COMPARISON OF EFFICIENCY AND COSTS

BETWEEN THREE CONCEPTS

FOR DATA-CENTRE HEAT DISSIPATION

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1. Introduction: the increasing importance of energy efficiency

Information technology and telecommunications (ITC) is a significant factor in modern economies. In Germany alone, gross value added has increased in this sector by nearly 50 per cent since the mid-1990s and is now larger than the automotive industry and engineering. There is however a downside: the energy consumption of the roughly 50,000 server rooms and data centres in Germany in 2008 was some 10.1 TWh, more than double the figure for 2000. Accordingly, in 2008 German data centres were the cause of almost 6.4 million tonnes of CO_2 emissions.

Worldwide, commercial IT generates about 2 % of CO_2 emissions, roughly equal to that generated by aviation. It can thus be seen that energy efficiency must play an increasingly important role, from both economic and environmental perspectives.

This paper examines three concepts for data centre heat dissipation. On the basis of values obtained from experience we examine and compare the advantages, disadvantages, average investment costs and running costs of the three concepts for a data centre with an assumed 300 kW power dissipation.

1.1 Power consumers in the data centre

In fact only about half of the energy costs are for data processing itself. The other 50 % is used to provide the necessary security and availability - as backup power supply systems, security, fire warning and fighting and climate control systems. And it is climate control that is responsible for about a quarter of these energy costs. It follows that one of the most important areas to be addressed in improving energy efficiency is that of climate control.

1.2 Power dissipation trends in the data centre

Another trend today is the increasing packing density per cabinet. While previously dissipation levels of 4 to 8 kW per cabinet were common, today values of 10 to 15 kW are frequently encountered. Future projections suggest dissipation in excess of 30 kW per cabinet.

1.3 Air and water as heat carriers

Various materials are used to dissipate heat, selected for a given application according to the quantity of energy they can transport; the commonest materials used are air and water. The relationships of the variables to the energy that can be transported by a given material are represented by the following formula:

$$Q = \rho \times V \times c_p \times dT$$

where ρ = density of the material, V = volume flow rate, c_p = specific heat capacity of the material and dT = temperature difference.

Different materials offer different values for density (ρ) and specific heat capacity (c_p). Moving from air to water, the combined factor increases by nearly 4000 times. Once the heat carrier material has been decided, the only remaining variable quantity in the formula is the volume flow rate (V) and thus the speed of the heat carrier.

2. Efficiency comparison of various cooling concepts

Cooling efficiency and costs were examined for three cooling concepts for the same heat dissipation.

Concept I is a design with cold and hot aisles and pure air cooling.

Concept II is a design with cold and hot aisles in a containment structure with pure air cooling. In principle it is possible to contain either the cold or the warm aisles. The differences between cold-aisle and hot-aisle containment will not be discussed in detail here. For the purposes of this efficiency comparison we have selected cold-aisle containment.

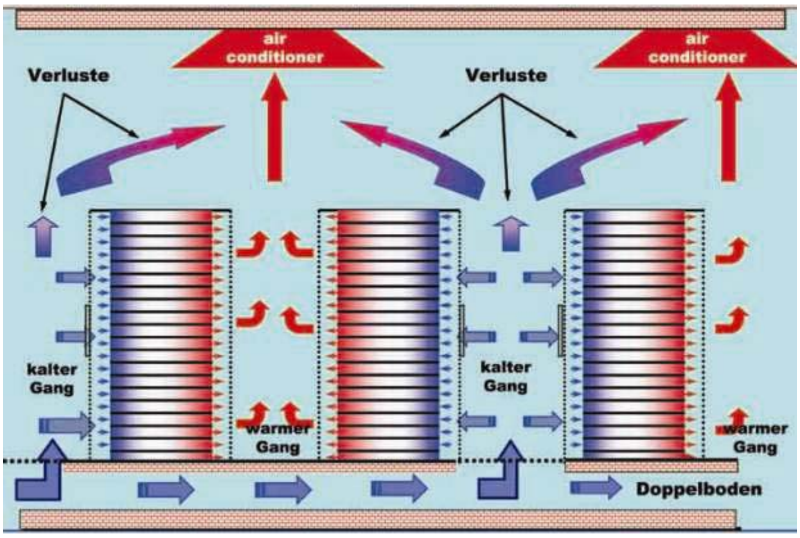
Concept III is a design with water-cooled server cabinets.

