OPTIMIZED ENERGY EFFICIENCY WITH CONTROLLED COLD AISLE CONTAINMENTS

Whitepaper

Revision B: In this revised version, the latest findings on losses caused by idle running servers have been incorporated. In addition, a more modern and energy-efficient air cooling unit was used.

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EXECUTIVE SUMMARY

The comparison showed that SmartAisle™ control via temperature is the considerably better option over pressure control.

- Only approx. 40% of the power requirement for fan drive in comparison with pressure control
- Reliable supply of all coldaisles
- No negative effects on fans in IT equipment

INTRODUCTION

Due to rising power costs and increased environmental awareness, almost every operator's current objective is to operate their data center as energy efficiently as possible.

Many have already implemented the basic separation of cold air from warm air with dummy (blanking) panels, bushings for cable entry, cold aisle containment, etc. The data center can be further optimized by adjusting the fan speed of the high precision air conditioning units. This is an essential and important factor for an energy- efficient data center. The operator can save enormous power costs by choosing the right type of control. The right choice can also increase availability. The failure of a high precision air conditioning unit is compensated by increasing the speed of the other high precision air conditioning units.

There are two main control principles in use – pressure control and control via the cold aisle temperature.

PRESSURE CONTROL WITH APPROX. 20 PA

With this excess pressure control the raised floor and the contained cold aisles area is constantly kept at a differential pressure of typically 20 Pa (see Figure 1).

The servers suck in the amount of air that the cooling needs, and are additionally overpressured.

The speed of the fans in the high precision air conditioning units is controlled with the pressure sensor. If the servers have a higher air volume requirement than the high precision air conditioning units deliver, the pressure in this area sinks. The speed is increased. With a lower cooling air requirement, the pressure here increases and the fans' speed in the high precision air conditioning units is reduced.

The cold aisle is constantly oversupplied to some degree. The control is performed in the "Partner Mode", i.e. all high precision air conditioning units run at the same speed.

