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

Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres

Recommendation ITU-T L.1320

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Summary

Recommendation ITU-T L.1320 contains the general definition of metrics, test procedures, methodologies and measurement profiles required to assess the energy efficiency of power and cooling equipment for telecommunications and data centres. More detailed measurement procedures and specifications can be developed in future related ITU-T Recommendations.

Metrics and measurement methods are defined for power equipment, alternating current (AC) power feeding equipment (such as AC uninterruptible power supply (UPS), direct current (DC/AC) inverters), DC power feeding equipment (such as AC/DC rectifiers, DC/DC converters), solar equipment, wind turbine equipment and fuel cell equipment.

In addition, metrics and measurement methods are defined for cooling equipment such as air conditioning equipment, outdoor air cooling equipment and heat exchanging cooling equipment.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

Energy efficiency, methodology, metrics.

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Introduction

Typically energy efficiency is defined as the ratio of work output to energy consumed, which in scientific terms can be expressed in the same functional units of joules. As applied to pieces of equipment, the energy efficiency term of work output has transformed to "useful work" or "useful output" to apply to specific items of interest. The energy consumed has also been transformed to units that reflect the primary form or unit of measure tracked to deliver that output, such as electricity or more specifically Watt-hours (Wh). While the measurement of the electricity consumed is generally straightforward, the definition of useful output is context driven and required to be explicit to the application to provide effective measures of monitoring and improvement. In fact, the use of energy efficiency metrics is expressly intended to monitor and drive programmes that gain the most useful output for the energy being consumed. Note that "useful-output" has finite bounds to the context of the application. These bounds may drive categorization methods towards groups such as applications, size, and/or conditions. To apply this concept for the targeted application or equipment, useful work or output must be defined in order to describe the energy efficiency for the subject entity.

For the purposes of this Recommendation, the energy efficiency of the power (delivery and conditioning) equipment will be expressed solely as the ratio of output energy (Watt-hours delivered) to input energy (Watt-hours consumed). This ratio may also be expressed in terms of power (i.e., Watts) if normalized under the condition of use (e.g., root mean square (RMS) over a reasonable application time period). The energy efficiency for air conditioning and air cooling equipment is designated as the ratio of cooling capacity to energy consumed. The cooling capacity is transformed from units of temperature and air/area properties to Watts. Thus for cooling purposes, the ratio is that of cooling capacity in Watts to energy consumed in Watts.

Recommendation ITU-T L.1320

Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres

1 Scope

This Recommendation specifies principles and concepts of energy efficiency metrics and measurement methods for power feeding equipment and cooling equipment in telecommunications rooms and data centres.

The methodologies defined in this Recommendation are applied at single equipment level. The efficiency of power conversion and cooling in the data centre or telecommunication facility is only partially attributed to the equipment. The architecture and organization of the space and equipment to deliver the power or cooling to the systems is as equal, if not a more significant factor in energy efficiency. Another general factor is the interoperability, management and response of these systems across the demand and operational range.

NOTE – Cooling equipment: In general, data centre level systems should be referred (or normalized) with respect to a full year, in order to take into account the yearly variability of environmental conditions and the consequent possible use of various cooling methods. The reference to a whole year helps to establish a power usage effectiveness (PUE) comparison, especially with respect to an individual data centre.

This Recommendation covers:

- Power feeding equipment:
  - AC power feeding equipment;
  - DC power feeding equipment;
  - Renewable energy equipment[1].
- Cooling equipment:
  - Air conditioner equipment;
  - Outdoor air cooling equipment;
  - Heat exchanging cooling equipment.

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.

[ATIS-0600015.04] ATIS-0600015.04 (2010), *Energy Efficiency for Telecommunication Equipment: Methodology for Measurement and Reporting DC Power Plant – Rectifier Requirements*.

[1] Renewable energy equipment implies the inclusion of either energy storage (e.g., battery and/or fuel cell) or power from/to the electrical grid. These sources and/or losses in the transmission are outside the scope of this Recommendation but should be taken into account for an overall efficiency assessment.

[IEC 61215] IEC61215 Ed 2.0 (2005), *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*.

