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White paper –
Metrics in IT and data centre technology

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ENCLOSURES POWER DISTRIBUTION CLIMATE CONTROL IT INFRASTRUCTURE SOFTWARE & SERVICES

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Executive summary

Data centres are basic building blocks in every key sector of society in the digital world of the 21st century. They can be found in industry, hospitals and airports, but also in all fields of communication and the Internet. The growing use of mobile terminal devices and the increasing amount of data being transferred means that data centres will also continue to grow in the future.

The large-scale data centres of cloud and colocation providers require amounts of energy in the double-digit megawatt range. The total number of data centres around the world worldwide is responsible for a growing share of global CO_2 emissions. Thus the GeSI (Global e-Sustainability Initiative) [Ref. 1] predicts that IT' share of worldwide CO2 emissions will rise from 1.3% (in 2002) to 2.3% in 2020.

Reducing greenhouse gas emissions is not only a political and social task, but it is accompanied by making savings in electricity costs and is therefore of growing importance for every data centre operator – whatever their scale of operations.

In an increasingly competitive environment, data centres that are efficiently and – as part of a "Green IT Policy" – can be an important advantage, as the examples of Google [Ref. 2] and Apple [Ref. 3] are demonstrating.

To evaluate the efficiency of data centres, there is a whole series of metrics that permit no only the evaluation of energy use and CO_2 emission but also the sustainable use of water. Furthermore, metrics can be also employed to compare individual components and activities and thus the solutions offered by a variety of suppliers.

This white paper provides an overview of the most important metrics for the IT infrastructures of data centres. In the process, it becomes evident that individual metrics alone are not conclusive enough, but that data centre operators need to define an appropriate set of different parameters that are tailored for their particular applications.

The continuous recording of the relevant data and its transparent visualisation in the form of trend analyses makes it possible to operate data centres efficiently and sustainably. This way, improvements over the same months of the previous year can be displayed, while sources of variations from the target values can be sought.

Introduction

As data centres make a non-negligible contribution to global CO_2 emissions, the need for efficient operation and a sustainable use of natural resources is growing. The reduction in CO_2 emissions goes hand in hand with savings in electricity costs and it is therefore a matter of growing importance for every of data centre operator.

It is vital to capture, log and evaluate all the relevant parameters. Only the comparison of the current values with the targets, as well as with the historical data will make it possible to achieve long-lasting improvements.

In the context this white paper, a set of metrics are introduced that have been defined for assessing the effectiveness of physical IT infrastructures. Table 1 gives an overview.

Metric	Description
PUE – Power usage effectiveness	Evaluation of the effectiveness of a data centre's physical IT infrastructure
pPUE – partial PUE	Restricting this approach to a subset of a data centre
DCiE – Data Center Infrastructure Efficiency	Evaluation of the effectiveness of a data centre's physical IT infrastructure
CUE – Carbon Usage Effectiveness	Evaluation of CO_2 emissions, based on the amount of electricity used
WUE – Water Usage Effectiveness	Evaluation of water usage (e.g. in the case of adiabatic data centre cooling)
EER – Energy Efficiency Ratio	Classification of refrigeration equipment and systems
COP – Coefficient of Performance	Classification of refrigeration equipment and systems
ESEER – European Seasonal Energy Efficiency Ratio	Taking account of the installation site and ambient temperature when evaluating refrigeration equipment and systems
SEER – Seasonal Energy Efficiency Ratio	Taking account of the installation site and ambient temperature when evaluating refrigeration equipment and systems
cosφ – Power factor	Evaluation of the efficiency of UPS systems
AC/AC efficiency	Evaluation of the efficiency of UPS systems

Table 1: Overview of the metrics

Metrics

PUE – Power usage effectiveness

The “Green Grid” organisation [Ref. 4] is a non-profit association of companies, institutions and organisations founded in 2006, whose aim is to increase the efficiency and sustainability of data centres. To this end, “The Green Grid” has defined a number of metrics such as PUE, CUE and WUE in order to ensure the international comparability of measurements and the resulting conclusions.

