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Free Cooling for Data Centers

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Contents

1. Abstract

This white paper provides an overview of free cooling for data centers. It consists of a general description of free cooling and an explanation of different available free cooling solutions, as well as their strengths and weaknesses. The term “free cooling” is equivalent to the term “economizer” that is nowadays predominantly used in the North American region.

2. Introduction

What is free cooling? Is free cooling really free of charge as implied?
Free cooling for data centers generally refers to the removal of heat, created by IT equipment in the data center by means of cold outdoor air and therefore without the use of refrigeration compressors. In any case, air needs to be moved to remove the heat, which means that fans must be in operation. Indirect free cooling systems use both, fans and pumps, but no energy-intensive refrigeration compressors. Free cooling therefore means to remove heat from the data center with the minimum amount of energy required to operate fans and pumps. This amount of energy required to cool the data center (or to remove the heat) is much lower compared with systems without free cooling where refrigeration compressors are required for heat removal.

3. Data Center Temperatures and Free Cooling

There are various measurable temperatures present in a data center e.g. supply air, return air, room air, cold aisle, server inlet temperature and so on. When talking about data center temperature, it is important to be clear which temperature you are most concerned with.
Server inlet temperature and server exit temperature are well known to have a significant effect on the efficiency of any cooling system. The server inlet temperature is similar to the supply air temperature of the cooling equipment (assuming minimal losses). The server exit temperature is similar to the return air temperature of the cooling equipment, considering a properly designed airflow through the data center without air recirculation, bypass air or significant leakages (see STULZ white paper on this topic for a detailed discussion).
The higher the server inlet temperature, the more efficient the cooling system can become and the more free cooling hours per year can be realized.
Twenty years ago, the CRAC (packaged Computer Room Air Conditioner) return air temperature was the main control parameter and was set to 22-24°C (72-75°F). This resulted in unnecessarily low supply air temperatures in a range of 12°C (54°F). Today, the best practices are very different. In a modern data center, the supply air temperature is the main control parameter. It is typically set between 18°C and 27°C (64°F and 81°F) as recommended by ASHRAE TC9.9 (2011 Thermal Guidelines for Data Processing Environments). This has resulted in return air temperatures to the cooling equipment of 25-40°C (77-104°F). As you can see, the overall temperature levels in data centers has been increased by around 10°C (18°F).

4. Direct Free Cooling

On the most basic level, direct free cooling could be described as follows: open a window, blow cold air from outside through the data center, pick up the heat, transport it back outside, done! Physically speaking, that's exactly what happens. However, the process of "moving the air" requires energy.
Unfortunately, in real life things are not that simple. Outdoor air is not always in a condition that the IT equipment is comfortable with. Sometimes it's hot and sometimes cold, sometimes it's very humid and sometimes very dry. What's more, outdoor air is not always