[IEC 61646] IEC 61646 Ed.2.0 (2008), *Thin-film terrestrial photovoltaic modules – Design qualification and type approval*.

[IEC 62040-3] IEC 62040-3 Ed.2.0 (2011), *Uninterruptible power systems (UPS) − Part 3: Method of specifying the performance and test requirements*.

[IEC 62108] IEC 62108 Ed.1.0 (2007), *Concentrator photovoltaic (CPV) modules and assemblies − Design qualification and type approval*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 energy [b-ISO 16818]: Capacity for doing work; having several forms that may be transformed from one to another, such as thermal (heat), mechanical (work), electrical or chemical and is expressed in Joules. For the purposes of this Recommendation, energy will be expressed in Watt-hours (Wh) or kilo Watt-hours (kWh).

3.1.2 power [b-ISO 16818]: Rate at which energy is transmitted.

NOTE 1 − Power is measured in units of Watts.

NOTE 2 − Though the rate of change can be observed as instantaneous values, use of power in these specifications imply normalization based on a reasonable representative period. Typically, energy is measured and a RMS power level is determined.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 alternating power (AC) power feeding equipment: AC power feeding equipment can be composed of an AC uninterruptible power supply (UPS), a direct current to alternating current (DC/AC) converter and an AC power distribution unit, if considered.

3.2.2 cooling capacity: It is the cooling power of air conditioners and refers to the rate that heat is removed from a space. It is most commonly measured as tons per hour or British thermal units (BTUs).

3.2.3 direct current (DC) power feeding equipment: DC power feeding equipment can be composed of a rectifier, a direct current to direct current (DC/DC) converter and DC power distribution units, if considered.

3.2.4 external static pressure: Static pressure at the air blower exit. High external static pressure is necessary for a cooling system with a raised floor or duct because of the high airflow resistance.

3.2.5 response time capability: The level of ability to respond to changes in the conditions in a certain time.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC Alternating Current

BTU British Thermal Unit

CF Crest Factor

DC	Direct Current
FC	Fuel Cell
PF	Power Factor
PV	Photovoltaic
RMS	Root Mean Square
UPS	Uninterruptible Power Supply

5 General test methodology

5.1 Power feeding equipment efficiency testing

5.1.1 Conditions for power feeding equipment efficiency testing

Environmental conditions (such as temperature, humidity and air pressure), electrical conditions (such as input DC voltage, input AC voltage and frequency) and metrology requirements shall be reported when measuring energy efficiency.

Appendix I illustrates an example of how conditions for power feeding equipment efficiency testing should be defined in other domestic or international standards.

Measurement conditions for AC/DC equipment could be considered with reference to [ATIS 0600015.04].

5.1.2 Load and environmental conditions

For test repeatability and consistency, load conditions and test configurations are fixed and static. The test procedures provide mechanisms to test representative points along a load range and across the environmental range. These data points may be representative as long as the load demand range, the environmental range and response requirements are comprehended[2].

On the other hand, dynamic load and the related equipment response are the main factors which influence the overall energy efficiency of the equipment. Therefore it is very important to select the values of different static load and environmental conditions that best represent the dynamic equipment behaviour.

Since the environmental conditions and load vary and are interdependent factors, the dynamic response should be factored into the model. Worst case variance in conditions and response time requirements should be included for the equipment under test.

The individual data points (determined as the other conditions are held fixed) together with the response time capabilities should provide sufficient information to model the environment. These conditions should be documented as part of the data reporting for the individual systems.

The efficiency of the power conversion is dependent on the operating temperature and the load of the system.

NOTE – In fact, efficiency (especially at low load) would be expected to be worse at high temperatures of operation versus low temperature operations. If generic testing is completed at room temperature (~21ºC) but

[2] As with most critical equipment, safety mechanisms to protect operations or equipment beyond the expected operational range should be documented. The equipment reaction or compliance should be evaluated according to those operational failure points as well. These conditions are not described or supported in these evaluation methods, though the safety features may impact the efficiency calculations in the range of operation. As a result, these conditions should be documented as part of the assessment so as to compare similar pieces of equipment.

the facility is set to 35ºC, the effective efficiency would be lower than predicted. Therefore test conditions must be carefully set.