In this context, one of the most important metrics is PUE (Power Usage Effectiveness) [Ref. 5], which is defined as follows:

$$\text{PUE} := \frac{\text{Total output of data centre}}{\text{Total output of IT devices}}$$

where:

Total output of the data centre: = IT infrastructure and IT equipment

IT devices: = e.g. servers, switches and storage systems

Definition 1: PUE – Power usage effectiveness

The PUE calculates the ratio of the total power consumption of a data centre in relation to the calculated power that is used by the active components such as servers, storage and network.

The less power the IT infrastructure needs (e.g. for climate control, power protection, and lighting), the closer the PUE is to “1”. This theoretical value can only be achieved if the entire current of data centre is only used by the servers, storage and the other active IT components.

A PUE value does not indicate the total consumption of a data centre. Thus, the PUE alone as a metric does not really tell us whether power is really saved. One simple example illustrates the problem:

> *If the server inlet temperature is set higher, the proportion of the current required for cooling decreases. However, if the temperature is so high that the fans of the servers go to full power to provide emergency cooling, the power consumption of the IT equipment will increase. The PUE is (at first sight) better, though the power consumption actually increases.*

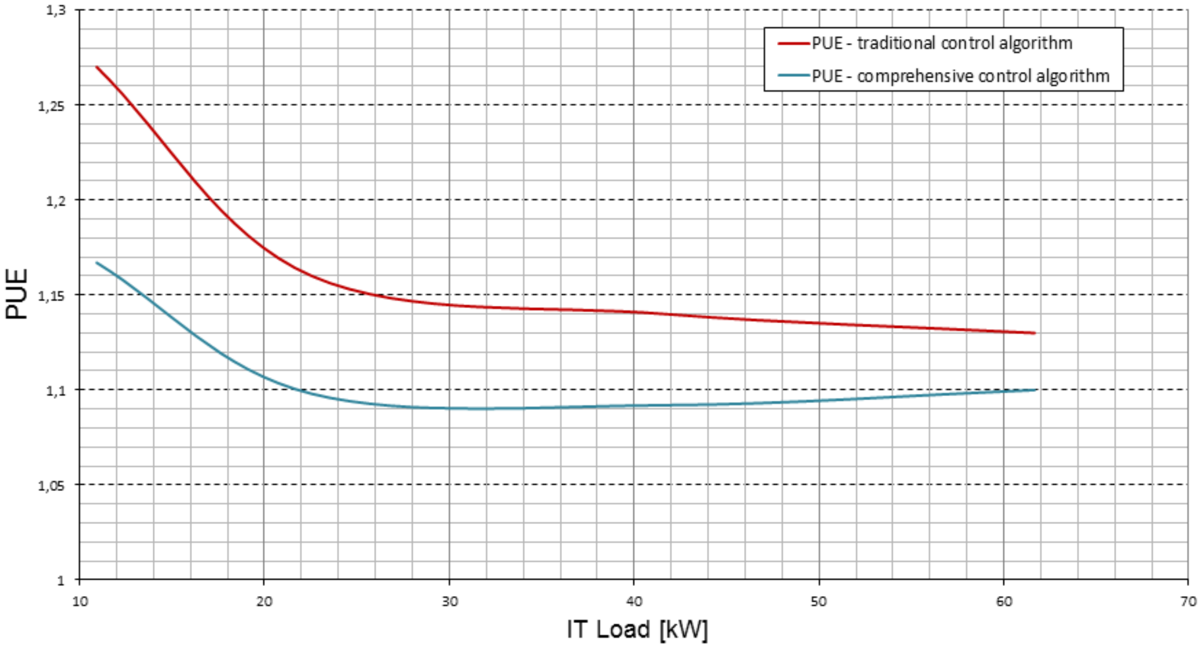

Figure 1: PUE of the “RiMatrix S – Single 6” data centre

For the reason stated, the PUE of a data centre is therefore also load-dependent, as Figure 1 shows. It is worse at a low server load, since infrastructure components – such as the UPS and air conditioning supply – are more significant. In an “overarching regulation”, the DCIM (Data Centre Infrastructure Management) software tries to find the optimal data centre operating conditions across all activities. In the case of standard regulation, the devices are optimised separately.