As a starting point, a data centre with a total dissipation loss from all its servers of 300 kW was assumed. On the basis of the highest possible dissipation per cabinet, cooling efficiency and costs were examined for the three cooling concepts.

2.1 Concept I: Cold and hot aisles

In the case of pure air cooling, the maximum possible cooling capacity per cabinet is limited by the capacity of the surrounding space to deliver sufficient cold air to the fronts of the cabinets and to extract the warm air from the space. The cold and hot aisles are laid out so that the cabinets are arranged in rows. In one row the cabinets are positioned so that their fronts face one another (the cold aisle), while in the next row their rears face one another (the hot aisle). For such a configuration there are various methods for introducing the cold air:

- Cold air enters from below via a raised floor to the fronts of the cabinets, i.e. into the cold aisle. In calculating the airflow speed it must be ensured that the servers positioned uppermost in the cabinets receive enough cold air, but the speed should not be so high that the servers lower down receive too little.
- Cold air enters the cold aisle from above. Here the problem arises that the cold air reaches the servers low down only with great difficulty.
- Cold air is introduced both from above and below into the cold aisle. In such a 'high-efficiency' cold aisle design the upper rows of servers are supplied from the upper air stream and the lower servers from below.

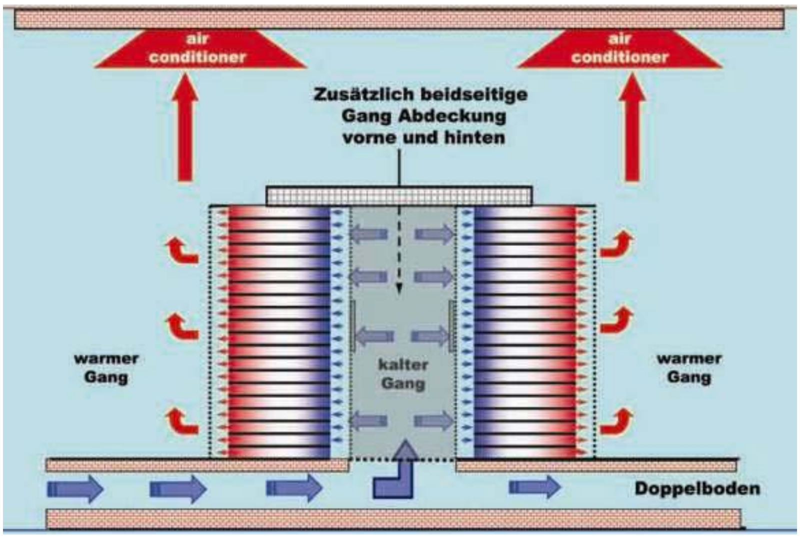


In our Concept I, cold air is introduced solely from below through a raised floor. In addition the exhaust devices of the air conditioning system, which extract the warm air, are positioned and spaced over the hot aisles in such a way that the warm air is uniformly drawn away.

In many existing data centres this is not implemented systematically. As a consequence, in many cold/hot-aisle layouts the warm and cold air become mixed in the upper areas, resulting in additional unnecessary energy loss.

2.2 Concept II: Cold and hot aisles with containment

A number of further steps are available for introducing air from the raised floor to minimise losses from the cold aisles and to avoid the difficulty of balancing between too high and too low an airflow speed. One very efficient solution is to cover the cold aisles over from above. This both allows a lower airflow speed and prevents the occurrence of air short-circuits. The vertical temperature gradient through the cabinet height is considerably reduced and the efficiency of the air conditioner consequently improved. Cold air introduced into the cold aisle is now drawn precisely to where it is needed and can be sucked by the servers into the cabinets.



As well as being sealed from above, the cold aisle is also closed to the front and rear using a door or sluice. Once in this sealed cell, the cold air can flow nowhere except into the server cabinets. To ensure that the resultant cold aisle now functions correctly, a constant overpressure is applied within it that should ideally be kept as low as possible.