5.1.3 Power equipment energy efficiency measurements

A general formula for measurement of power feeding equipment energy efficiency based on Figure 1 is shown below.

Figure 1 − General power feeding equipment basic configuration

$$\eta = P_o / P_i$$

where:

P_o is output power [W]

P_i is input power [W]

This energy efficiency value is measured or calculated from the testing data over a specified time period. The detailed energy efficiency for different types of power feeding equipment is defined below.

Testing configurations require well-defined loads and load conditions. As such, parameters used for static and dynamic load conditions shall be documented. As the load itself may vary based on the conditions and reaction during testing, the load ranges and tolerance during testing should be restricted and documented. The load range shall be consistent with the operational range of the application targeted loads. Given the phase variation in AC sources, power factor correction should also be tested when evaluating the efficiency of the conversion performed by the unit under test.

Monitoring values include other anomalies that dynamically change the power assessments. Monitoring power from AC sources entail considerations such as power factor correction that impact the effective efficiency measurements. Monitoring requires energy (not power) assessments to determine the active power level within a specified time period. In this case the time period used should be consistent with the capacitive load and time scale of the equipment under test and the targeted application. The time period can usually be determined in the control loop parameters of the equipment under test. The remainder of this Recommendation is focused on testing and evaluation of power conversion.

5.1.3.1 AC power feeding equipment

Measurement conditions for UPS shall be considered according to [IEC 62040-3].

AC UPS:

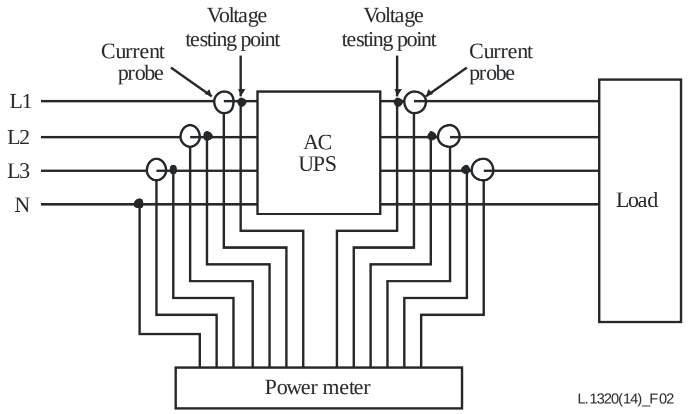

Figure 2 − AC UPS basic testing configuration

Figure 2 reports an example of AC UPS basic testing configuration. The measurement point of the voltage should be at the input interface and output interface of the AC UPS. Load could be either linear or non-linear: testing conditions shall therefore define both static and dynamic testing parameters including, e.g., crest factor, frequency and voltage range, etc.

$$\eta_{AC} = P_o / P_i$$

where:

η_{AC} is the efficiency of the AC UPS

P_o is the active output power [W]

P_i is the active input power [W]

The P_i and P_o calculation shall be conducted in accordance with [IEC 62040-3].

DC/AC inverter:

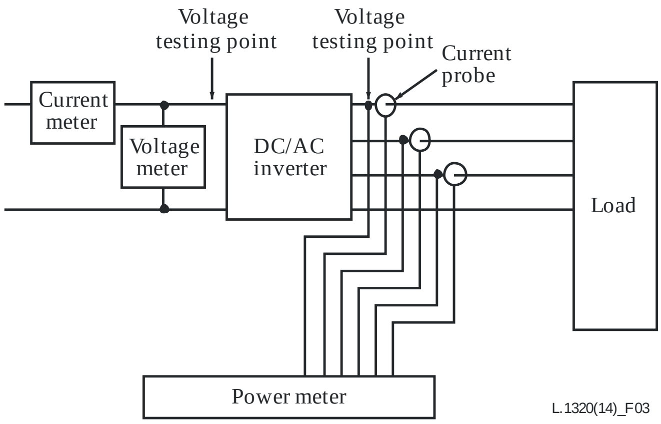

Figure 3 − DC/AC inverter basic testing configuration

Figure 3 shows an example of a DC/AC inverter basic testing configuration. The measurement point of the voltage should be at the input interface and output interface of the DC/AC inverter.

