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white paper – The Cooling Technology of the RiMatrix S Data Centre

SCHALTSCHRÄNKE STROMVERTEILUNG KLIMATISIERUNG IT-INFRASTRUKTUR SOFTWARE & SERVICE

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Executive summary

With the RiMatrix S modular data centre system, we take a new path in the planning, implementation and operation of data centres. The RiMatrix S modular system concept consists of a range of optimally matched data centre modules.

A standardised data centre provides all advantages of a serial product. Data centre construction means assembling intertwining modules which all have interfaces matched to one another. If the boundary conditions are specified, the data centre data sheet is already known in the planning phase. Further advantages of a serial product bear fruit in the project phase: to be counted among that are easy planning, short delivery time and fast commissioning. An important aspect – apart from the low prime cost – is also the high energy efficiency which involves low operating costs. The low operating costs can amortise the investment in a RiMatrix S data centre in a reasonable period of time.
Energy efficiency is achieved by means of matched data centre modules. Here, the cooling circuit (cold air generation, transport of cold air / waste heat and cold air distribution in the data centre) is essential. An intelligent closed-loop control controls the IT infrastructure dependent on the server load in such a way that as few energy as possible is consumed, thus achieving optimum energy efficiency.

An advantage of standardised data centre modules is that they were developed for best possible efficiency already at the requirements definition. Moreover, they include complete data sheets stating the efficiency under different operating conditions (for example, electrical consumption of the servers, geographical position of the site). Thus, it is possible to determine the energy demand of a planned data centre already in the quotation phase and to consider this in the investment decision.

This technical report describes the cooling technology of the RiMatrix S modules.

Introduction

An elaborate modular system of complementary data centre modules (Figure 1) opens up new perspectives in the planning, implementation and operation of data centres. By means of defined, standardised interfaces, individual server modules (Ref. 1) are combined with central supply modules (power supply, cooling) to complete solutions.

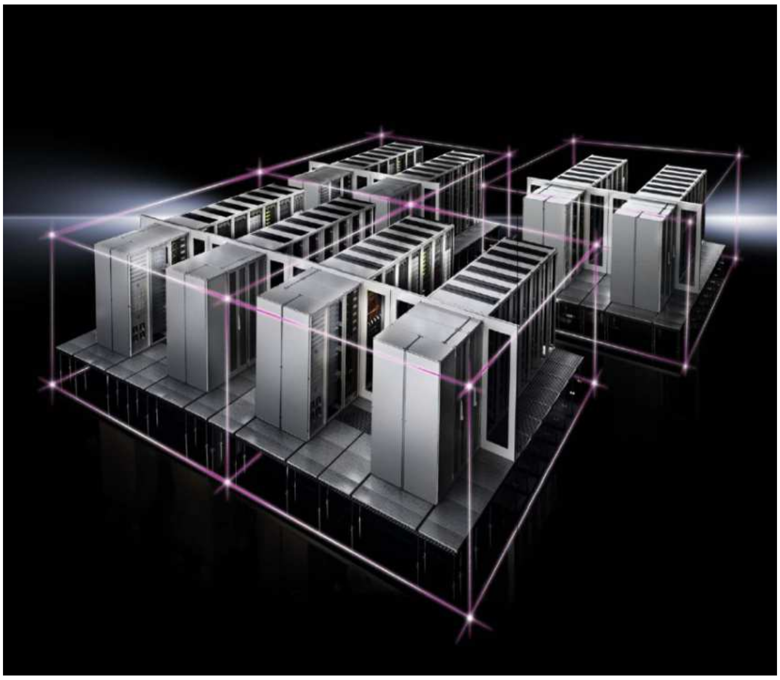

Figure 1: Data centre modules of the RiMatrix S modular system

This not only facilitates the planning phase but also clearly shortens the delivery and commissioning time. Moreover, the individual modules are optimally matched to one another, which results in excellent energy efficiency.

The data sheets of the data centre modules allow a complete ROI (Return on Investment) consideration. This includes not only the investment sum but also a detailed analysis of the operating costs to be expected; here, in particular the electricity costs are to be analysed, which can be considerably reduced by means of an intelligent climate control.