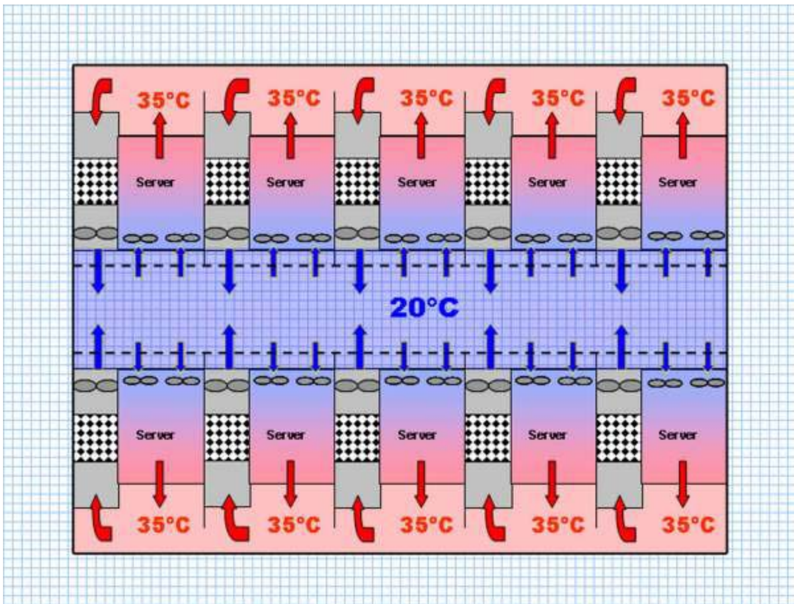
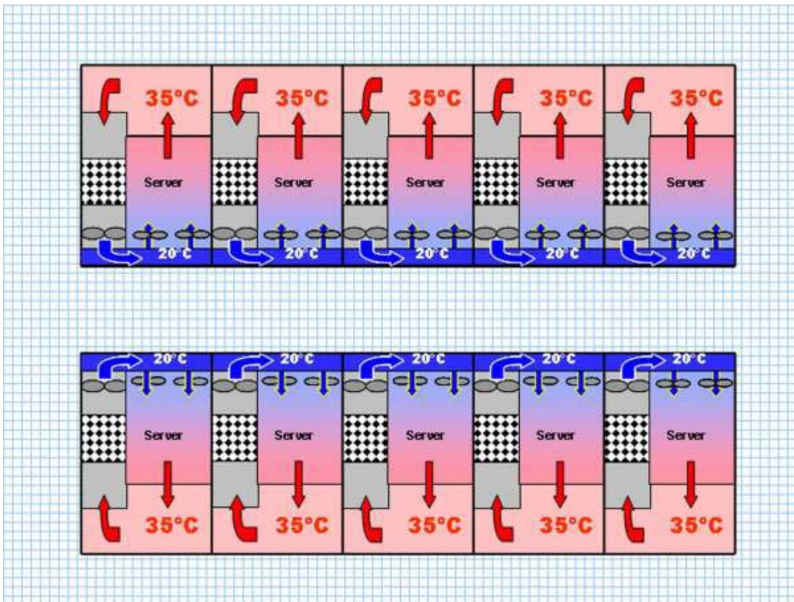


Illustration: Cold aisle containment with multiple LHX 20s as cooling units

2.3 Concept III: VARISTAR cabinets with integral LHX 20 air/water heat exchangers

The server cabinets are cooled with air/water heat exchangers in a closed system. This results in a space-independent cooling concept in which the benefits of water cooling can be obtained without restrictions.



The inner temperature of the cabinets is set to the exact requirements of the servers, while the remaining infrastructure is unaffected. Only those areas of the data centre are cooled that require cooling. Thus under normal operating conditions the output of the air conditioner can be reduced to a necessary minimum. The air conditioner must only remove that fraction of heat that is conducted into the room from the cabinet surfaces, but it also assumes a safety function.

3. Efficiency comparison between the cooling concepts

For each concept the cooling capacity per cabinet is different. Thus the total dissipation of the servers (300 kW) must be distributed over a different number of cabinets in each case.

Concept I: Cold/hot aisle layout	Concept II: Cold aisle containment	Concept III: Water-cooled server cabinets
5 kW per cabinet	10 kW per cabinet	15 kW per cabinet
60 cabinets required	30 cabinets required	20 cabinets required

For comparison purposes we assume the same room size for all concepts. The raised floor required for the air-cooled data centres is retained in the water-cooled version (Concept III) and used to accommodate the water pipes and some of the cabling. The increased space requirement for cold and hot aisles compared to containment and relative to water-cooling is a significant advantage for Concept III. The varying number of server cabinets is factored into the investment costs, but the cost of increased space cannot be easily calculated and is not taken into account in the further efficiency comparison. Where there is extra space available, however, there is a significant advantage here.