$$\eta_{DC/AC} = P_o / P_i$$

where:

$\eta_{DC/AC}$ is efficiency of the DC/AC inverter

P_o is the output active power [W]

P_i is the input DC power [W]

5.1.3.2 DC power equipment

AC/DC rectifier:

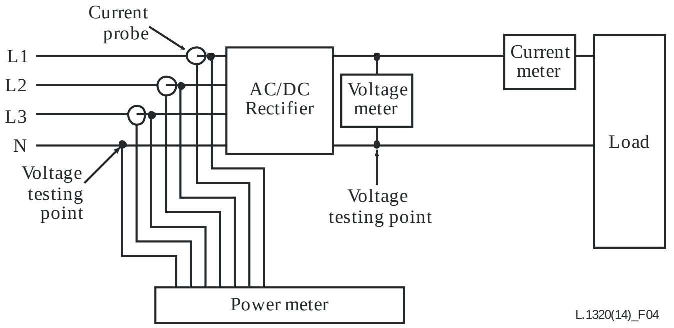

Figure 4 − AC/DC rectifier basic testing configuration

Figure 4 shows an example of an AC/DC rectifier basic testing configuration. The measurement point of the voltage should be at the input interface and output interface of the AC/DC rectifier.

$$\eta_{AC/DC} = P_o / P_i = (V \times I) / P_i$$

where*:*

$\eta_{AC/DC}$ is the efficiency of the AC/DC rectifier

P_i is the input active power [W]

P_o is the output power [W]

V is output voltage [V]

I is output current [A]

The P_i and P_o calculation could be conducted in accordance with [ATIS 0600015.04].

DC/DC converter:

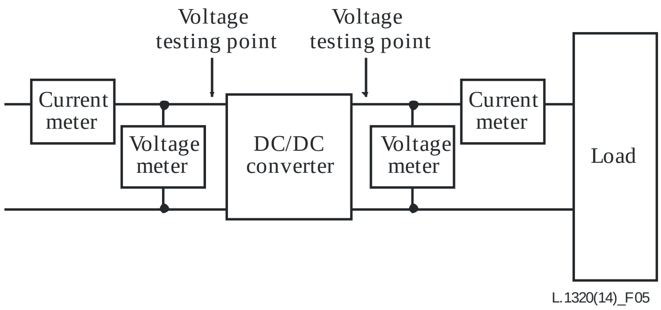

Figure 5 − DC/DC converter basic testing configuration

Figure 5 shows an example of a DC/DC converter basic testing configuration. The measurement point of the voltage should be at the input interface and output interface of the DC/DC converter.

$$\eta_{DC/DC} = P_o / P_i = (V_o \times I_o) / (V_i \times I_i)$$

where:

$\eta_{DC/DC}$ is the efficiency of the DC/DC converter

P_i is the input power [W]

P_o is the output power [W]

V_o is the output voltage [V]

I_o is the output current [A]

V_i is the input voltage [V]

I_i is the input current [A]

5.1.3.3 Renewable energy equipment

Photovoltaic (PV) panel efficiency

$$\eta_{PV} = P_o / P_i = (V \times I) / (Ir \times S)$$

where:

η_{PV} is the efficiency of the PV panel

P_i is the input power [W]

P_o is the output power [W]

V is the output voltage [V]

I is the output current [A]

Ir is irradiance

S is the squire of the PV arrays

Environmental conditions (e.g., irradiance, ambient temperature, etc.) shall be compliant with [IEC 61215] and [IEC 61646].