This technical report describes the cooling technology of the standardised RiMatrix S data centre (server modules and cooling module).

Efficiency metrics

A primary feature of the RiMatrix S modules is the guaranteed, calculable efficiency. This is based on the fact that the data centre modules are regarded as one complete unit. These data centre modules are completely documented and include a specification which renders all relevant parameters. This is the basis for the efficiency and operating costs calculation. Therefore, the most important metrics will be explained first:

A) Energy consumption / (electrical energy) [kWh]

Every data centre operator's primary objective is to keep the energy consumption of the data centre as low as possible. From the energy consumption you can directly derive the CO_2 balance, the electricity costs and thus a part of the operating costs.

B) PUE / DCiE

The two best known metrics are the **P**ower **U**sage **E**ffectiveness (PUE) and its reciprocal, the **D**ata **C**entre **I**nfrastructure **E**fficiency (DCiE). These metrics were defined by Green Grid (Ref. 2).

"PUE = Total Facility Energy divided by the IT Equipment Energy
- This takes into account energy use within a facility
- Partial PUE is for energy use within a boundary

pPUE = Total Energy within a boundary divided by the
IT Equipment Energy within that boundary"

With regard to RiMatrix S this means that the division is to be considered as follows:

IT Equipment := server load
Total Facility Energy := losses of UPS and power distribution + cold air production + cold air transport + cold air distribution + IT equipment + lighting + other consumers

The DCiE is the reciprocal of the PUE. The PUE or DCiE alone are no suitable variables to optimise a data centre, as they just represent the ratio of two values but no absolute numbers. However, the PUE in the course of the year shows the sustainability or improvement due to optimisation measures.

C) EER / COP

To optimise a data centre with regard to efficiency, it is necessary to view individual sections in detail, in particular the cold air generation. For this, special metrics such as EER and COP are available.

The EER (**E**nergy **E**fficiency **R**atio) is used to specify the efficiency of cooling systems. The EER is defined as the ratio of cooling capacity (in BTU/h) to absorbed electric power (W).
BTU is an old English unit (British Thermal Units). It corresponds to 1.055 joules, which are required to heat "1 Pound" of water (0.454 kg) from 3.8 to 4.4° C.

The COP (**C**oefficient **o**f **P**erformance) of a refrigerating system is the ratio of the heat change to the energy spent for that. Therefore, the following applies to a cooling system:

$$\boxed{COP = Q_C / W}$$

where Q_C is the cooling capacity (reduced heat) and W the energy spent for that.

The climate concept of the server modules

The RiMatrix S modular system concept provides four different server modules. In the following Figure 2, the variants Single 9 and Double 9 are shown.

Figure 2: Server modules Single 9 and Double 9

The Double 9 variant consists of two Single 9 modules mirrored at the symmetry axis. The following front view clarifies the structure.

Figure 3: Structure of the Single 9 module

In the left part of the Single 9 module, eight server enclosures and one network enclosure are placed, followed by the subdistribution. The cold area is situated before the server level.

The warm area – on the rear of the server enclosures – is separated from the cold area by means of a partition.

The following Figure 4 shows the Single 6 as well as the Double 6 module, which is in turn composed of two Single 6 modules.

Figure 4: Server modules Single 6 and Double 6

In the left part of the Single 6 module, six server enclosures and one network enclosure are placed in the data centre area. The technical part with USP, battery and subdistribution is separated from that by means of an aisle partition. The Double 6 variant consists of two Single 6 modules mirrored at the symmetry axis.

The separation of data centre area and the technical area allows decoupling of the server injection temperature from the lower temperature in the technical area so that two climate zones arise. This provides two advantages:

- The service life of the battery is prolonged if it can be kept at a temperature of ~20° Celsius.
- Moreover, the battery room can be ventilated so that even in the event of a battery failure, no detonating gas can form.

The raised floor of the server modules serves not only for air routing but also for taking the air conditioners of the cold air distribution, as shown in Figure 5.

Figure 5: Air routing of the server modules

In order that as many server racks as possible can be placed within a server module, the air conditioners were placed in the raised floor.