3.1 Investment costs for the climate-control elements of each concept

<table>
<tr><td></td><td>Concept I
Cold/hot aisle layout</td><td>Concept II
Cold aisle containment</td><td>Concept III
Water-cooled server cabinets</td></tr>
<tr><td rowspan="4">Same climate-control components in all concepts</td><td colspan="3">Refrigerating machine</td></tr>
<tr><td colspan="3">Chiller</td></tr>
<tr><td colspan="3">Dual pumping station with fault changeover</td></tr>
<tr><td colspan="3">Refrigeration pipes</td></tr>
<tr><td>Total cost of these components</td><td colspan="3">approx. € 150,000</td></tr>
</table>

<table>
<tr><td rowspan="6">Concept-specific climate-control components</td><td colspan="2">CRAC (computer room air conditioner)</td><td>Water pipes</td></tr>
<tr><td colspan="2">Shut-off flaps</td><td>Insulation for water pipes</td></tr>
<tr><td colspan="2">Air channels for removal of warm air</td><td>Water cut-off valves</td></tr>
<tr><td colspan="3">Corner pieces for air channels</td></tr>
<tr><td></td><td>Containment housing for cabinet row, incl. fitting</td><td></td></tr>
<tr><td>60 server cabinets for 5 kW each</td><td>30 server cabinets for 10 kW each</td><td>20 water-cooled cabinets (LHX 20) for 15 kW each, with individual fans and water control systems</td></tr>
<tr><td>Additional costs for each concept</td><td>approx. € 140,000</td><td>approx. € 120,000</td><td>approx. € 160,000</td></tr>
</table>

Total climate component investment	**€ 290,000**	**€ 270,000**	**€ 310,000**

3.2 Additional costs incurred by increased air and energy demand

In Concepts I and II sometimes considerable air losses occur through leakage, and as a result we incur extra costs. The extra costs for energy are caused by the undercooling of the data centre space that is necessary for both concepts. Concept III (water-cooled cabinets), by contrast, involves an airtight, closed system without losses. Accordingly, with this concept no additional costs arise for increased air and energy requirements.

3.2.1 Additional costs incurred by increased air and energy demand for Concept I

The cold aisle of a data centre with raised floor will inevitably contain air short-circuits in both upper and lower areas. These cannot be avoided and are inherent to the basic functioning of the concept. The main cause is that it is not possible to control the quantity of air entering from the raised floor so accurately that the uppermost servers always receive exactly the right quantity of cold air. Such a control system would in any case have to respond to the varying demands placed on the servers as network loading fluctuates throughout the day. It is thus a simple and low-cost alternative to supply a constant excess of cold air. However, the resultant air short-circuits have a negative impact on the cold-air temperature available due to the vertical temperature gradient on the one hand, and on the real volume of cold air on the other. Appropriate countermeasures must be undertaken to reduce these negative effects.

The vertical temperature gradient (variation) in front of the servers and through the cabinet height can reach some 4 K. It is thus necessary to cool the entire room by this amount in order that the servers mounted at the top receive sufficient cold air. On top of this are further heat losses in the raised floor area, which must be countered by cooling the air by at least 2 K below the desired cold-air temperature. The larger, longer and more poorly insulated the raised floor, the larger this figure will be.

From experience we estimate the real volume of cold air lost through the air short-circuits mentioned above at about 15 %, dependent to a large extent on the quality of the sealing of gaps in the lower cabinet area and on the position and quality of the warm air extraction from the room.