Wind turbine energy efficiency:

$$\eta_W = P_o / P_i = (V \times I) / (1/2 \rho S \upsilon^3)$$

where:

η_W is the efficiency of the wind turbine

P_i is the input power [W]

P_o is the output power [W]

V is the output voltage [V]

I is the output current [A]

ρ is the air density

S is the wind wheel sweeping area

υ is the wind speed

Hydrogen fuel cell (FC) stack efficiency:

$$\eta_F = P_o / P_i = (V_o \times I_o) / (m_{H_2} \times LHV_{H_2}) \times 100\%$$

where:

η_F is the efficiency of the fuel cell stack

m_{H2} is the hydrogen flow rate [g/s]

LHV_{H2} is the hydrogen low heat value [J/g]

5.2 Cooling equipment efficiency testing

5.2.1 Conditions for cooling equipment efficiency testing

Environmental conditions (such as temperature, humidity, air pressure and external static pressure) and metrology requirements shall be reported when measuring energy efficiency. Measurement of cooling equipment efficiency should be conducted under multiple conditions of outside temperature and humidity to consider the annual performance.

Appendix II provides some information on conditions for cooling equipment efficiency testing defined in other domestic or international standards.

5.2.2 Cooling equipment efficiency measurement

5.2.2.1 Air conditioner

Figure 6 shows an example of the air conditioner equipment basic testing configuration

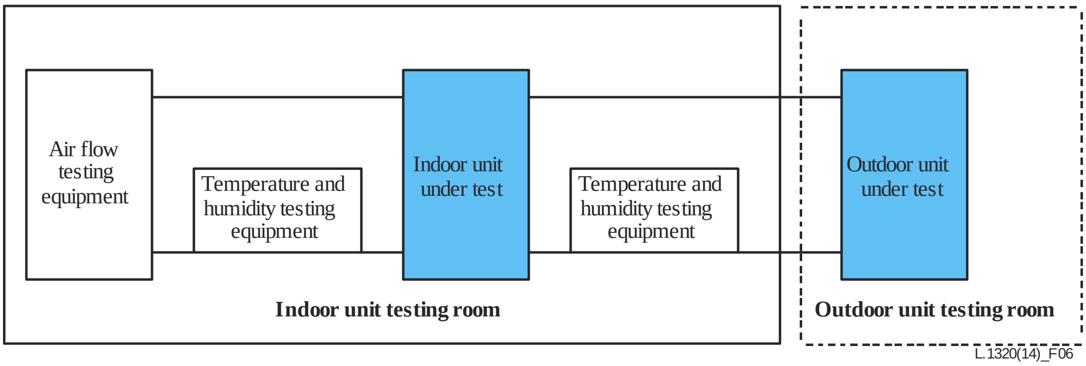

Figure 6 − Air conditioner equipment basic testing configuration

$$\eta_{air} = Q_T / P_i$$

where:

η_{air} is the efficiency of the air conditioner

$Q_T = Q_S + Q_L$

$Q_S = Cp \times \rho \times L \times \Delta T$

$Q_L = K \times \rho \times L \times (W_1 - W_2)$

$L = S \times V$

P_i is the input power [W]

S is the exhaust area of the outdoor air unit [m^2]

V is the outdoor air unit wind speed [m/s]

Qs is the sensible cooling capacity [W]

Q_L is latent cooling capacity [W]

C_p is specific heat of the air [J/kg°C]

ρ is air density [kg/m^3]

L is the total room air volume [m^3/s]

ΔT is the temperature difference between inside and outside the room [°C]

W_1 is the initial water content of the air [kg/kg]

W_2 is the final water content of the air [kg/kg]

K is the latent heat of vaporization water [J /kg]

5.2.2.2 Outdoor air cooling equipment

Figure 7 shows an example of the outdoor air cooling equipment basic testing configuration.