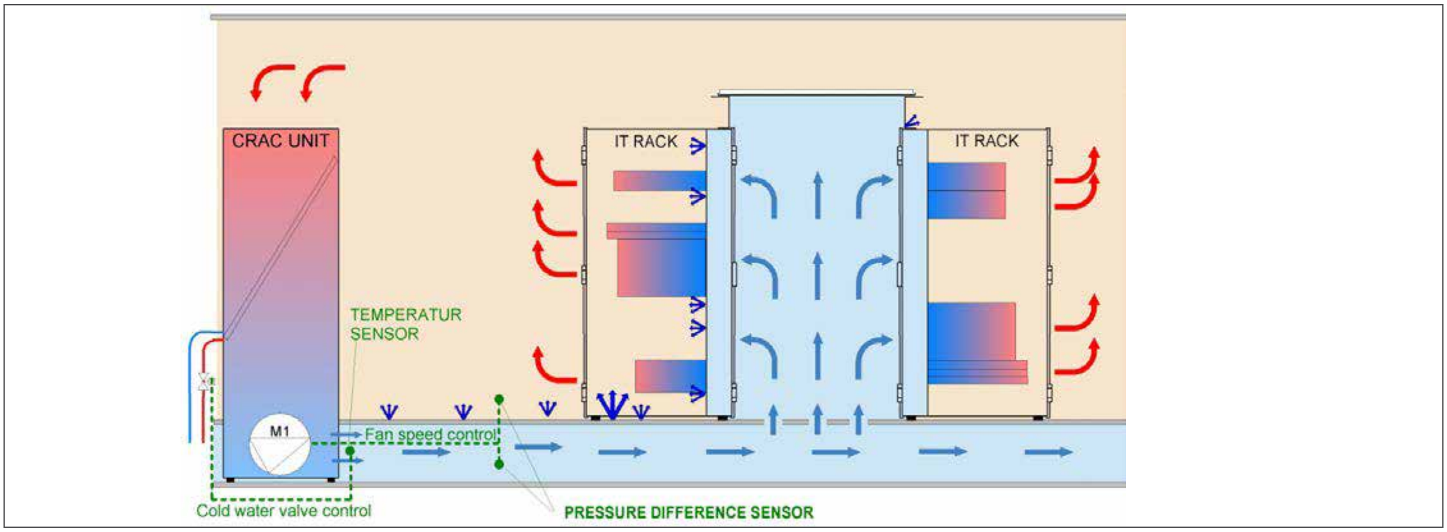

Figure 1: *Pressure control*

SMARTAISLE™ CONTROL VIA TEMPERATURE

With the SmartAisle™ control principle the fans in the room's air handling units are controlled via the cold aisle temperature, i.e. the supply air temperature for the servers (see Figure 2). This control principle is patented.

The raised floor and cold aisles area is filled almost pressure-less with cold air. The servers suck in exactly the amount of air required for the cooling.

A small amount of the cold air flows controlled through the air control opening of the angular extrusion of the cold aisle containment in which the T1 temperature sensor is positioned. This temperature sensor controls the speed of the fans in the high precision air conditioning units. If the servers have a higher air volume requirement than the high precision air conditioning units deliver, the flow direction on the T1 temperature sensor changes. Warm air flows into the cold aisle. The T1 temperature sensor measures this, and the control unit increases the speed of the fans in the high precision air conditioning units. The control usually takes place via the sensor with the highest temperature.

To ensure that the cold aisle is not oversupplied, the speed of the high precision air conditioning units is continuously reduced slowly, until some warm air flows from the warm zone to the temperature sensor. The speed is then increased again, and the amount of air increases. This cycle is continuously repeated. The control is performed in the "Partner Mode", i.e. all high precision air conditioning units run at the same speed.

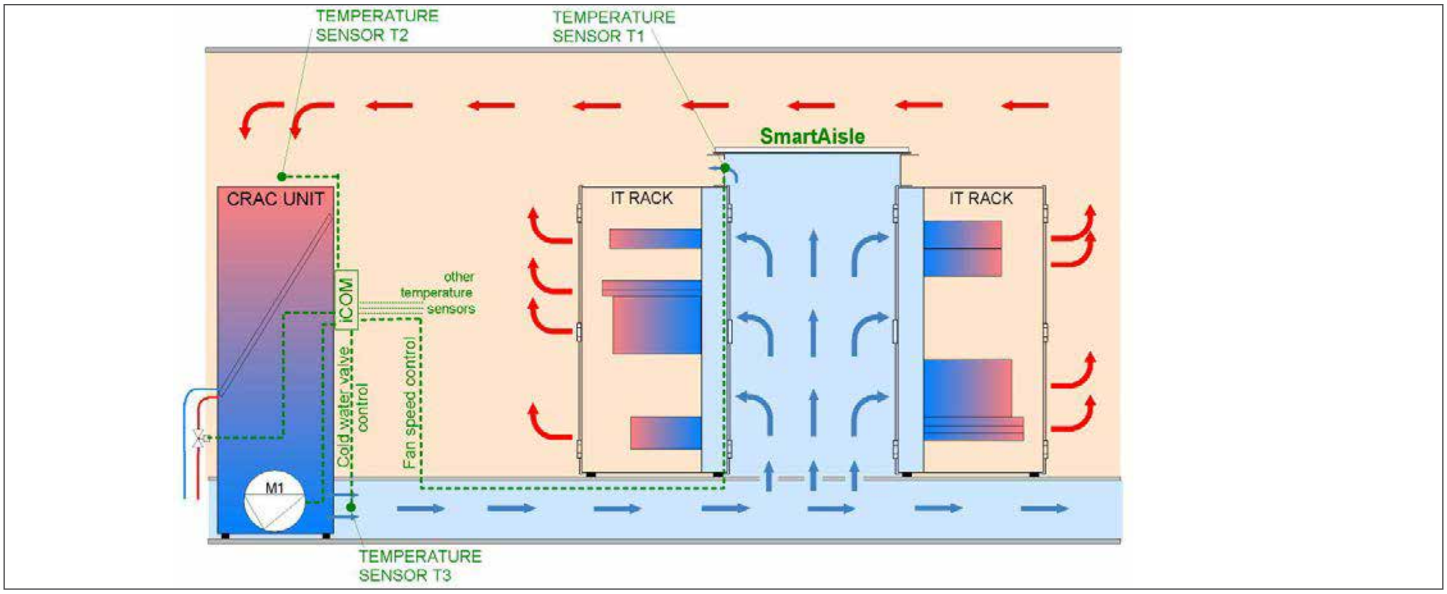

Figure 2: *SmartAisle™ control via temperature*

BASIC DATA FOR THE COMPARISON

A medium-sized example data center was chosen for the comparison (see Figure 3).

