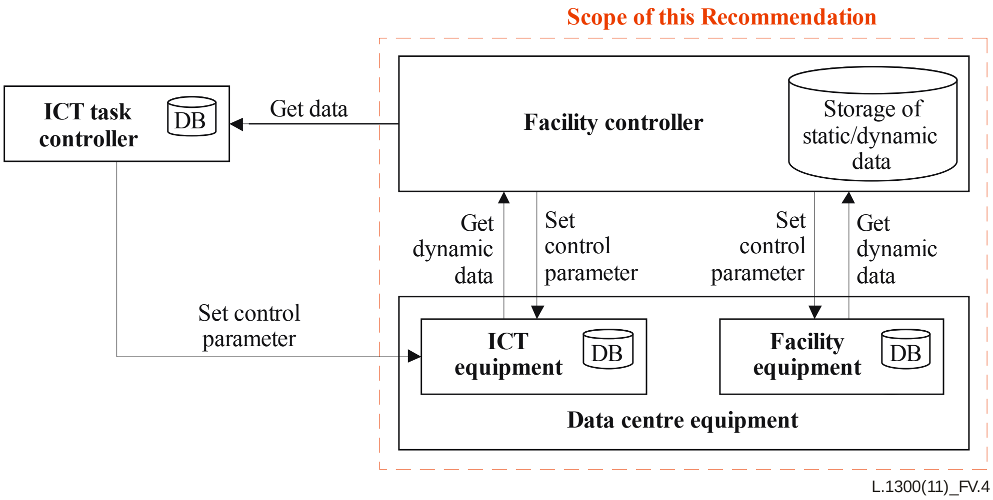

Figure V.4 – Example of control architecture

V.4.3 Details on data set

V.4.3.1 ICT equipment

✓ Power state setting of ICT equipment (shutdown, activation) (dynamic data)

Energy consumption varies depending on the power state of ICT equipment (i.e., shutdown, sleep state, active state). Examples of energy consumption patterns due to the power state of ICT equipment are shown in Figure V.5 Some types of equipment can reduce their energy consumption by changing their power state to the sleep state (as shown in (1) in Figure V.5), and other types can only achieve a large reduction in energy consumption by changing the power state to shutdown (as shown in (2)). Some other types cannot achieve a significant reduction in energy consumption just by changing their power state (as shown in (3)).

Based on these characteristics, energy consumption can be reduced by setting the appropriate power state of ICT equipment based on the workload. Therefore, the power state of ICT equipment should be included in the data set as a control parameter.

✓ Present power state of ICT equipment (shutdown, sleep, active) (dynamic data)

Prior to changing the power state of ICT equipment, it is necessary to determine whether the present power state is shutdown, in sleep mode, or active. For example, when ICT equipment is required to be shut down, the power state needs to be checked to make sure it is in sleep mode.

Therefore, the power state of ICT equipment should be collected as dynamic data.

✓ Input power of ICT equipment (dynamic data)

Input power of ICT equipment should be collected as dynamic data in order to check whether the power is reduced by changing the power state.

✓ Energy consumption data of ICT equipment under shutdown and sleep modes (static data)

If these data are available, it will be effective for power saving to preferentially shut down ICT equipment. Large power reduction is achieved when its power state is changed from stand-by to a shutdown state.

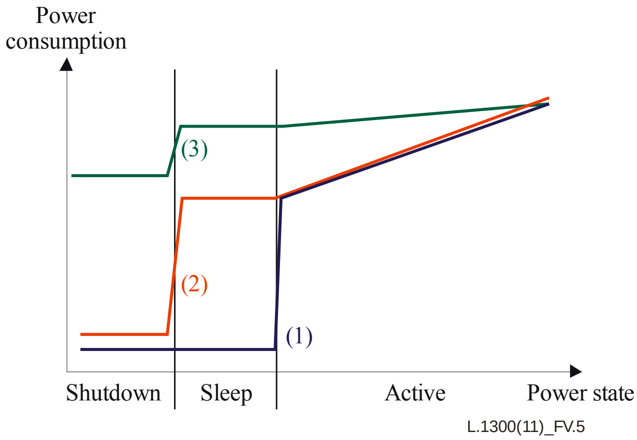

Figure V.5 – Power patterns due to the power state of ICT equipment

- ✓ Equipment ID and description (static data)

  These are necessary for identifying each piece of equipment.