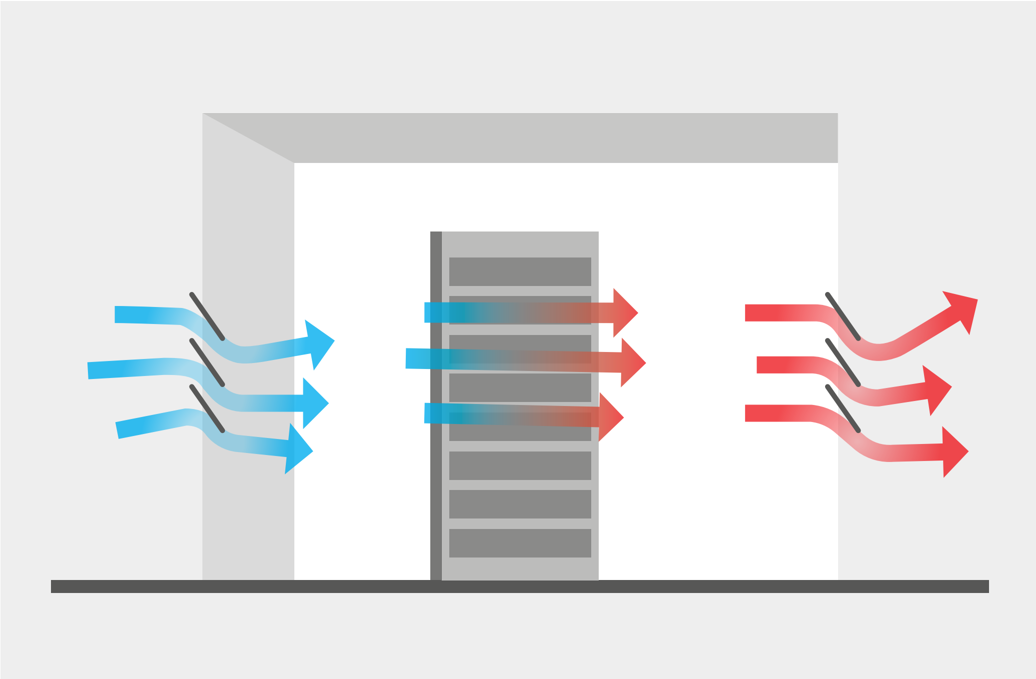

Figure 1: Direct Free Cooling

Direct Free Cooling

STRENGTHS

- Highest theoretical efficiency of any free cooling system

WEAKNESSES

- Depends on outdoor air quality
- Significant air filtration is required
- High maintenance requirements
- Measures for humidification and dehumidification required
- Huge indoor space requirements for ductwork
- Security issues to consider
- Limited to locations with colder climates
- Client service level agreements with humidity tolerances to be agreed
- 100% mechanical cooling backup required

clean. The outdoor air is often full of particles which can be very hostile to modern IT equipment. So, direct free cooling should only be used where the negative properties of the outdoor air can be controlled by financially acceptable measures.
Before the outdoor air is allowed access to the data center, it must be filtered – a process that can be expensive. If the outdoor air is too cold, a certain proportion of warm air from the data center must be mixed in with the cold air to supply controlled, tempered air to the IT equipment. The airflow concept and the control system in the data center must be designed to ensure this. If the outdoor air is too warm, additional mechanical cooling will be required. Therefore, in locations with very high average annual temperatures, direct free cooling may not be a feasible option.

Air humidity is yet another challenge. Although they are only machines, servers really don't like excessively dry or excessively humid air. Methods to humidify or dehumidify the air can also be very expensive and complex.
The amount of cooling that can be transported by outdoor air is much less than can be transported by traditional means using chilled water or refrigerant pipes. This means that large ductwork systems are required in addition to large openings in the building fabric to bring in the outdoor air plus an equally large ductwork system and fabric openings for the exhaust air. The openings and ductwork brings a security risk to the data center that has to be considered.
So as we can see, the main advantages are put into perspective if expensive additional measures are necessary due to conditions at the site in question.

5. Indirect Free Cooling

With indirect free cooling, the window stays shut. The outdoor air, with all its contaminating particulates, can't get into the data center and remains outside. The weaknesses of direct free cooling mentioned above do not apply with indirect free cooling. Unfortunately, indirect free cooling is theoretically less efficient than direct free cooling, as at least one heat transfer must always take place between the air in the data center and the outdoor air. At least one heat exchanger is required, and that means a loss of efficiency.

5.1. Single-stage Indirect Free Cooling

Single-stage Indirect Free Cooling systems transfer heat using an air/air heat exchanger.