Therefore, the perforated raised floor panels feature an integrated high-performance fan in EC design – as shown in Figure 5 –, which blows the cold air directly before the server racks. The heat exchanger, which cools down the air using cold water, is located in the raised floor beneath the respective enclosure. Above the bayed enclosure suites, a partition ensures the division into a cold area before the servers and a warm area behind the servers.

The combination of heat exchanger and associated fans is called ZUCS (Zero U-space Cooling System), as no useful area for servers (height unit, U, U-space) is required.

Therefore, the airflow is as follows: the warm exhaust air of the servers flows through the raised floor, is cooled down by the heat exchanger and blown before the server level again via the fans.

For this innovative, highly compact climate control technology, a patent has been applied.

Cold air generation – the RiMatrix S cooling module

For cooling, the heat exchangers must be supplied with cooling water. The cold air container required for that consists of a large, V-shaped free cooler, redundant chillers and a pump and control station at the head end.

The RiMatrix S cooling module is optimally designed for the RiMatrix S server modules. It is available in two performance classes:

- 70 kW (for Single 6 server modules)
- 100 kW (for Single 9 server modules)

Each cooling module consists of the following basic components:

- Free cooler
- Two redundant chillers
- Pump and control station

Figure 6: RiMatrix S cooling modules

To analyse the system efficiency and behaviour in different operating states at different ambient temperatures, we recommend regarding the EER. The RiMatrix S cooling module has the following efficiency curve in the range of an inlet temperature of 15-20° C:

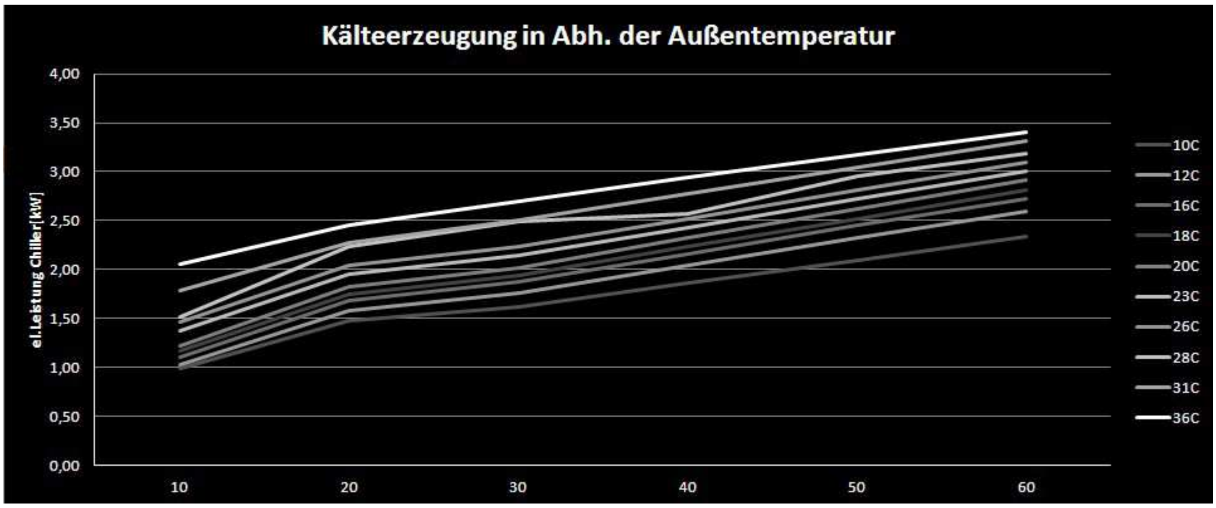

Figure 7: Efficiency of the cooling module

The free cooler features EC fans that show a non-linear progress in the characteristic curve, which is reflected in the power consumption of the free cooler.