pPUE – partial Power Usage Effectiveness

Only a portion of a data centre is considered with the partial PUE, the pPUE [Ref. 5]. For example it is permissible to ignore cooling by free cooler or chiller when calculating a pPUE value. In this case, the interface of the pPUE would be the building limits of technology and server rooms , for example. The pPUE is therefore defined as follows:

$$\text{pPUE} := \frac{\text{Total power in one section of a data centre}}{\text{Total power of the IT devices in this section}}$$

Definition 2: pPUE – partial PUE

Figure 2 below shows the pPUE of a RiMatrix S data centre module, which must be connected to an external cooling supply in order to operate. This can be provided by the customer or achieved by using a cooling module.

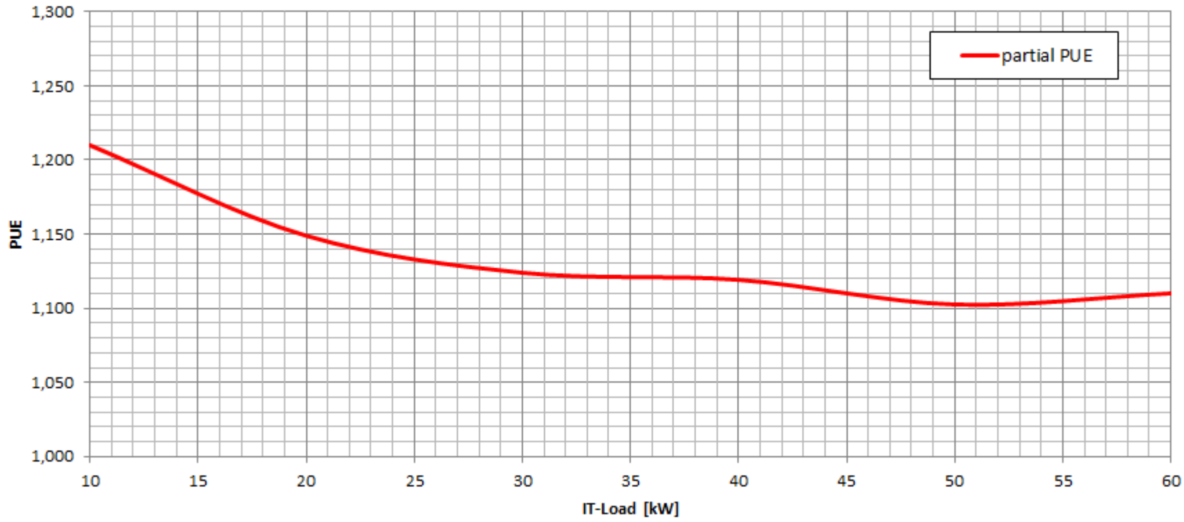

Figure 2: pPUE of the "RiMatrix S – Single 6" data centre

In this example, the pPUE indicates how efficient the module is without the external cooling source.

DCiE – Data Center Infrastructure Efficiency

The DCiE (Data Centre Infrastructure Efficiency) [Ref. 5] is defined as the inverse of the PUE:

$$\text{DCiE} := \frac{\text{Total output of IT devices}}{\text{Total output of data centre}}$$

where:

IT devices: = e.g. servers, switches and storage systems

Total output of the data centre: = IT infrastructure and IT equipment

Definition 3: DCiE – Data Center Infrastructure Efficiency

The PUE calculates the ratio of the total power consumption of a data centre in relation to the calculated power that is used by the active components such as servers, storage and network.