- ✓ Inlet temperature of ICT equipment (dynamic data)
- ✓ Operating temperature range of ICT equipment (static data)

  ICT equipment has an operating temperature range, and cooling equipment must be controlled to meet this temperature range for each piece of ICT equipment. Therefore, the inlet temperature of ICT equipment should be collected, and control parameters of cooling equipment should be determined to keep the inlet temperature of ICT equipment within the allowable range.

V.4.3.2 Cooling equipment

- ✓ On-off state of cooling equipment (dynamic data)

  For areas where there is a small heat load, power consumption can be reduced by switching off the cooling equipment. Therefore, the on-off state of cooling equipment should be included in the data set as a control parameter.

- ✓ Temperature of refrigerant supplied from the indoor unit to the ICT equipment (dynamic data)
- ✓ Amount of refrigerant supplied from the indoor unit to the ICT equipment (dynamic data)

Generally, as shown in Figure V.6, cooling equipment is composed of indoor and outdoor units. This equipment controls the temperature and the amount of refrigerant supplied from the indoor unit to the ICT equipment, in response to the heat generation due to the operation of ICT equipment. A large amount of power is used in devices that cool the refrigerant and in those that transport the refrigerant. For example, the former device is a compressor and the latter device a fan when the refrigerant is air, while the former device is a chiller and cooling tower, and the latter a pump when the refrigerant is water. Power saving depends on the control of these devices, and the temperature setting and amount of refrigerant supplied from the indoor unit to the ICT equipment affects their operation. Thus, these parameters should be included in the data set as control parameters.

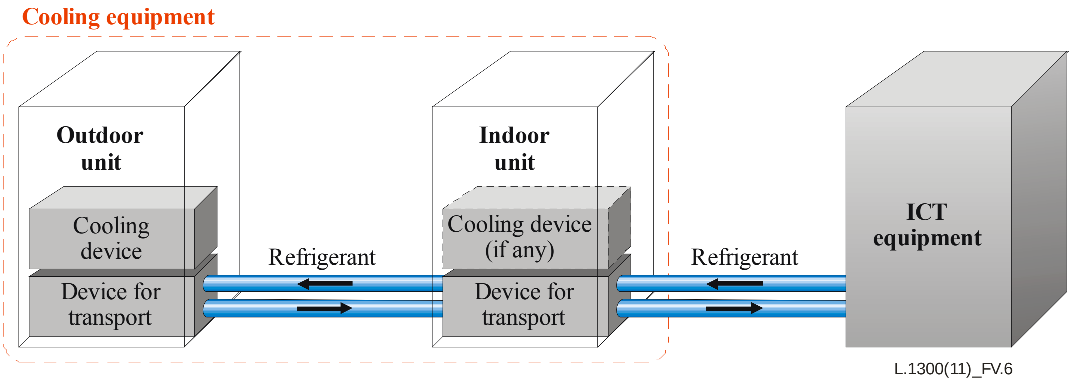

Figure V.6 – General configuration of cooling equipment

NOTE – If the temperature and amount of refrigerant cannot be obtained from the cooling equipment, it can be estimated by using alternative data that can be obtained from the cooling equipment and from static data of the cooling equipment.

Take the amount of refrigerant supplied from the indoor unit of cooling equipment as an example. This corresponds to the supply air volume for cooling equipment using air as the refrigerant. With certain types of cooling equipment, the supply air volume cannot be obtained as dynamic data. In this case, the fan speed, if available, can be used to estimate the supply air volume. Static data such as the number of fans and the sectional area of each fan can be used for estimation.

Since available data from cooling equipment depends on the control method, the estimation method using dynamic and static data can be discussed further for each control method at a later date.

✓ Equipment ID and description (static data)

These are necessary for identifying each piece of equipment.

✓ Input power of cooling equipment (dynamic data)

The input power of cooling equipment should be collected as dynamic data in order to check whether the power is reduced by changing the settings of the control parameters.

✓ Inlet temperature of indoor unit (dynamic data)

✓ Outside temperature (dynamic data)

✓ Energy consumption characteristics of device used for cooling the refrigerant (static data)

✓ Temperature setting range of refrigerant supplied from the indoor unit to the ICT equipment (static data).

✓ Temperature setting step size of refrigerant supplied from the indoor unit to the ICT equipment (static data).