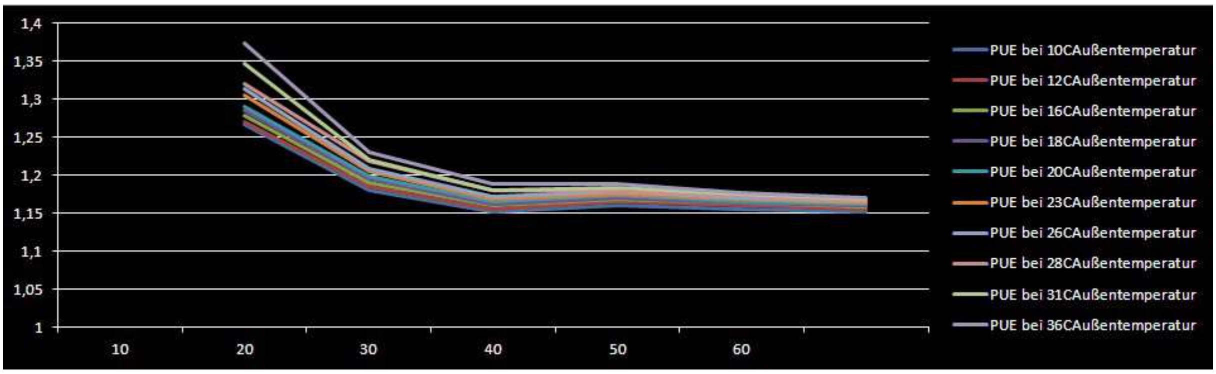

Figure 8: Efficiency dependent on the ambient temperature

With the ambient temperature increasing, a continuous efficiency reduction is recognizable. Therefore, the objective must be to operate the servers with an air intake temperature as high as possible to minimize the use of the chillers (compressor cold air) and to precool as much as possible with the free cooler.

The cooling concept allows the realisation of an almost homogeneous temperature distribution before the servers. A delta T of ~ 1K, measured from the 1st to the 42th height unit, can be realised for the RiMatrix S. This provides the option to select the server injection temperature close to the recommendations by ASHRAE and to ensure high availability in addition to energy efficiency.

Efficiency consideration

The RiMatrix S components in the cooling circuit (cold air generation, cold air transport and its distribution in the server module) are optimally matched to one another. A decisive factor for efficiency increase is the closed-loop control.

Figure 9 first of all shows a measurement without optimised closed-loop control. First, the load of a Single 6 server module is increased up to 60 kW at an ambient temperature of 5° C and an inlet temperature of 20° C.

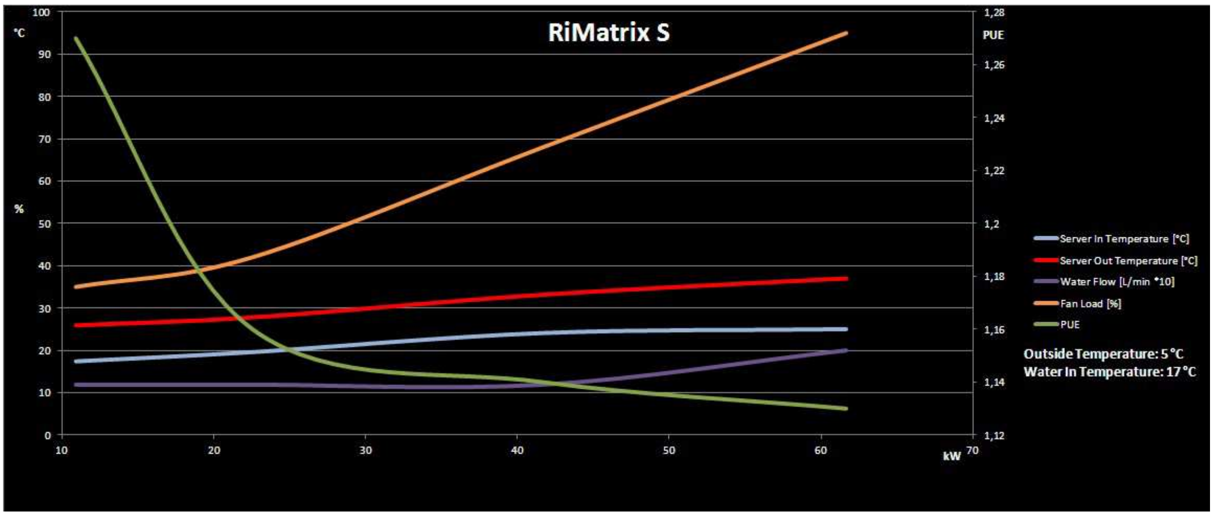

Figure 9: Characteristic curve of the RiMatrix S – without optimised closed-loop control

The measurement shows an efficiency drop (PUE, green curve) at low outputs. Among other things, this is due to the non-linear behaviour of the UPS, as the efficiency of the UPS drops clearly in the lower part-load range.