As a rule, the DCiE is specified as a percentage, as shown in Figure 3. An ideal data centre would have a DCiE value of 100% would thus be "one hundred per cent efficient".

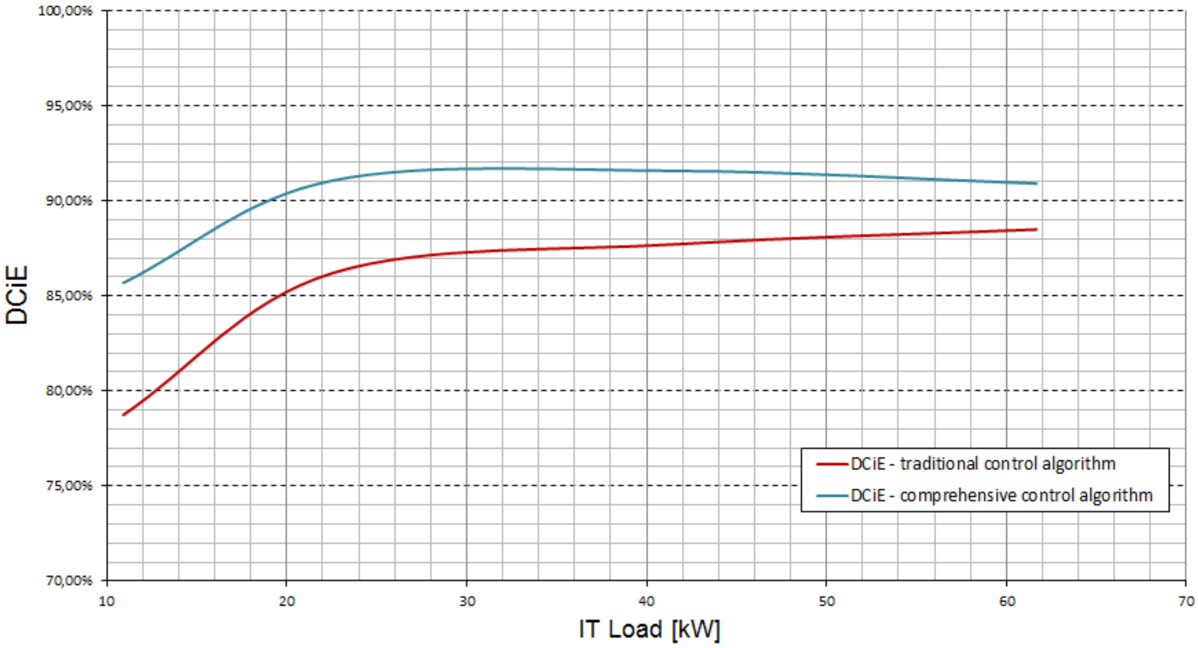

Figure 3: DCiE of the “RiMatrix S – Single 6” data centre

In order to ensure sustainability, it is necessary to consider the PUE or DCiE over the time, based on trend analyses made over the course of the year. This is because the cooling supply depends on the external climatic influences at the respective location.

It is necessary to note how these values were determined, both in the case of PUE and DCiE data:

- Are these theoretical values, determined based on the data sheets of the components and devices installed?
- Are they measured values, whereby a distinction must be made between:

  a) A current value, which was measured at a particular point in time,

  b) A mean value measured over a given time period (for example one year)?

The following equation applies when a calculating a mean PUE:

$$PUE = \frac{1}{n} * \sum_{i=1}^{n} PUE(i)$$

n: = Number of measured values

Definition 4: Mean PUE

Where attention must be paid to measurements made at equidistant time intervals.