- 3 cold aisles with 2 x 8 racks
- Rack at 800 mm x 1200 mm x 2200 mm (W x D x H)
- Rack at 5 kW dissipation power (ΔT = 15K), i.e. 240 kW in the room; 50% equipped (6 x 4 HE); rest blanking panels, 2U (11ST)
- 50% of the time idle mode of the IT-equipment
- Cold aisle containment with sliding doors on both sides
- Grid plates in the raised floor
- Air cooling unit Liebert PH091EL (water supply temperature 15 °C; water return temperature 20 °C)
- Power costs: € 0.15 per kWh

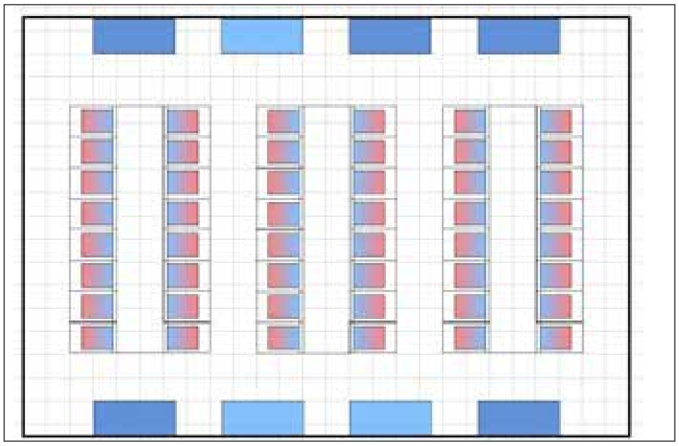

Figure 3: *Example data center*

Required volume flow calculation

The airflow volume required for the cooling is provided by the energy equation for open systems.

$$f(250-500) = 3{,}3[m^3K/Wh]$$

$$V = \frac{(f(h) \times Q)}{\Delta T}$$

$$V = \frac{(3{,}3 \times 240.000)}{15}[m^3/h]$$

$V = 52{,}800\ [m^3/h]$

V = volume flow $[m^3/h]$

$f(h)$ = help factor $[m^3K/Wh]$

ΔT = temperature difference [K] Q = required cooling power [W]

h = operating height above sea level [m]

$f(0\text{-}100) = 3.1\ [m^3K/Wh]$

$f(100\text{-}250) = 3.2\ [m^3K/Wh]$

$f(250\text{-}500) = 3.3\ [m^3K/Wh]$

$f(500\text{-}750) = 3.4\ [m^3K/Wh]$

$f(750\text{-}1000) = 3.5\ [m^3K/Wh]$

As in reality containments are never completely air-tight, depending on the pressure difference, air is lost through gaps, and this air also has to be convected through the fans in the high precision air conditioning units.

SURFACE CALCULATION OF ALL GEOMETRIC GAP SURFACES

Inevitably there are gaps and openings with components that have to be flexibly set up or installed (e.g. 19” equipment).