Moreover, the PUE calculation according to Green Grid shows that at low IT load the share of the infrastructure load becomes greater in the computation, as the infrastructure – such as the UPS – cannot be scaled linearly.
In the medium and upper load range, however, the UPS shows excellent efficiency.

Inlet temperatures and aisle partition

An important aspect is the inlet temperatures. The higher the inlet temperatures are, the longer can the free cooling be used. ASHRAE (Ref. 3) issues recommendations for that:

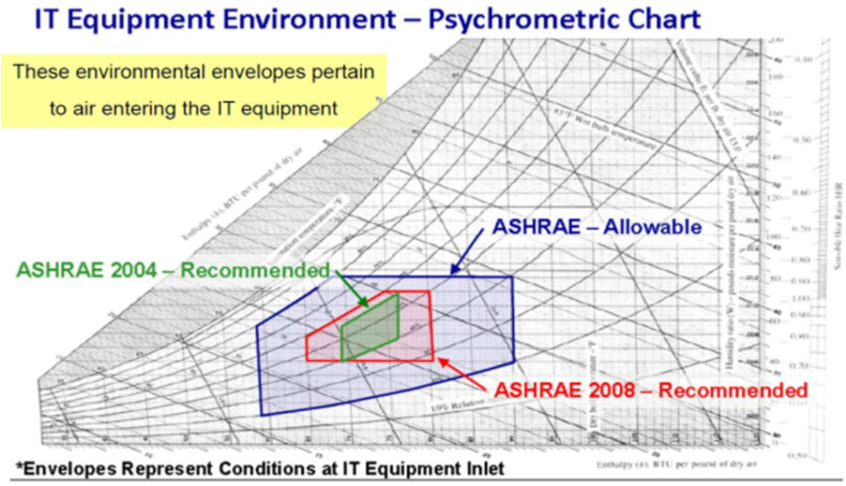

Figure 10: HX diagram from ASHRAE

The inlet temperature must be selected such that the air injection temperature before the server level complies with the ASHRAE specifications.

A second important aspect is the aisle partition, that is, the systematic separation of the warm and cold areas in the data centre. Complete aisle partitioning is the prerequisite for a high temperature at the rear of the servers. The difference between air injection temperature and discharge temperature is decisive for climate control.

The higher the return air temperature is, the more energy efficiently does the cold air generation work. The following applies to the thermal energy Q:

$Q := c\ m\ \Delta T$

where

c := specific thermal coefficient

m := mass of the transport medium (water or air)

This means, the higher delta T is, the less air needs to be circulated to transport the waste heat of the servers. Likewise, the higher delta T is between water inlet and water outlet, the less water needs to be pumped between cold air generation and cold air distribution to transport the heat out of the data centre.

Moreover, the higher the water return temperature, the longer can the free cooling be used in the course of the year to cool down the water or to precool it in mixed operation.