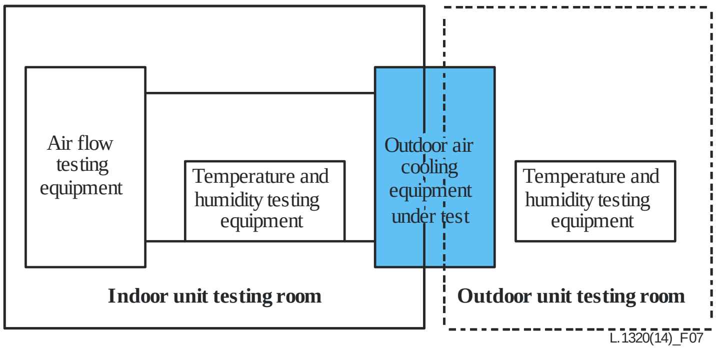

Figure 7 − Outdoor air cooling equipment basic testing configuration

$$\eta_{oair} = Q_S / P_i$$

where:

η_{oair} is the efficiency of the outdoor air conditioner

$Q_T = Q_S + Q_L$

$Q_S = Cp \times \rho \times L \times \Delta T$

$Q_L = K \times \rho \times L \times (W_1 - W_2)$

$L = S \times V$

P_i is the input power [W]

V is the outdoor air cooling equipment wind speed [m/s]

S is the exhaust area of the outdoor air cooling equipment [m^2]

Qs is the sensible cooling capacity [W]

C_p is the specific heat of air [J /kg°C]

ρ is the air density [kg/m^3]

L is the total room air volume [m^3/s]

ΔT is the temperature difference between inside and outside the room [°C]

W_1 is the initial water content of the air [kg/kg]

W_2 is the final water content of the air [kg/kg]

K is the latent heat of vaporization water [J /kg]

5.2.2.3 Heat exchanging cooling equipment

Figure 8 shows an example of the heat exchanging cooling equipment basic testing configuration.

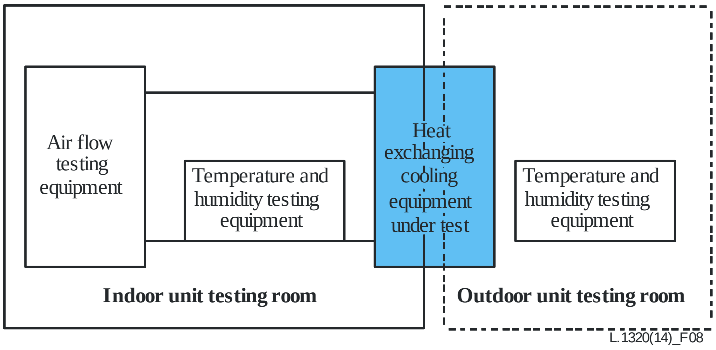

Figure 8 – Heat exchanging cooling equipment basic testing configuration

$$\eta_{he} = Q_S / P_i$$

where:

η_{he} is the efficiency of heat exchanging cooling equipment

Q_T $= Q_S + Q_L$

Q_S $= Cp \times \rho \times L \times \Delta T \times \eta_e$

Q_L $= K \times \rho \times L \times (W_1 - W_2)$

L $= S \times V$

P_i is input power [W]

V is the outdoor air cooling equipment wind speed [m/s]

S is the exhaust area of the outdoor air cooling equipment [m^2]

Q_S is the sensible cooling capacity [W]

Cp i s the specific heat of air [J/kg°C]

ρ is the air density [kg/m^3]

L is the total room air volume [m^3/s]

ΔT is the temperature difference between inside and outside the room [°C]

W_1 is the initial water content of the air [kg/kg]

W_2 is the final water content of the air [kg/kg]

K is the latent heat of vaporization water [J/kg]

η_e is the efficiency of the core heat exchanger

Appendix II describes specific examples of load conditions.

Appendix I

Example of conditions for power feeding equipment efficiency testing

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

I.1 Environmental conditions

Temperature

A power feeding equipment testing configuration was evaluated at standard temperature test conditions, which was a temperature within the range of 25° ±3ºC [b-ATIS-0600015]. The difference in temperature has an influence on test results; see Figure I.1 for more detailed information. The equipment itself was offline or operated at this ambient temperature for no less than three hours prior to the test. No ambient temperature changes were allowed until the test was complete and the temperature of the equipment was stable.

For some types of equipment, additional measurement at its rated temperature boundaries could be required to also test the energy efficiency at the limits of its operating temperature, as indicated in the detailed product specific requirements.

Humidity

For power feeding equipment, the equipment was evaluated at a relative humidity within the range (30%-75%) [b-ATIS-0600015].