CUE – Carbon Usage Effectiveness

The CUE (Carbon Usage Effectiveness) metric [Ref. 6] has been defined by the "Green Grid" [Ref. 1], in order to supplement the PUE metric. The aim of the CUE is to describe the sustainable use of electrical energy in a data centre. The CUE has been defined such that an ideal data centre has no CO_2 emissions:

> CUE := CEF x PUE
>
> Where the term CEF (Carbon Emission Factor) specifies the CO_2 factor of the electrical power mix.

Definition 5: CUE – Carbon Usage Effectiveness

The calculation of CO_2 emissions per kWh electricity consumed is country-specific, because it is based on the respective electrical power mix (nuclear power, coal and gas or renewables). In Germany, the calculation of the coefficient is performed by the German Environmental Agency (UBA) [Ref. 7] and it is published annually as shown in Figure 4.

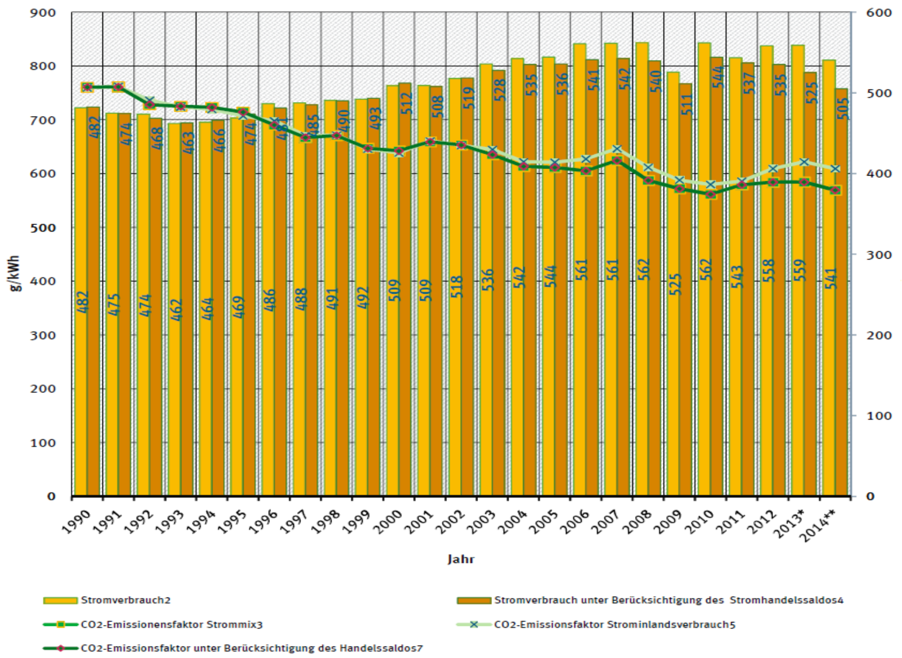

Figure 4: CO_2 calculation based on the German electrical power mix (1990 – 2014)

Similarly, these figures and factors are also published in other countries , such as in the United States by the US Energy Information Administration [Ref. 8]. From above equation [Definition 5], it is clear that the CUE has the value "0", if a data centre exclusively uses electricity from renewable sources.

WUE – Water Usage Effectiveness

With regard to the growing use of direct free cooling in particular, the sustainable use of water is gaining in significance. The ASHRAE organisation [Ref. 9] provides exact targets with regard to the temperature and humidity [Ref. 10] at which the active IT components of a data centre are to be operated. For example, if the air is too dry (in the case of direct free cooling) it must be humidified. Free cooling is also often used in connection with an adiabatic cooling system.

On hot days, the air/air heat exchanger is sprayed with water. The evaporative cooling reduces the temperature of the cold air supplied to the data centre via the heat exchanger. Water is also used for example in the Facebook data centre in Prineville [Ref. 10, Ref. 12].