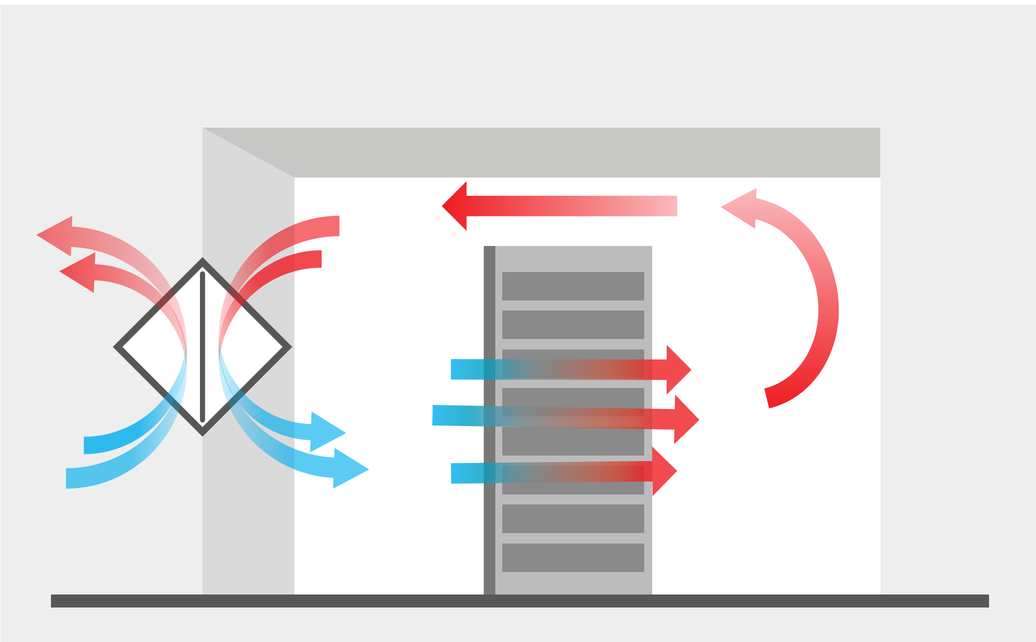

Figure 2: Indirect Free Cooling with air/air plate heat exchanger

The air in the data center is circulated and conveyed through the inside section of the air/air heat exchanger without making direct contact or mixing with the outdoor air. Likewise, the outdoor air is ducted through the outdoor air section of the air/air heat exchanger and then ducted back outdoor the data center.
This air/air heat exchanger can either be a cubic formed box, typically a plate heat exchanger with fixed positions, or a large, slow rotating heat exchanger thermal wheel.

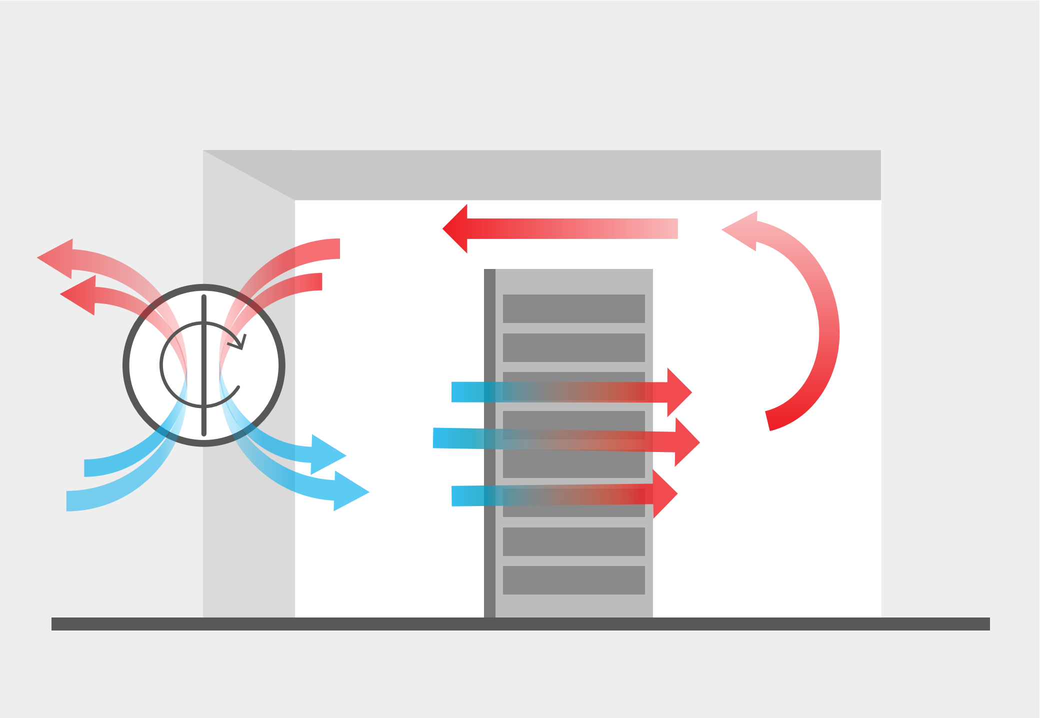

Figure 3: Indirect Free Cooling with heat exchanger thermal wheel

Single-stage Indirect Free Cooling

STRENGTHS

- Very high efficiency
- Independent from outdoor air quality
- Independent from outdoor air humidity