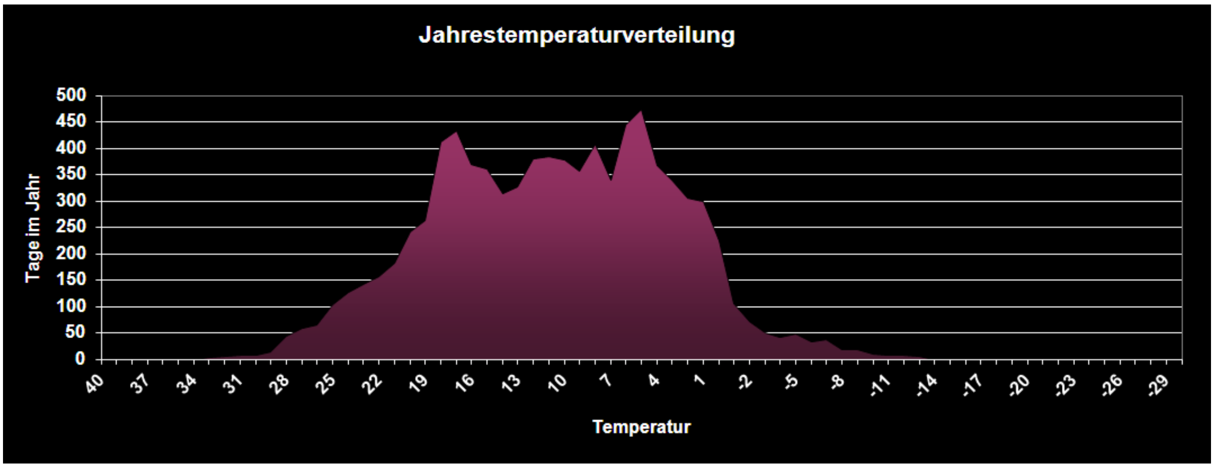

Figure 11: Typical annual temperature curve

The use of free cooling operation depends greatly on the geographical position (annual temperature curve) and the set temperatures. In order that a desired server air intake temperature of 24.0° C can be set with the free cooler, the ambient temperature must be lower than 20° C, for example. If the ambient temperature is higher, the water can be precooled using the free cooler so that subsequently the desired temperature can be generated in mixed operation with the chiller. If the ambient temperature is higher than the temperature in the return flow (26.2° C), the free cooler cannot be used any longer and the cold air needs to be generated mechanically/electrically.

In the example above, the temperature is warmer than 22.0° C in 343 hours only. However, this means that in 96.1% of the year the free cooling can be used to cool down the data centre.

This makes clear again how important it is to increase the inlet temperatures and to set a delta T as great as possible. All this must, of course, be done in compliance with the IT requirements (ASHRAE or customer specifications).

Cross-section closed-loop control

Cross-section control means optimal, consumption-dependent control of all components involved in the cooling process (cold air generation, cold air transport, cold air distribution).

Figure 12 shows a typical measurement with cross-section closed-loop control, where the water inlet temperature is 22° C.

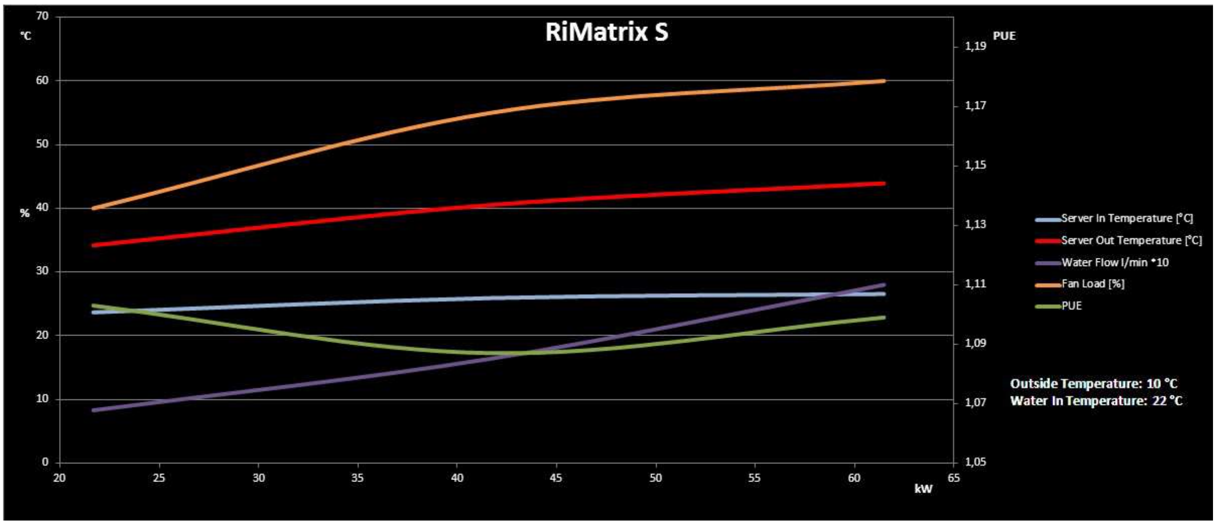

Figure 12: Characteristic curve of the RiMatrix S – with optimised closed-loop control

In the upper performance range, the efficiency (PUE) shows a slight increase again. This can be explained with the characteristic curve of the EC fans used in the climate control system, as this shows a non-linear increase in the upper performance range (fan law). Therefore, in the dimensioning of the fans as well as in the closed-loop control algorithm, it was paid attention to operating the fans in the medium performance range – that is, energy efficiently – only.