In order to take this trend that into account, “The Green Grid” [Ref. 1] defined a WUE metric [Ref. 11] with which the use of water is used in relation to the power consumption of the IT components:

$$\text{WUE} := \frac{\text{Annual water consumption}}{\text{Functional testing of all active components}}$$

The unit of WUE is therefore: [l/kWh] (litre per kWh)

Definition 6: WUE – Water Usage Effectiveness

EER – Energy Efficiency Ratio

The EER (Energy Efficiency Ratio) is used to specify the efficiency of cooling systems and devices. The EER is defined as the ratio of cooling output to the absorbed electrical power:

$$\text{EER} := \frac{\text{Output of the cooling system}}{\text{Electrical power consumption of the refrigeration system}}$$

Definition 7: EER – Energy Efficiency Ratio

The EER is a number that indicates how efficiently a cooling system works. The greater the EER, the more efficiently the electrical energy is used to cool.

COP – Coefficient of Performance

The COP (Coefficient of Performance) of a heat pump or refrigerating machine is the ratio of the change in the heat to the applied expended for this purpose. Thus the following applies for a cooling system:

$$\text{COP} := \frac{\text{Cooling output}}{\text{Work expended}}$$

A COP can also be displayed as an EER by a conversion:

EER := 3.41214 x COP

Definition 8: COP – Coefficient of Performance

The standards DIN EN 255 [Ref. 13] and DIN EN 14511 [Ref. 14] describes how the COP or the EER can be measured. This ensures that the data sheets of the different manufacturers of refrigerating machines can be compared.

ESEER/SEER – (European) Seasonal Energy Efficiency Ratio

The efficiency of a cooling system is dependent on the external climatic conditions, as well as the subsequent Figure 5 shows, in which the EER curves for some Rittal chillers with free cooling are shown.