WEAKNESSES

- Very high indoor footprint required. 4 to 6 times more than two-stage systems require.
- 100% mechanical cooling backup required
- Security issues to consider
- Additional equipment for humidification and dehumidification required

5.2.
Two-stage Indirect Free Cooling

Two-stage Indirect Free Cooling systems have a considerably smaller footprint than their single-stage counterparts, but are somewhat less efficient as they function with two heat transfers. In the first heat exchanger, the heat from the air in the data center is transferred to a liquid, normally glycol. This is then pumped to the outside in relatively small pipes, where heat from the data center is rejected to the outdoor air via a second heat exchanger. Again, we lose some efficiency through this second heat transfer. Here, the mechanical cooling unit is an integral part of the system, and is only used to supplement the free cooling at high outdoor air temperatures. If the outdoor air is very hot, all cooling will take place mechanically.
There are generally two different Two-stage Indirect Free Cooling systems available; one consists of a CRAC (packaged Computer Room Air Conditioner) and dry cooler or cooling tower, the other of a CRAH (chilled water Computer Room Air Handler) and chiller.

5.2.1.
Two-stage Indirect Free Cooling: CRAC with dry cooler

In this type of system, a CRAC is located in the data center and is equipped with an additional free cooling heat exchanger. The CRACs are connected via water pipes with the dry cooler that is located outside the building.
During cold periods, the dry cooler supplies cold water to the CRAC. At this time it operates in free cooling mode with the compressor off. When outdoor air temperatures are high, the water temperature supplied from the dry cooler is not cold enough for free cooling and the CRAC must use mechanical cooling to make up the difference. In between, at moderate outdoor air temperatures, the system works in mixed mode; in addition to free cooling, the mechanical cooling works to top-up cooling when required. The advantage of this system is that the mixed mode already starts at relatively high outdoor air temperatures. As soon as the dry cooler can produce water with a temperature below the return air temperature in the data center, the mixed mode starts and the compressor operating time can be reduced. Depending on the sizing of the dry cooler mixed mode takes place when the outdoor air temperature is approximately 5°C (9°F) below the return air temperature in the data center. Full free cooling can then start at relatively high (moderate) outdoor air temperatures when the dry cooler can produce a water temperature which is sufficient to run the CRAC in full free cooling mode. Modern Two-stage Indirect Free Cooling Systems, such as STULZ's Dynamic Free Cooling System (see separate STULZ white paper), work with a dynamic water temperature between CRAC and dry cooler.
This leads to a dynamic adaptation and increase in free cooling hours to the part load behavior in the data center. The lower the load, the higher the water temperature, the more free cooling hours will be achieved. The coolant water is normally mixed with glycol acting as an anti-freeze to protect the dry cooler when the outdoor air temperature is below freezing.