Air pressure

The equipment was evaluated at site air pressure within the range (81 200 pa-102 000 pa) [b-ATIS-0600015]. No targeted airflows were allowed.

I.2 Electrical conditions

Input AC voltage and frequency

The input to the power feeding equipment (all active feeds) was at a nominal specified voltage ±1% and the specified frequency is ±1%. In the case where the equipment can work at a different nominal voltage, the measurement should be repeated at any nominal voltage, e.g., equipment declared able to work at 110V, 220V and 230V should be tested at each of these voltages.

I.3 Metrology requirements

Every active power feed had the power (current) meter [b-ATIS-0600015] installed in the power line with a desired accuracy not less than ±1% [b-ATIS-0600015] of the actual power consumption. All energy consumption calculations were based on averaging multiple readings over the course of measurements. Power meters were able to produce not less than 100 evenly-space readings in every full test cycle duration.

All measurement instruments used were calibrated by a counterpart national metrology institute and within a calibration due date and the measurement tolerances were within ±1%:

- Power source: Power sources used to provide power to the equipment under test were capable of providing a minimum of 1.5 times [b-ATIS-0600015] the power rating of the equipment under test.

- Power measurement instrument: The power measurement instrument (such as voltmeter and ampere meter or power analyser) had a resolution of 0.5%. The power measurement instrument had the following minimum characteristics:
  - a minimum digitizing sample rate of 40 kHz,
  - input circuitry with a minimum bandwidth of 80 kHz,
  - ability to log data over time and store the total measurement period and
  - overall measurement accuracy within ±1%.

I.4 Test configurations and results

UPS testing equipment connection methods are shown in Figure I.1.

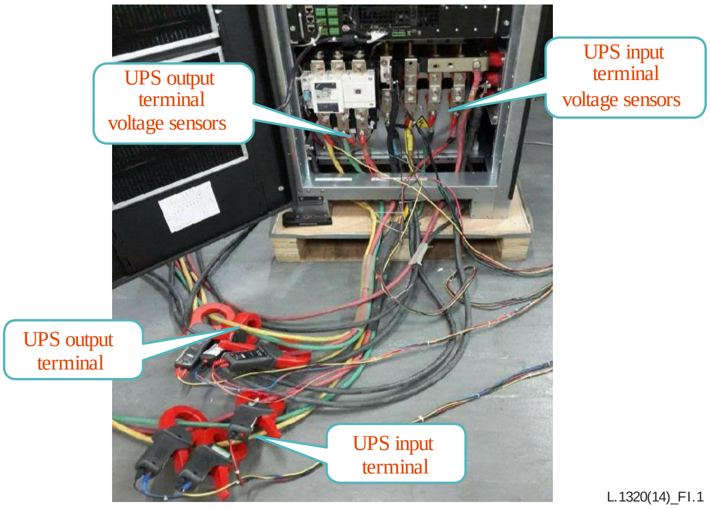

Figure I.1 – UPS testing configurations

A UPS whose output capacity is 100 kVA is tested in this example.

If the power meter has enough channels, the efficiency can be read directly from the test equipment, if this is not the case, two or more power meters can be connected. The result is calculated from data read synchronously from the several power meters. Throughout the testing period, the load is constant and without variation.

Test results are shown in Table I.1.

Table I.1 – UPS test results in different test conditions

	25%	50%	75%	100%
Linear load	22.84/24.14 = 94.56%	46.31/48.35 = 95.78%	68.56/71.68 = 95.67%	89.18/93.64 = 95.24%
Non-linear load CF = 2	___________	48.99/51.22 = 95.66%	___________	85.05/89.10 = 95.31%
Non-linear load CF = 3	16.33/17.55 = 93.02%	32.25/34.15 = 94.43%	47.38/50.18 = 94.42%	63.07/67.02 = 94.01%

Appendix II

Example of conditions for cooling equipment efficiency testing

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

Appendix II describes specific examples of cooling equipment efficiency testing and test configurations.