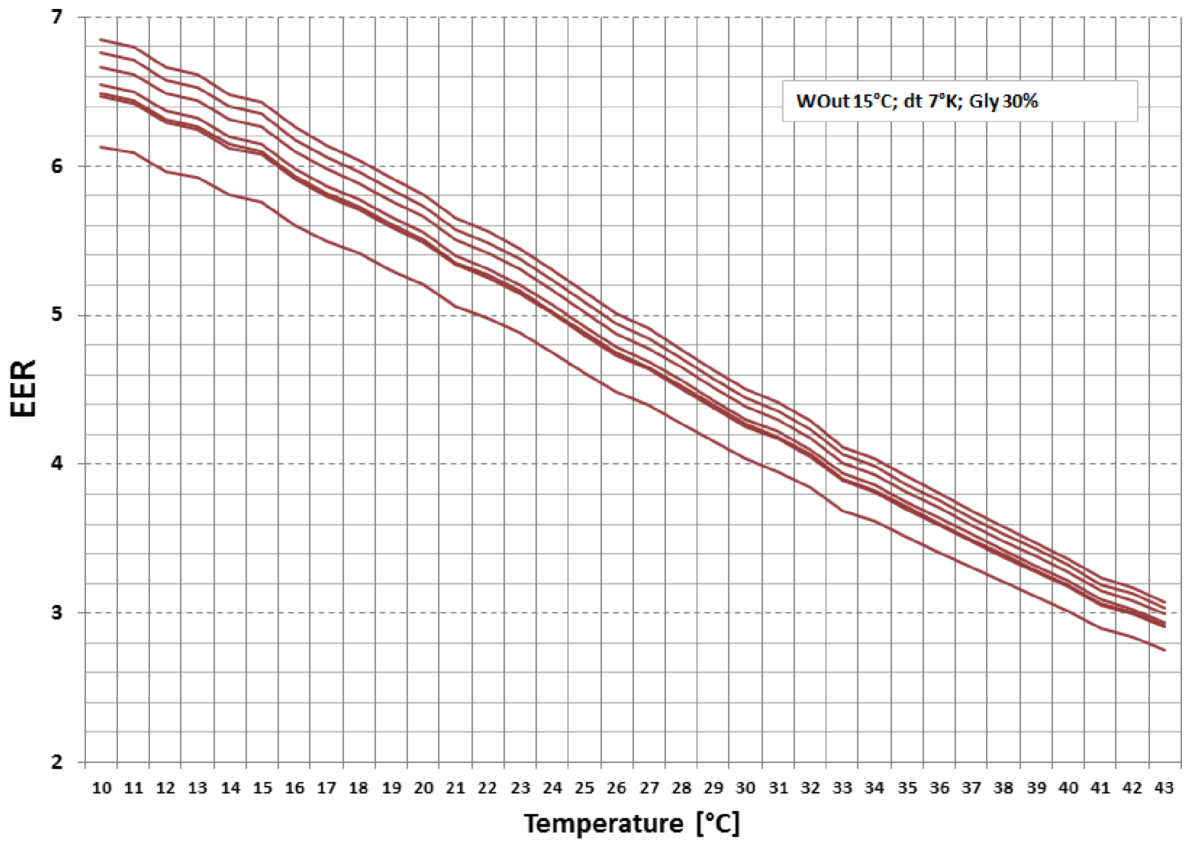

Figure 5: Temperature dependence of the EER

Eurovent [Ref. 15] defined the ESEER to adjust the EER to the influences of temperature. In Table 2 below, the relevant factors are listed, as they arise for either an air-cooled or water cooled refrigerating machine.

Load / partial load	Air temperature	Water temperature	Factor
100%	35°C	30°C	3%
75%	30°C	26°C	33%
50%	25°C	22°C	41%
25%	20°C	18°C	23%

Table 2: ESEER factors

According to the Eurovent specifications [Ref. 15] the ESEER is calculated from the EER as follows:

$$\text{ESEER} = \text{EER}\ [100\%] \times 0.03 + \text{EER}\ [75\%] \times 0.33 + \text{EER}\ [50\%] \times 0.41 + \text{EER}\ [25\%] \times 0.23$$

Definition 9: ESEER – European Seasonal Energy Efficiency Ratio

The SEER (Seasonal Energy Efficiency Ratio) metric set out as follows in the ANSI/AHRI STANDARD 210/240 [Ref. 16]:

$$\text{SEER} := \frac{\text{Total annual cooling output}}{\text{Total annual electrical power consumption}}$$

Definition 10: SEER – Seasonal Energy Efficiency Ratio

cosφ – Power sfaktor

The power factor is often used in conjunction with UPS systems to characterise the efficiency of such systems. This is reasonable if the signal form on the output side is a pure sine wave and has no harmonics. This applies for modern double transducer systems of the VFI-SS-111 category, in accordance with IEC EN 62040-3 [Ref. 17].

The power factor cosφ is defined as follows:

$$\cos\varphi := \frac{\text{Active power}}{\text{Apparent power}}$$

Definition 11: cosφ – Power factor

The closer the power factor is to "1", the more efficient the USP system is. The power factor, defined by the ratio between the active and apparent power, is a measure of the phase shift between current and voltage of the alternating current, as it occurs due to capacitive or inductive effects.

The input-side power factor of a UPS is also dependent on the load, and is generally specified for a variety of loads on the UPS system, as Table 3 below shows for a ABB-Rittal DPA Upscale System:

cosφ	Load
0.999	100%
0.995	75%
0.985	50%
0.960	25%

Table 3: Input-side power factor, ABB Rittal DPA Upscale

Since a pure sine wave is again created by the battery from the output-side, the power factor on the output side is “1”.

AC/AC efficiency

Another important parameter of a UPS system is the efficiency, which is calculated as the ratio of the output power to the input power. The AC/AC efficiency is therefore:

$$\text{AC/AC efficiency:=} \quad \frac{\text{Power output}}{\text{Power input}}$$

Definition 12: AC/AC efficiency

Due to the internal losses of the UPS, the efficiency depends on the load. The efficiency is better the more a UPS system is subjected to load.