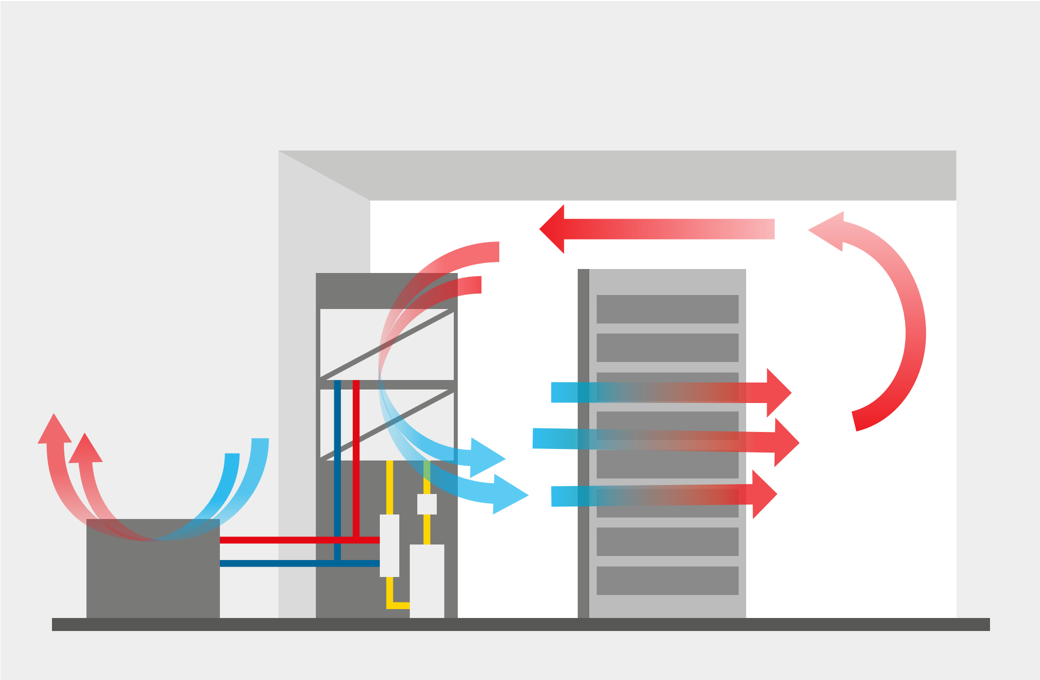

Figure 4: Indirect Free Cooling with CRAC and dry cooler

Two-stage Indirect Free Cooling by CRAC and dry cooler

STRENGHTS

- High efficiency
- Independent from outdoor air quality
- Independent from outdoor air humidity
- 100% mechanical cooling backup included
- Tried and tested system

WEAKNESSES

- Unknown, so far

5.2.2. Two-stage Indirect Free Cooling: CRAH with chiller

The second typical Two-stage Indirect Free Cooling system consists of CRAHs and a chiller with free cooling heat exchanger. This can either be an air cooled chiller with integral built-in free cooling heat exchanger or a water cooled chiller connected to a dry cooler or cooling tower. The chilled water temperature from the chiller to the CRAH is relatively low, and when the outdoor air temperature is below the chilled water temperature, the chiller can activate mixed mode free cooling and reduce the chiller's compressor run time. If the outdoor air temperature is significantly lower than the chilled water temperature, then 100% free cooling can be achieved. Due to relatively low chilled water temperatures with this type of indirect free cooling system, it is less efficient than the above system (5.2.1.) with packaged CRAC units. The chilled water is normally mixed with glycol acting as an anti-freeze to protect the chiller's free cooling coil or dry cooler when the outdoor air temperature is below freezing. This system can usually be found in large applications with a large number of CRAH's connected to chillers in the megawatt range.