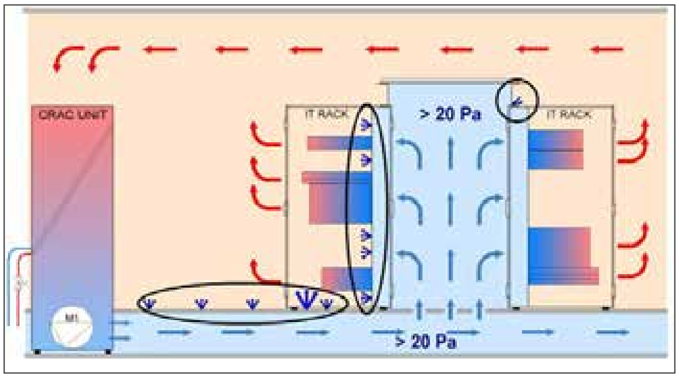

Figure 4: *Cooling air loss through slits with pressure control as example*

The rack has the biggest geometric gap surface, as it must be flexible in accepting components. The biggest gap surface is with the 19” standard between 19” components and the 19” dummy (blanking) panels. There are also gap surfaces with the side panels for the cold-warm separation in the rack and with bushings. The containment itself has a relatively low gap surface. Gap surfaces with the raised floor are mainly the result of the cable routing through bushings or similar.

	Pressure control	SmartAisle™ temperature control
Rack	0.529 m²	0.529 m²
Containment	0.093 m²	0.121 m² *)
Raised floor	0.454 m²	0.454 m²
Entire data center	1.076 m²	1.104 m²
		*) including air control openings

The gap surfaces only differ with the air control openings, in which the temperature sensors are housed with the SmartAisle™ control.

ACTUALLY EFFECTIVE GAP SURFACES

In gaps there is always a more or less distinctive jet contraction. The effect of the jet contraction on the flow characteristics is considered with a contraction number of μ. The contraction reduces the actually effective gap width of small gaps.

The contraction number μ expresses the strength of the contraction, and is defined as

$$\mu = \frac{A_1}{A_{Sp}}$$

Whereby, as shown in fig. 1, A_{Sp} is the geometric gap cross-section, and A_1 is the cross-section of the jet on the point of the strongest contraction (see Figure 5).

The contraction caused by sharp-edged labyrinth plate is significant and must not be neglected.

μ_0 is the contraction number of a sharp-edged panel, which according to Greitzer is 0.611 for an infinitely long gap ($A_0/A_{Sp} >> 1$).

According to Trutnovsky and Komotori, the contraction number μ of an orifice can be approximately calculated as follows [1].

$$\mu = \mu_0 \times \frac{s + r}{s}$$

s = gap width [m]

r = edge radius [m]

μ = contraction number

μ_0 = contraction number (infinite gap) = 0.611

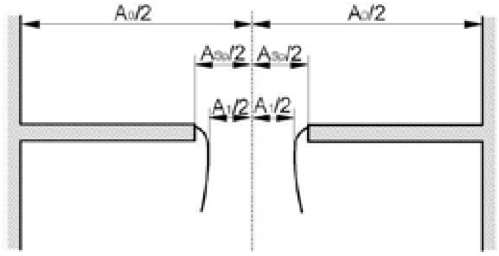

Figure 5:

In reality we therefore have the following actually effective gap surfaces.

	Pressure control	**SmartAisle™ temperature control**
Rack	0.485 m²	0.485 m²
Containment	0.074 m²	0.092 m² *)
Raised floor	0.322 m²	0.322 m²
Entire data center	0.882 m²	0.899 m²
		*) including air control openings

AIR SPEED AND VOLUME FLOW THROUGH GAP

The air speed through slits is calculated as follows.

$$v = \sqrt{\frac{(2 \times \Delta p)}{\rho}}$$

$$\text{and } \Delta p = \frac{(v^2 \times \rho)}{2}$$

v = air speed [m/s]

Δp = differential pressure [Pa]

ρ = density [kg/m³]; $\rho_{\text{air, 25°C}}$ = 1.1839 kg/m

Pressure control

The control is made with a minimum pressure of 20 Pa. The air speed is determined in accordance with the formula:

$$v = \sqrt{\frac{(2 \times 20)}{1{,}1839}[m/s]}$$

v = 5.81 [m/s]

SmartAisle™ temperature control

The control is m the air flows through the controlling openings with approx. 1 m/s.