Efficiency	Load
95.5%	100%
95.5%	75%
95.0%	50%
94.5%	25%

Table 4: Representation of the load-dependent efficiency of an ABB Rittal DPA Upscale

References

Ref. 1 Global e-Sustainability Initiative, “GeSI SMARTer2020: The Role of ICT in Driving a Sustainable Future“, Link: http://gesi.org/assets/js/lib/tinymce/jscripts/tiny_mce/plugins/ajaxfilemanager/uploaded/SMARTer 2020 - Executive Summary -December 2012.pdf

Ref. 2 Google data centre – efficiency link: http://www.google.com/about/datacenters/inside/efficiency/power-usage.html

Ref. 3 Apple data centres – renewable energies, link: http://www.apple.com/environment/renewable-resources/

Ref. 4 The Green Grid, Link: http://www.thegreengrid.org/

Ref. 5 The Green Grid, WHITE PAPER #49, PUE™: A COMPREHENSIVE EXAMINATION OF THE METRIC http://www.thegreengrid.org/en/Global/Content/white-papers/WP49-PUEAComprehensiveExaminationoftheMetric

Ref. 6 The Green Grid, WHITE PAPER #32, CARBON USAGE EFFECTIVENESS (CUE™):A GREEN GRID DATA CENTER SUSTAINABILITY METRIC http://www.thegreengrid.org/~/media/WhitePapers/CUE

Ref. 7 Umweltbundesamt (*German Environment Agency*), 2015, Strom- und Wärmeversorgung in Zahlen (*Power and heat supply in figures*), link: http://www.umweltbundesamt.de/themen/klima-energie/energieversorgung/strom-waermeversorgung-in-zahlen

Ref. 8 U.S. Energy Information Administration, 2015, Environment Analysis and Projections, Link http://www.eia.gov/environment/emissions/carbon/

Ref. 9 https://www.ashrae.org

Ref. 10 https://nsidc.org/about/green-data-center/project.html

Ref. 11 The Green Grid, WHITE PAPER #35, WATER USAGE EFFECTIVENESS (WUE™):A GREEN GRID DATA CENTER SUSTAINABILITY METRIC http://www.thegreengrid.org/~/media/WhitePapers/WUE

Ref. 12 Gigaom, 2015, Link: https://gigaom.com/2012/08/17/a-rare-look-inside-facebooks-oregon-data-center-photos-video/

Ref. 13 DIN EN 255, “Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers using electrically driven compressors”

Ref. 14 DIN EN 14511, “Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling”

Ref. 15 Eurovent Association, Link: http://www.eurovent-association.eu/

Ref. 16 ANSI/AHRI STANDARD 210/240, “Performance Rating of Unitary Air - Conditioning & Air - Source Heat Pump Equipment”

Ref. 17 IEC EN 62040-3, Uninterruptible power systems (UPS) – Part 3: Method of specifying the performance and test requirements.

List of abbreviations

AC	Alternating Current
AC/AC	AC-AC Efficiency: Degree of efficiency of UPS systems
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CEF	Carbon Emission Factor
COP	Coefficient of Performance
CUE	Carbon Usage Effectiveness
DCiE	Data Center Infrastructure Efficiency
DPA	Digital Parallel Architecture
EER	Energy Efficiency Ratio
ESEER	European Seasonal Energy Efficiency Ratio
IT	Information Technology
ICT	Information and Communications Technology
pPUE	Partial Power Usage Effectiveness
PUE	Power Usage Effectiveness
RZ	Rechenzentrum
SEER	Seasonal Energy Efficiency Ratio
SPEC	Standard Performance Evaluation Corporation
UPS	Uninterruptible Power Supply
VFI-SS	Voltage, Frequency Independent - sine wave form at both input and output
WUE	Water Usage Effectiveness

Rittal – The System.

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- Enclosures
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