A comparison of the measurements without optimised closed-loop control (Figure 9) and with optimised closed-loop control (Figure 12) shows the effect of cross-section closed-loop control. The following factors are taken into account:

Delta T closed-loop control (ΔT)

Already in the first measurement (Figure 9) without cross-section closed-loop control the principle of delta T closed-loop control becomes clear. In a delta T closed-loop control, the fan speed is controlled dependent on the temperature difference between server inlet (light blue curve) and server outlet (red curve) and thus the volumetric flow is adapted.

Delta P closed-loop control

Here, it is paid attention that the servers are provided with only as much air as they can currently take in with their internal fans. The air is provided on the cold aisle side with the lowest overpressure of 1-2 Pa.

A delta P closed-loop control takes care that the air pressure between the cold area (server inlet) and the warm area (server outlet) is constant.

Sliding inlet temperatures

The inlet temperature is increased autonomously by the cooling system until a defined server air intake temperature can no longer be maintained. For that, the external cooling system "may", for example, autonomously change the flow rate or switch between compressor and indirect free cooling or change the fan / compressor speed. However, the limit temperature / maximum server injection temperature must be observed by all means.

In this way, additional energy efficiency is achieved, as the share of free cooling is increased due to the respective maximum inlet temperature. The inlet temperature is fed in dynamically with the IT load. This results in a clear efficiency increase.

Cross-section closed-loop control

The objective of cross-section closed-loop control is an optimisation across all components involved in cooling, taking into account the electrical power consumptions. The control variable is the electrical power consumption of the complete system, which is to be minimized.

The previous "server air intake temperature" control variable endures only insofar as it represents an upper limit temperature.

For this, the master control may change the same parameters as described above as well as all ZUCS control variables (parameters of the cold air distribution in the data centre). The parallel measurement of all electrical power consumptions ensures the direct influence of a "control action" on the energy balance of the complete system. The individual parameters must be adapted such that the minimum total energy is absorbed and the limit temperature is not exceeded.

Figure 13 shows a PUE comparison between normal operation (without cross-section closed-loop control) and the use of cross-section closed-loop control.