II.1 Environmental conditions

Temperature and humidity

For cooling equipment, the testing condition considered constant outdoor temperature and room temperature. For the air conditioner, the room temperature was (24±1)°C (dry bulb) and (16±0.5)°C (wet bulb), and the outdoor temperature was (35±1)°C (dry bulb) and (24±0.5)°C (wet bulb). No ambient temperature changes were allowed until the test was complete.

Air pressure

The equipment was evaluated at site pressure in the range of 86 000 pa to 106 000 pa. No targeted airflows were allowed.

II.2 Metrology requirements

All measurement instruments used were calibrated by the counterpart national metrology institute and within the calibration due date and the measurement tolerance was within ± 1%:

- Power measurement instrument: The power measurement instrument (such as voltmeter and ampere meter or power analyser) had an accuracy of 0.5% or better.
- Temperature measurement instruments: Temperature measurement instruments (such as a mercury glass thermometer or an electronic thermometer) had an accuracy of 0.1% or better.
- Anemometer: An Anemometer (such as a dry or wet bulb anemometer) had an accuracy of 0.1% or better.
- Air flow tester: An air flow tester had an accuracy of 0.1% or better.

Test conditions and results

An air conditioner indoor unit and outdoor unit testing configurations are shown in Figures II.1 and II.2.

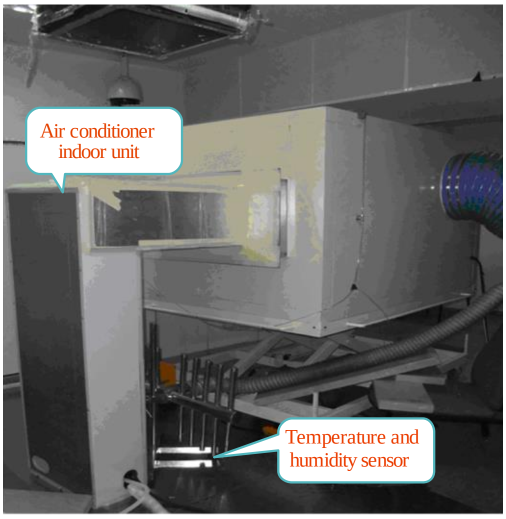

Figure II.1 – Air conditioner indoor unit testing

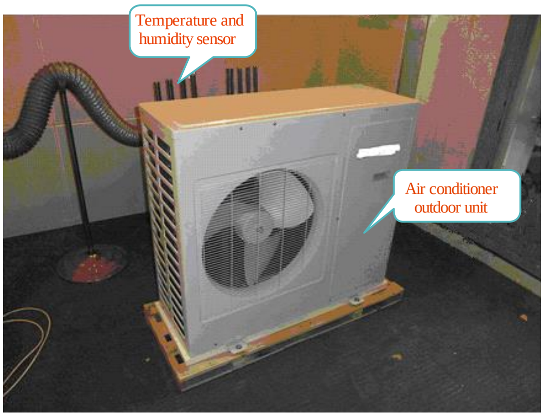

Figure II.2 – Air conditioner outdoor unit testing

An air conditioner whose output total cooling capacity is 100 kW was tested in this example. The input electrical energy and output cooling power were tested synchronously and the indoor air testing room and outdoor air testing room conditions (including temperature and humidity) were constant during whole testing process. In addition, as the testing result is influenced by ambient temperature and humidity, it was tested in the condition listed in this appendix. If the test conditions are different, the result will be completely different. Test results are shown in Table II.1.

Table II.1 – Cooling equipment test results in different test conditions

Item	Value
Room dry bulb temperature	24.04°C
Room wet bulb temperature	16.35°C
Outdoor dry bulb temperature	34.97°C
Outdoor wet bulb temperature	24.22°C
Air pressure	104.582 kPa
External static pressure	41 Pa
Phase A voltage	218.18 V
Phase B voltage	218.51 V
Phase C voltage	219.50 V
Phase A frequency	50.00 Hz
Phase B frequency	50.00 Hz
Phase C frequency	50.00 Hz
Input power	32.32 kW
Total room air volume	25613 m^3/h
QS	90.01 kW
QT	98.24 kW
η_{air}	3.04

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