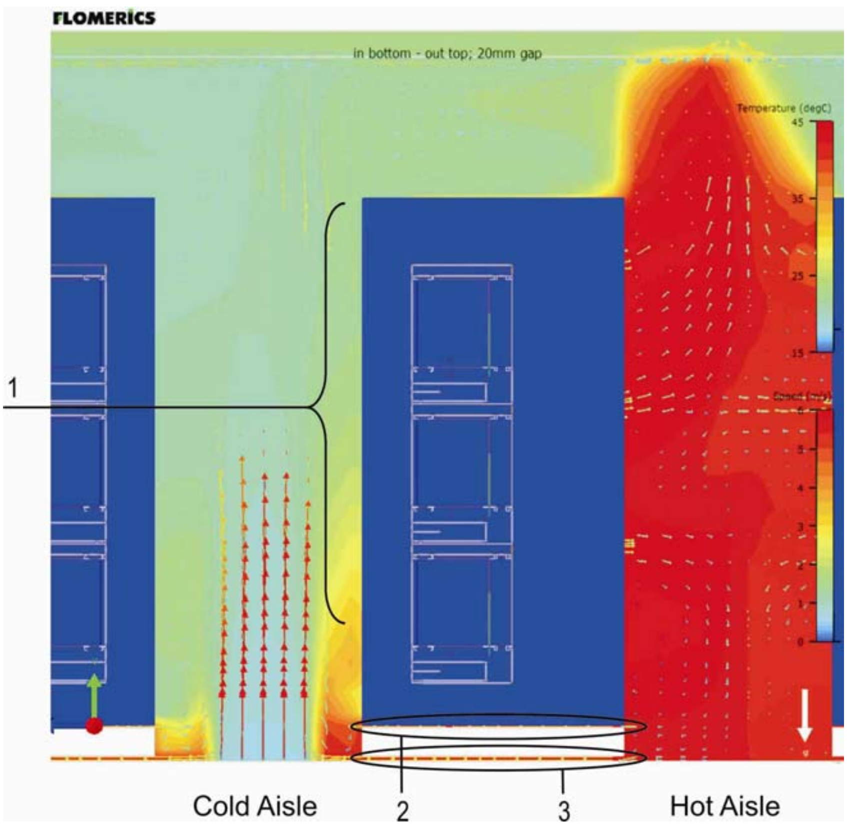


Illustration:
Gaps at base not sealed
1 – Warm air reaches upper servers;
2 – Gap = 10 mm,
3 – Gap = 21.5 mm;
Warm air in the lower region is drawn through the servers.

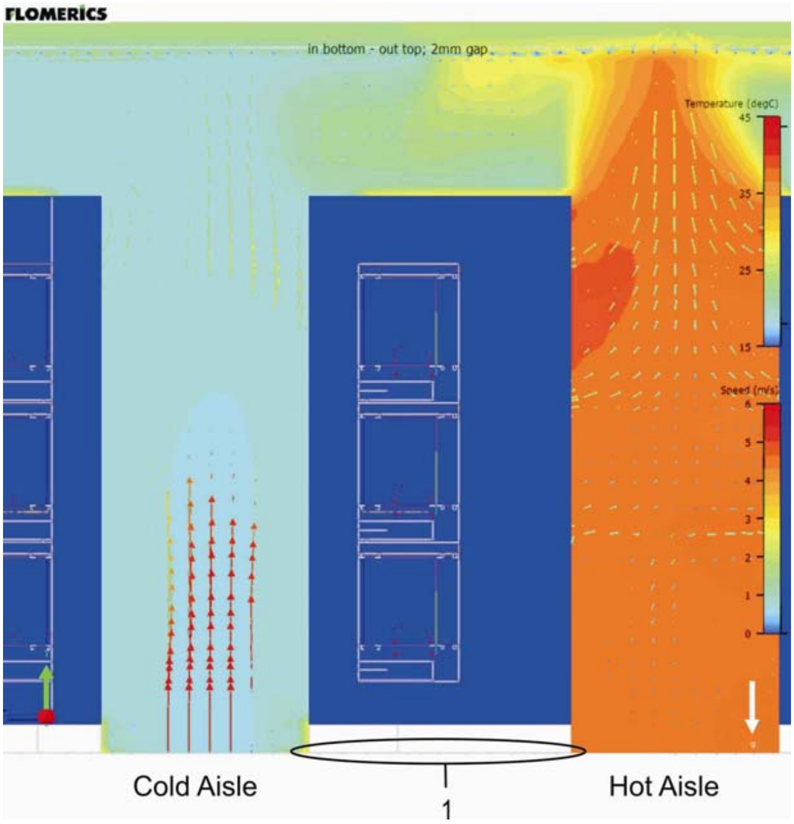


Illustration:

With gaps sealed: Negligible warm air is drawn into the servers higher in the cold aisle;

1 – Gap 2 mm or sealed;

Very little warm air is drawn into the servers in the lower region of the cold aisle.

Compensating for these air deficits results in increased airflow speeds in front of the servers, which makes it more difficult for air to be drawn into the servers. To lessen this effect, an additional air cooling of at least 1 K is necessary. This increases overall air cooling in the data centre to at least 7 K. This unavoidable extra cooling leads to additional energy costs.

As a rule of thumb, the extra energy required to cool the space of a data centre below a specified air entry temperature is roughly 3 % to 4 % per 1 K temperature difference within the climate control system. Thus, in the example above with its requirement of 7 K undercooling, power costs will increase by between 21 % and 28 %.