The differential pressure for this is:

$$\Delta p = \frac{(1^2 \times 1{,}1839)}{2}[Pa]$$

Δp = 0.59 ≈ 0.6 [Pa]

The volume flow loss through the gap is calculated as follows:

$$V = v \times A$$

V = volume flow [m^3/h]

v = air speed [m/s]

A = gap surface [m^2]

The following values are returned for the chosen example:

	Pressure control	SmartAisle™ temperature control
Pressure	20 Pa	0.6 Pa
Air speed	5.81 m/s	1.00 m/s
Volume flow loss through gap	18,446 m^3/h	3,238 m^3/h

Considerably more air is therefore lost through the gaps with pressure control. This has a critical influence on the energy consumption for the air circulation, as the fans in the high precision air conditioning units must process a considerably higher amount of air.

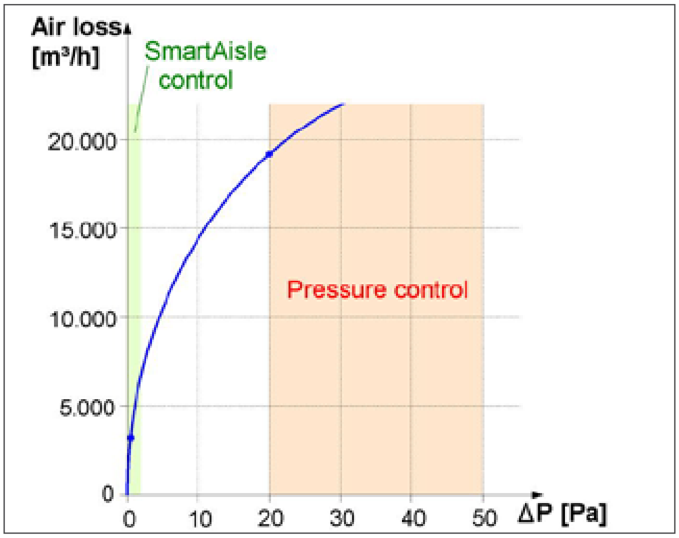

Figure 6: *Air loss*

This diagram visualizes that the higher the pressure the higher the air loss.

SmartAisle™ operates in an area with less air loss through gaps.

The air loss of the pressure control is much higher.

AIR LOSS THROUGH SERVER

Modern servers are typically designed for a pressure-free operation, i.e. the fan design is configured in a way, that there is no positive or negative static pressure on the server inlet and outlet. Usually it is assumed that idle servers are sealed (also in CFD simulations). But that theoretical model of a sealed server is wrong [1].

Daniel Kennedy has measured some servers at different pressures. The following table shows a summary of the percent leakage of all measured servers in the idle mode. He assumes that about 70% of the time, the servers are in the idle mode. Because of server virtualization, we assume that in the near future the servers are maximum 50% of the time in idle mode.

Pressure [in/H_2O]	Pressure [P]	More air requirement of server in the idle mode
0	0	0,0%
0,02	5	23,5%
0,04	10	39,7%
0,05	12,5	47,8%
0,06	15	56,0%
0,08	20	69,4%
0,1	25	82,6%
0,12	30	93,5%
0,14	35	105,1%
0,16	40	116,9%
0,18	45	126,5%
0,2	50	136,5%