Operation of devices that cool the refrigerant (e.g., compressor, chiller) depends on the difference between the inlet temperature of the indoor unit and the temperature setting of the refrigerant supplied from the indoor unit to the ICT equipment. The outside temperature (e.g., inlet temperature of outside unit as a measurement point) also affects the operation, thus, it should also be collected. Thus, energy consumption characteristics of devices used to cool the refrigerant (i.e., the relation between power consumption, outside temperature, supply temperature of refrigerant, and amount of refrigerant supplied) is necessary to determine the optimal supply temperature setting. Additionally, the temperature setting range and step size of the refrigerant supplied from the indoor unit should be collected, and the optimal supply temperature setting should meet these conditions.

✓ Amount of refrigerant supplied from the indoor unit of cooling equipment (dynamic data).

✓ Presence or absence of mode controlling the amount of refrigerant supplied (static data).

- ✓ Rated amount of refrigerant supplied from the indoor unit to the ICT equipment (static data).
- ✓ Energy consumption characteristics of devices used to transport the refrigerant (static data).

Operation of devices used to transport the refrigerant (e.g., fans, pumps) depends on the setting of the amount of refrigerant. Thus, energy consumption characteristics of the device used to transport the refrigerant are necessary to determine the optimal setting of the amount of transported refrigerant. Additionally, the rated amount of refrigerant is necessary to understand the transport limit.

V.4.3.3 Power equipment

- ✓ Equipment ID and description (static data)

  These are necessary to identify each piece of equipment.
- ✓ Efficiency characteristics (i.e., load percentage versus efficiency) (static data)

  Power equipment has individual efficiency characteristics, and such equipment should be operated at high efficiency in order to save power. Efficiency characteristics are necessary as static data to determine the optimal operating point of power equipment.

V.4.3.4 Equipment configuration

- ✓ Configuration of server room (static data)

Figure V.7 illustrates a common configuration of a server room, which depends on the cooling method. As shown in Figure V.7(a), a common cooling method in data centres is to cool the whole server room by supplying cold air from cooling equipment to cold aisles via a free access floor. In addition, installing modular cooling equipment in rack rows, as shown in Figure V.7(b), is an efficient method for cooling racks with high heat density.

To control multiple pieces of cooling equipment in a coordinated way, it is necessary to determine which cooling equipment should be preferentially controlled in response to the operation status of ICT equipment. Configuration information of the server room helps to understand the cooling zone of each piece of cooling equipment and the preferential order of control.

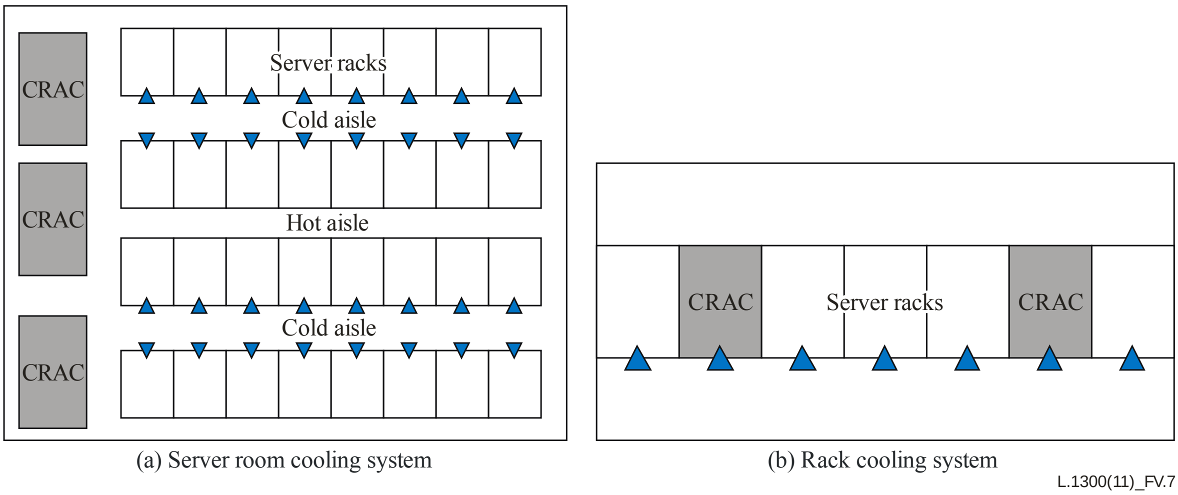

Figure V.7 – Common configuration of a server room

- ✓ Connection between ICT equipment and power equipment (static data)

To control the power supply of ICT equipment, knowing which ICT equipment is connected to which power equipment is necessary as static data.