3.2.2 Additional costs incurred by increased air and energy demand for Concept II

In a containment, air losses similarly occur due to the prevailing overpressure and can be traced to leakages between the cabinets themselves and between the plinth and floor. BITKOM recommends a general overpressure of about 25 pascals within a containment. This value is often difficult to maintain; most users make do with a value closer to 15 Pa.

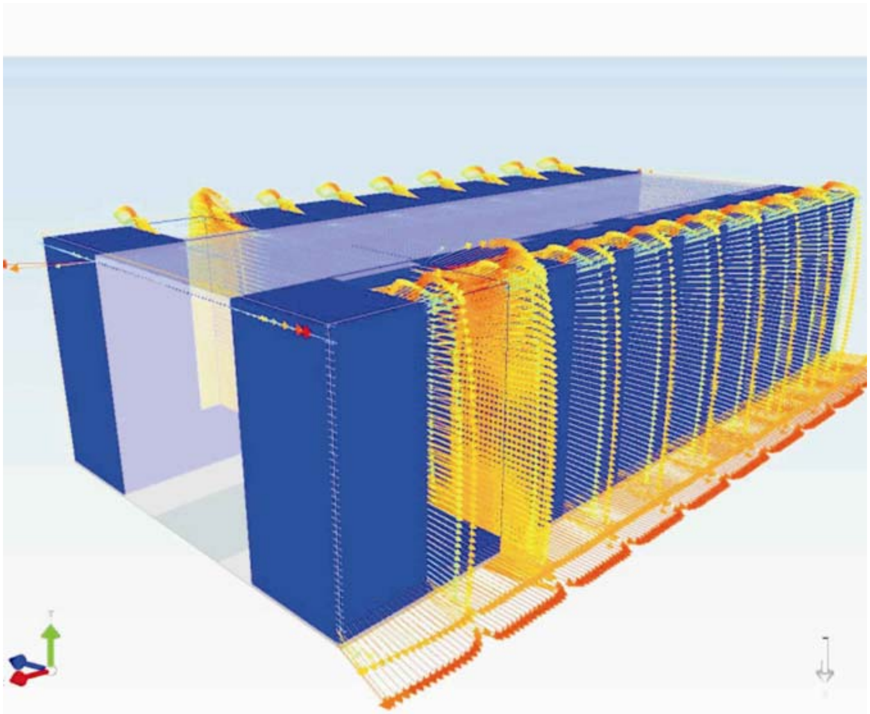


Illustration:
Air losses in a cold-aisle containment

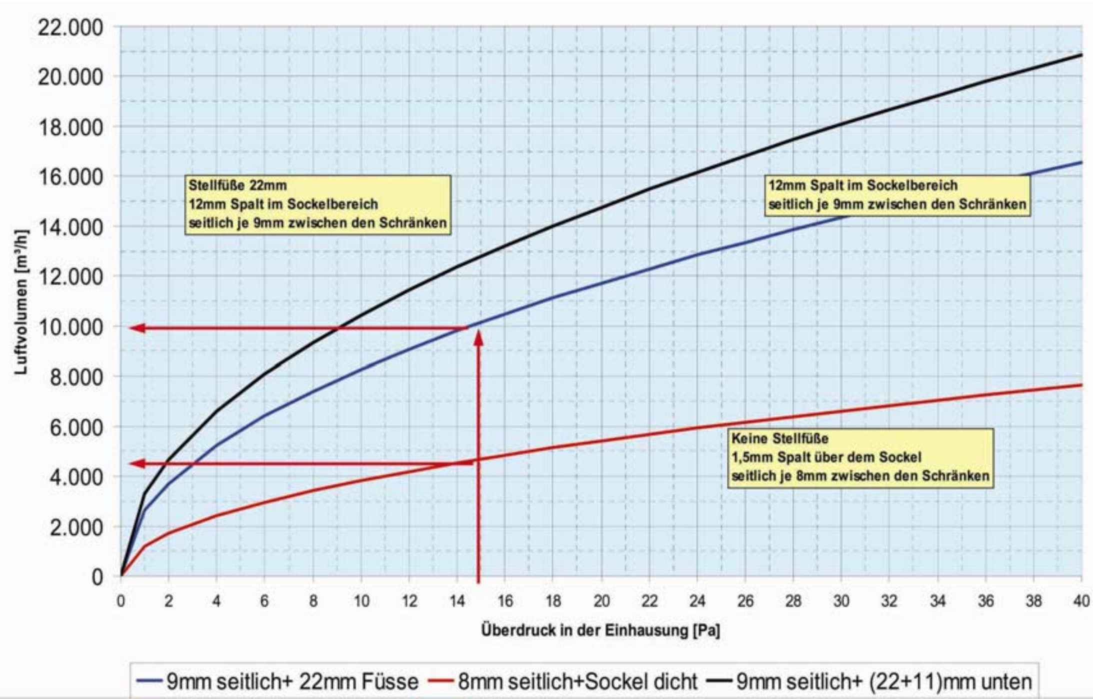


Illustration:
Air losses resulting from overpressure in a 30-cabinet containment

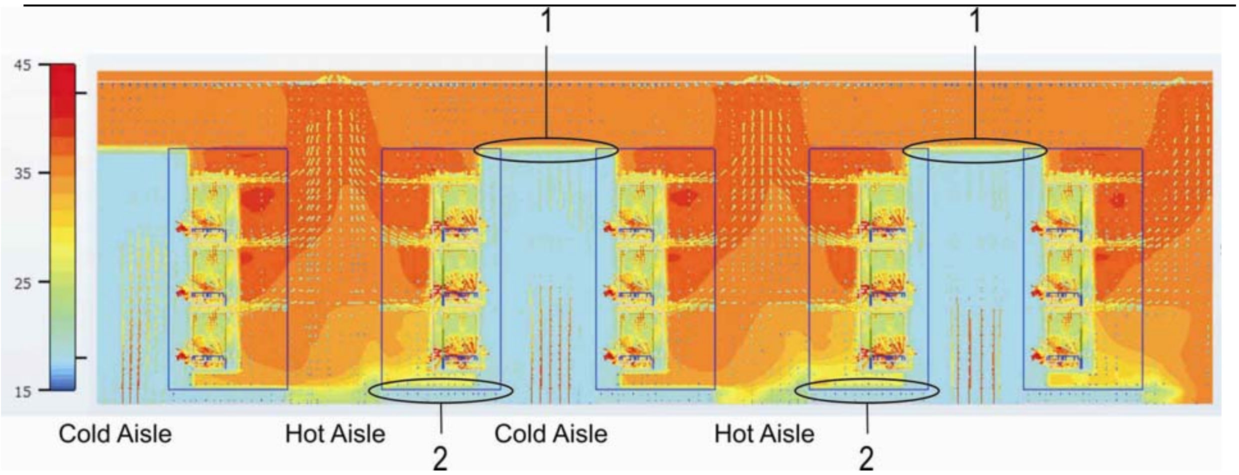


Illustration:

Cold-aisle containment:

1 – Negligible return of heat through the containment roof;

2 – Cold air flows through the 12 mm gap towards the hot aisle; warm air does not return to the cold aisle.

Cold air temperature is uniform throughout the cold aisle

Should the user wish to minimise the losses due to the general overpressure, he must measure the actual overpressure at the critical points (reference measuring points) within the containment and then adjust the volume of cold air. In a real situation this procedure is cumbersome, since as the loading on the servers frequently changes, the reference measurement points often change position. The control system must also respond very fast to