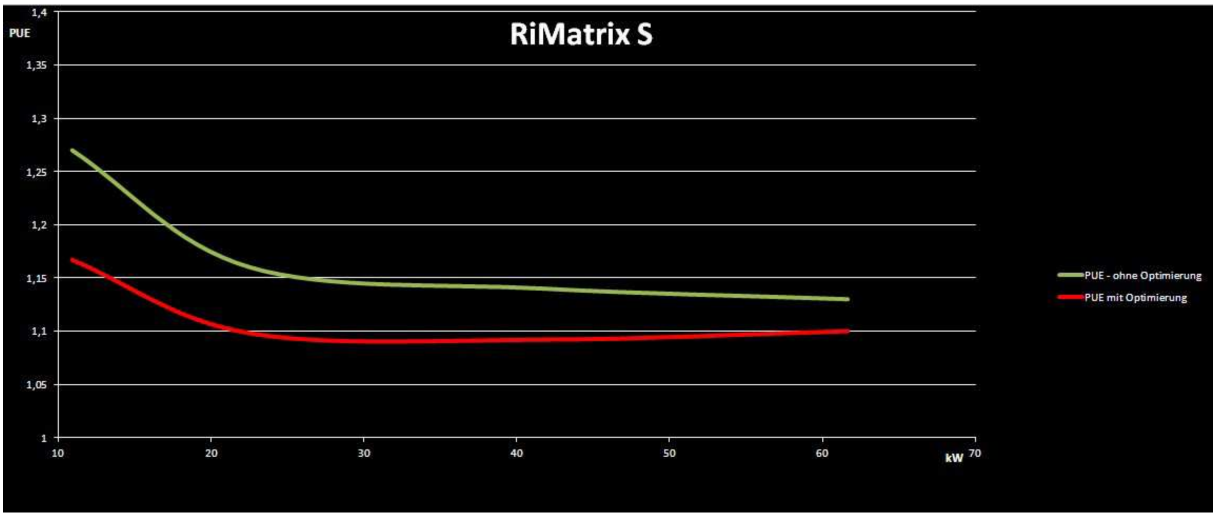

Figure 13: Efficiency comparison

Figure 20: PUE comparison without and with cross-section closed-loop control

It is ensured that the system consumes minimum electrical power and is operated securely. If simply the inlet temperatures and thus the server air intake temperatures were increased, the energy consumption of the servers would rise abruptly from a temperature of approx. 27° C on (dependent on the servers used). From a so-called limit temperature on, the powerful fans of the servers switch to 100% speed, which means significant increase of the IT load – the PUE improves, but the total energy balance does not. However, the customer pays kWh and not the PUE. Therefore, cross-section closed-loop control, which optimises with regard to the total energy consumption, is reasonable.

Assessment of the measurement results

The following sample calculation for a 60 kW data centre with medium load can be established from the above measurements.

Data centre information

60 kW data centre	30	kW average load
PUE with chiller operation	1.5	
PUE without cross-section closed-loop control	1.3	
PUE with cross-section closed-loop control	1.1	
Period: 365 days, 24 hours	8760	hours

Infrastructure share

Energy consumption in non-optimised chiller operation	131400	kWh	77526	kg CO_2
Energy consumption in non-optimised free cooling operation	78840	kWh	46516	kg CO_2
Energy consumption in optimised free cooling operation	26280	kWh	15505	kg CO_2

As described before, the free cooling operation can be used in 96.1% of the year. Therefore, an improvement of the PUE from 1.3 to 1.1 means annual savings of:

Saving	50510	kWh	29801	kg CO2

With an optimised closed-loop control, the CO_2 emission of the infrastructure share of the data centre can be reduced by another 60% in free cooling operation. However, even a PUE of 1.5 in pure chiller operation is already an excellent value for a data centre. Altogether, it can be stated that the new cooling concept (ZUCS climate control) as well as the cross-section closed-loop control lead to significant efficiency improvement.

Summary

A standardised data centre consisting of matched data centre modules provides a number of advantages. To be rated among that is the availability of the data centre operation, easy planning, short delivery times and fast commissioning. An important aspect – apart from the low prime cost – is also the high energy efficiency which involves low operating costs.

This is achieved by means of the matched data centre modules. Here, the cooling circuit (cold air generation, transport of cold air / waste heat and cold air distribution in the data centre) is essential. An intelligent closed-loop control controls the IT infrastructure dependent on the server load in such a way that as few energy as possible is consumed and high availability is achieved.

An advantage of standardised data centre modules is that they were developed for best possible efficiency and availability already at the requirement definition. Moreover, they include complete data sheets stating the efficiency under different operating conditions (for example, electrical consumption of the servers, geographical position of the site).

Thus, it is possible to determine the power requirements of a planned data centre already in the quotation phase and to consider this in the investment decision.

List of references

Ref. 1: Technical Report – RiMatrix S – A Concept for Standardised Data Centre Construction

Ref. 2: The Green Grid, http://www.thegreengrid.org/

Ref. 3: ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Organisation: https://www.ashrae.org/

List of abbreviations

ASHRAE	-	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	-	British Thermal Units
COP	-	Coefficient of Performance
DCIE	-	Data Centre Infrastructure Efficiency
DCIM	-	Data Centre Infrastructure Management
EER	-	Energy Efficiency Ratio
PUE	-	Power Usage Effectiveness
ROI	-	Return on Investment
UPS	-	Uninterruptible Power Supply
ZUCS	-	Zero U-Space Cooling System

Rittal – Das System.

Schneller – besser – überall.

- Schaltschränke
- Stromverteilung
- Klimatisierung
- IT-Infrastruktur
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