V.5 Summary of minimum data set and gap analysis with other standardization works

The minimum data set necessary for evaluating energy efficiency and for controlling data centre equipment for power saving in data centres is summarized in Table V.5. Dynamic information necessary from each type of equipment is shown in Table V.5(a), while an example of static information that the facility manager manages, such as equipment specifications, is shown in Table V.5(b). Note that a comparison with data sets discussed in other standardization works (ECMA and ETSI) has been added to Table V.5 (a). A "✓" in the table indicates that the data is included in the data set.

ECMA is working on "Smart Data Centre Resource Monitoring and Control" [b-ECMA], which defines the data set necessary for resource monitoring and control in data centres, while ETSI ES 202 336 [b-ETSI ES 202 336] is working on a monitoring/management interface of infrastructure equipment. In [b-ECMA], servers and air conditioners are included in the scope. Most of the minimum data set in Table V.5(a) is covered in [b-ECMA], but the amount of refrigerant supplied is not covered. On the other hand, [b-ETSI ES 202 336] focuses on air conditioning equipment and power equipment. The minimum data set in Table V.5(a) is covered in [b-ETSI ES 202 336].

Table V.5 – Minimum data set for evaluating energy efficiency and for controlling data centre equipment for power saving in data centres

(a) Dynamic information necessary from each type of equipment

<table>
<tr><th colspan="2" rowspan="2">Type of equipment</th><th rowspan="2">Purpose</th><th colspan="2" rowspan="2">Data set</th><th rowspan="2">Data flow direction</th><th colspan="2">Other data sets</th></tr>
<tr><th>ECMA</th><th>ETSI ES 202 336</th></tr>
<tr><td colspan="2" rowspan="4">ICT equipment</td><td>Evaluation and control</td><td colspan="2">Input power</td><td>G</td><td>✓</td><td rowspan="4">(Note 1)</td></tr>
<tr><td rowspan="3">Control</td><td colspan="2">Inlet temperature</td><td>G</td><td>✓</td></tr>
<tr><td colspan="2">Power state (shutdown, sleep, active)</td><td>G</td><td>✓</td></tr>
<tr><td colspan="2">Power state (shut down, activate)</td><td>S</td><td>✓</td></tr>
<tr><td rowspan="10">Facility equipment</td><td rowspan="9">Cooling equipment</td><td>Evaluation and control</td><td colspan="2">Input power</td><td>G</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="8">Control</td><td colspan="2">Inlet temperature of indoor unit</td><td>G</td><td>✓</td><td>✓</td></tr>
<tr><td colspan="2">Outside temperature</td><td>G</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="2">Amount of transport of refrigerant from indoor unit to ICT equipment</td><td>Supply airflow volume (if refrigerant is air)</td><td>G/S</td><td></td><td>✓ (Note 2)</td></tr>
<tr><td>Supply water volume (if refrigerant is water)</td><td>G/S</td><td colspan="2">(Note 3)</td></tr>
<tr><td colspan="2">On-off state</td><td>G/S</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="2">Temperature of refrigerant from indoor unit to ICT equipment</td><td>Supply air temperature (if refrigerant is air)</td><td>G/S</td><td>✓</td><td>✓</td></tr>
<tr><td>Supply water temperature (if refrigerant is water)</td><td>G/S</td><td colspan="2">(Note 3)</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Power equipment (UPS, rectifier, PDU)</td><td>Evaluation</td><td colspan="2">Output power</td><td>G</td><td>(Note 4)</td><td>✓</td></tr>
<tr><td colspan="8">NOTE 1 – [b-ETSI ES 202 336] limits its scope to facility equipment.
NOTE 2 – "Fan speed" is included in [b-ETSI ES 202 336-6] draft. Supply air volume can be calculated by using static data such as number of fans and sectional area of each fan.
NOTE 3 – Cooling equipment using water as a refrigerant is not included in the scope.
NOTE 4 – Scope of ECMA's data set is monitoring and control, not evaluation.</td></tr>
</table>

(b) Example of static information that the facility controller manages

Type of equipment	Data set
Configuration	Configuration of the server room
	Connection between ICT equipment and power equipment
ICT equipment	Equipment ID and description
	Operating temperature range
Cooling equipment	Equipment ID and description
	Energy consumption characteristics of devices used to cool the refrigerant
	Energy consumption characteristics of devices used to transport the refrigerant
	Presence or absence of the mode controlling the amount of refrigerant transported
	Temperature setting range of refrigerant supplied from the indoor unit
	Temperature setting step size of refrigerant supplied from the indoor unit
	Rated amount of refrigerant supplied from the indoor unit
Power equipment	Equipment ID and description
	Efficiency characteristics

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