ensure that the cooling (or air volume) requirements of individual servers are always satisfied immediately. Implementing such a system with an appropriate air-volume control unit is thus highly complex and costly.

3.2.3 Additional costs incurred by increased air and energy demand for Concept III

Dissipation loss in the servers is assumed to be 15 kW per cabinet with a temperature difference across the servers of 15 K. In the water-cooled Concept III no additional costs from air or energy losses are incurred.

	LHX 20 airflow volume	LHX 20 power consumption	Server dissipation loss	Chiller power consumption
Single 1 x VARISTAR LHX 20	2.311 m³/h	550 W	15 kW	---
Row of 20 x VARISTAR LHX 20	46.220 m³/h	11 kW	300 kW	90 kW *)

*) *Power consumption of chiller to cool the cold water: 30 % x 300 kW = 90 kW*

3.3 Comparison of additional costs incurred by increased air and energy demand for Concepts I and II relative to Concept III

Airflow volume losses

		Additional airflow volume required	Power consumption of fans	Annual fan energy costs (assuming € 0.13/kWh, 24h x 365 days)
Cold/hot aisle layout (Concept I)	15 % airflow volume losses	6,993 m³/h (15 % x 46,220)	approx. 2.0 kW	€ 2,278 p.a.
Containment with 9 mm gap between cabinets (Concept II)	Airflow volume losses for 1.5 mm gap	4,800 m³/h	approx. 1.3 kW	€ 1,480 p.a.
	Airflow volume losses for 12 mm gap	10,000 m³/h	approx. 2.8 kW	€ 3,188 p.a.