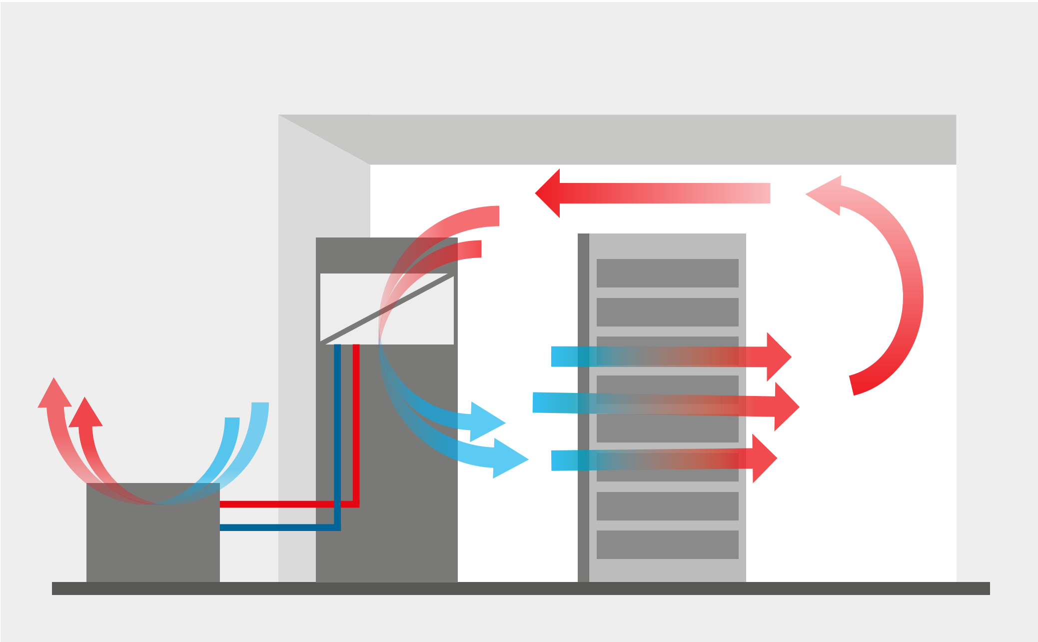

Figure 5: Indirect Free Cooling with CRAH and chiller

Two-stage Indirect Free Cooling by CRAH and chiller

STRENGTHS	WEAKNESSES
• Good efficiency • Independent from outdoor air quality • Independent from outdoor air humidity • 100% mechanical cooling backup included • Simple tried and tested system	• Full free cooling and mixed operation starts at relatively low outdoor air temperatures

6. Adiabatic Assistance

There is a physical principle that can further increase the efficiency of free cooling systems, whether they are direct, single-stage indirect or two-stage indirect. Air contains a certain amount of water. The amount of water that is contained in air is limited. This amount depends on the air temperature and barometric pressure. The amount of water content in relation to what is maximally possible is expressed in the metric relative humidity. If air has a relative humidity of 50% or 70%, this air can absorb more water (up to 100% RH).

As water absorbs into the air, an adiabatic process takes place; this means the temperature of the air will decrease (desired effect) while the energy content of the air remains unchanged. The physics behind this process is not important for this publication; however, the benefit of a reduction in the air temperature and increase in free cooling are of great importance.

Adiabatic Assistance

STRENGTHS

- Increase in efficiency of the data center free cooling systems
- Wider outdoor air temperature range (wet bulb approach) for free cooling
- Particularly suited for dry desert climates (if water is available

WEAKNESSES

- Not suited for humid tropical climates
- Requires large amounts of fresh water
- Assessing Legionella risk, control & monitoring responsibilities
- May be maintenance intensive
- Regional restrictions on safe fresh water handling
- Large water storage required if uninterrupted water supply is a concern

How can it be used to increase efficiency of data center free cooling systems?

6.1.
Adiabatic Assistance with Direct Free Cooling Systems

By using adiabatic assistance in direct free cooling systems the air that enters the data center will be cooled before entering the data center if it is too warm. This is by far a more efficient alternative to mechanical cooling. However, by doing so, the humidity of the air is increased and there are usually limits for the humidity levels of the air in the data center. This means that this is a great idea in theory, but its use is limited in practice.

6.2.
Adiabatic Assistance with Indirect Free Cooling Systems

Indirect free cooling and adiabatic assistance is more conducive for the data center, as the adiabatically assisted outdoor air never enters the data center. In Single-stage Indirect Free Cooling systems, adiabatic assistance will reduce the temperature of the outdoor air entering the air/air heat exchanger and therefore extend the amount of free cooling and reduce the amount of mechanical cooling required to satisfy the supply air temperature to the IT equipment.
In Two-stage Indirect Free Cooling systems, the warm outdoor air can be cooled by adiabatic assistance before entering the dry cooler to either increase the hours of usable free cooling or to extend the mixed mode at the upper limit to reduce the use of mechanical cooling.
Note: When designing a Two-stage Indirect Free Cooling system with adiabatic assistance from the initial stage, there is a risk associated with reducing the size of the dry cooler to save capital expenses with a smaller dry cooler with adiabatic assistance. With a smaller dry cooler in dry operation, the amount of full free cooling hours and mixed mode free cooling hours per year will be reduced. More importantly, should there be an interruption in the water supply in summer when the outdoor air temperature is hot the smaller dry cooler would not have the capacity to reject the heat from the CRAC units causing them to shut down on safety pressure switches.
This means that in systems like these the dry cooler should be sized based on dry cooling mode without the use of adiabatic assistance.