Energy losses due to necessary undercooling, on basis of 90 kW energy requirement for water cooling

	Undercooling required	Additional energy consumption (rule of thumb: 3 to 4 % per 1 K)	Power loss	Additional annual costs for power loss (assuming 0.13 €/kWh, 24h x 365 days)
Cold/hot aisle layout (Concept I)	7 K	21 to 28 %	18.9 to 25.2 kW	€ 21,523 to € 28,698
Containment with 9 mm gap between cabinets (Concept II)	2 K	6 to 8 %	5.4 to 7.2 kW	€ 6,150 to € 8,200

4. Overall cost comparison

	Cold/hot aisle layout (Concept I)	Containment with 9 mm gap between cabinets (Concept II)		Water-cooled server cabinets (Concept III)
Investments		Plinth gap 1.5 mm	Plinth gap 12 mm	
Total investment for climate components	€ 290,000	€ 270,000		€ 310,000
Investment differences relative to Concept III	approx. - € 20,000	approx. - € 40,000		--
Operating costs				
Additional annual costs from air volume losses	€ 2,278	€ 1,480	€ 3,188	--
Additional annual costs from energy losses	€ (21,523 to 28,698)	€ 6,150 to 8,200		--
Total annual extra costs	€ (23,801 to 30,976)	€ 7,630 to 9,680	€ 9,338 to 11,388	--

5. Conclusion

The need for energy efficiency in the climate control of a data centre is determined by both environmental and economic factors. In environmental terms it represents reduced CO_2 emissions, first and foremost through reducing power consumption to the minimum possible. The economic considerations are based principally on the investment and ongoing operating costs. The fundamental design concept of the climate control has considerable influence on these factors. Efficient climate control is obtained through the correct choice of technologies and principles. The results of the examinations conducted here reveal unanimously the benefits of a climate-control system based on water-cooled LHX 20 server cabinets. Environmentally, CO_2 emissions are lower thanks to relatively low power consumption. Additionally, water is a very environmentally friendly cooling medium. On top of this is a considerably reduced noise level and thus a more humane working environment: 100 x Varistar LHX 20 = 75 dB(A), whereas 1 x air-cooled rack > 80 dB(A). Since data centres are normally designed to operate for many years, the economic benefits of Concept III are also clear. The somewhat higher investment costs for the hardware are more than compensated by the lower running costs over a service life of 10 years. This means reduced costs and higher efficiency at the same time. And not least in importance are the technical benefits of using Varistar LHX 20 server cabinets, such as the scalability built in to the independent cooling of individual cabinets and the higher cooling capacity (up to 15 kW) per cabinet.

6. Schroff company portrait and notes on the authors

Schroff, based in Straubenhardt, Germany, is a leading developer and manufacturer of electronics packaging systems for electronics, automation, IT and communications systems worldwide. The company's standard products range from cabinets, enclosures and subracks through power supply solutions and backplanes to microcomputer assembly systems. With this product platform, Schroff is also able to realise custom modifications quickly and at favourable cost. The company's integration service combines its products and service options into a complete solution with real customer benefits. Our products and services are the result of decades of experience focussed on the global concerns of the electronics markets. Thus Schroff has constantly broadened its core competences, and today offers expertise in electronics packaging, thermal management and electromagnetic compatibility as extra value added.

Adam Pawlowski, Dr.-Ing, graduated from the "Politechnika Warszawska" in Warsaw in the department of aviation engines, specialising in combustion processes. While a researcher at the Technical University in Berlin he gained his doctorate in the department of mechanical vibrations studies. During his career he spent many years leading R&D departments in climate technology for companies producing switchgear air conditioning and in the automotive industry. Since August 2005 Dr Pawlowski has been principal engineer for thermal management at Schroff GmbH.

Markus Gerber graduated in business administration in the market and communications research department of the Hochschule Pforzheim. He has worked for Schroff GmbH since February 2007. Mr Gerber is project leader for the introduction of a comprehensive service concept, and since January 2009 has been product manager for cabinet accessories and vertical market manager for datacoms.