6.3.
Techniques of Adiabatic Cooling

There are different possibilities for evaporative (or adiabatic) cooling. Water may be evaporated by means of an ultrasonic humidifier which produces very small water drops, or using spray systems or systems where the air is drawn through water-moistened pads. The water-moistened pad system is very popular in combination with dry coolers and, though the system is easy to handle, it also represents a permanent resistance in the airflow, which increases the fan power consumption, even when adiabatic cooling is not required. Spray systems are commonly used in cooling towers and ultrasonic humidifiers can be found in some air handlers for adiabatic assistance.

6.4. Use of Adiabatic Assistance

The benefits of adiabatic assistance are best realized in dry climate areas, but they are now used almost anywhere where a small benefit can be achieved. The water itself is not free of charge and the equipment to evaporate the water may be expensive, not to mention the cost of operating the equipment. Handling water, in particular recycled sprayed water, involves a statutory requirement to provide a detailed risk assessment to prevent Legionella (Legionnaires disease) with sterilization control and ongoing monitoring. A high level of maintenance may also be required, so the use of adiabatic assistance must be evaluated carefully.

7. Other Free Cooling Systems

In the above chapters, we have described the most popular systems and principles of free cooling. There are several variants available that make use of pre-existing equipment. We will pick out the most popular variant here:
This is a system consisting of dual chilled water units. In this example, we will consider a CRAH with two independent circuits: one circuit is connected to a chiller plant without free cooling, and the other circuit is connected to a dry cooler or a cooling tower. The existing chiller plant is used for operation when outdoor air temperatures do not allow free cooling and, as soon as outdoor air temperatures are moderate or low, the second circuit will start to run the dual circuit CRAH in free cooling mode or mixed mode. Special control logics are required.

8. Summary

As shown in this white paper, there are several methods for reducing the PUE and the energy bill of a data center by means of free cooling. No system is perfect, and all systems described here have some limitations; some have regional advantages, others may offer advantages due to the size of the data center. Adiabatic assistance is useful but may not be used everywhere and not under all circumstances. It is important to evaluate what kind of free cooling is best suited to the application on a case by case basis.

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Benjamin Petschke was born in 1969 in Germany. After studying physics he joined STULZ in 1996 and, since then has been working in the R&D, Export and Marketing division in various positions. With 18+ years' experience in the data center cooling industry, Benjamin specializes in data center cooling design, energy saving and acoustic issues. He works closely with the Joint Research Centre of the European Commission for the Code of Conduct on Data Centres, Best Practice section, and recently with the German DKE on the development of the DIN EN 50600, Information technology – Data Centre facilities and infrastructures. Benjamin has written white papers on subjects like Best Practice for Data Centre Cooling and Indirect Free Cooling with Dynamic Control Logic.

ABOUT STULZ GMBH

Since it was founded in 1947, STULZ has evolved into one of the world's leading system suppliers for air-conditioning technology. STULZ manufactures precision air-conditioning units, chillers, air handlers and high density cooling solutions. Since 1974, the group has seen continual international expansion of its air conditioning technology business, specializing in A/C for data centers and telecommunications installations. STULZ employs 2,200 workers in Germany and maintains seventeen international subsidiaries (in France, Italy, Great Britain, Belgium, the Netherlands, New Zealand, Mexico, Brazil, Austria, Poland, Spain, Singapore, China, India, South Africa, Australia and the USA). The company also works with sales and service partners in over 130 other countries and therefore boasts an international network of air-conditioning specialists. It has production plants in Germany, Italy, the USA, China and India.

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