Tab. 1: *Air loss*

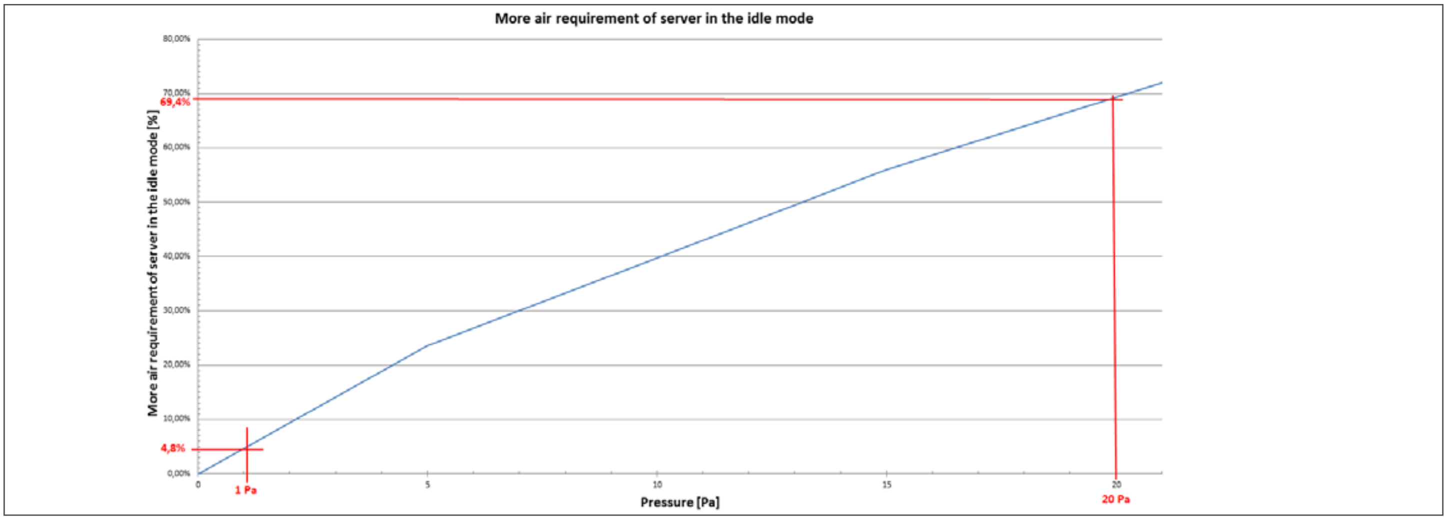

Figure 7: *Air loss*

According to the measurements by Daniel Kennedy arise for our two controls, an additional loss of volume flow due to idle servers of 69.4% for the pressure control and 4.8% for the SmartAisle™ temperature control.

The loss of volume flow through the servers is calculated as follows.

$$V_S = k \times t \times V_t$$

V_S = volume flow loss through server [m³/h]

k = coefficient by Daniel Kennedy

t = time idle mode of the server [%]

V_t = theoretical volume flow [m³/h]

For the sample object, the following values are obtained.

	Pressure control	**SmartAisle™ temperature control**
Pressure	20 Pa	0,6 Pa
Air speed	5,81 m/s	1,00 m/s
Volume flow loss through server (idle)	18.321 m³/h	1.267 m³/h

Considerably less cold air is lost through the SmartAisle™ temperature control during the idle mode of the servers.

SUM OF AIR LOSSES

In modern and energy-efficient data center with containments cold air is lost through overpressures through gaps and servers in idle mode. In sum the comparison of pressure control and the SmartAisle™ temperature control shows:

	Pressure control	SmartAisle™ temperature control
Pressure	20 Pa	0.6 Pa
Air speed	5.81 m/s	1.00 m/s
Theoretical volume flow	52,800 m^3/h	52,800 m^3/h
Volume flow loss through gap	18,446 m^3/h	3,238 m^3/h
Volume flow loss through server (idle mode)	18,321 m^3/h	1,267 m^3/h
Total necessary volume flow for cooling	89,567 m^3/h	57,305 m^3/h

POWER COSTS FOR HIGH PRECISION AIR CONDITIONING UNITS DRIVE

Depending on the number of high precision air conditioning units in the data center, the high precision air conditioning units work in more or less energy-efficient operation. As only EC fans are now used in modern high precision air conditioning units, the high precision air conditioning units are basically more energy-efficient at a low speed. The minimum speed is usually 30%.

The measured “Power consumption for fan speed” characteristic curve of a typical EC fan is shown in Figure 6.

For a 90% speed this EC fan requires power consumption of 1,130 watts. With a 30% speed the fan only requires 90 watts.

$$\text{90\%:}\ \frac{1130}{1350} = 0{,}83\left[\frac{W}{m^3/h}\right]$$

$$\text{30\%}\ \frac{90}{450} = 0{,}20\left[\frac{W}{m^3/h}\right]$$

This means that the fan at 30% works 4 times more efficiently vis-a-vis the supplied air volume than the one at 90% speed.

The power requirement was calculated using the calculation software for the used high precision air conditioning unit for 4 different states.

The power requirement for both control types was calculated for different „modes,“ i.e. with more or less high precision air conditioning units.

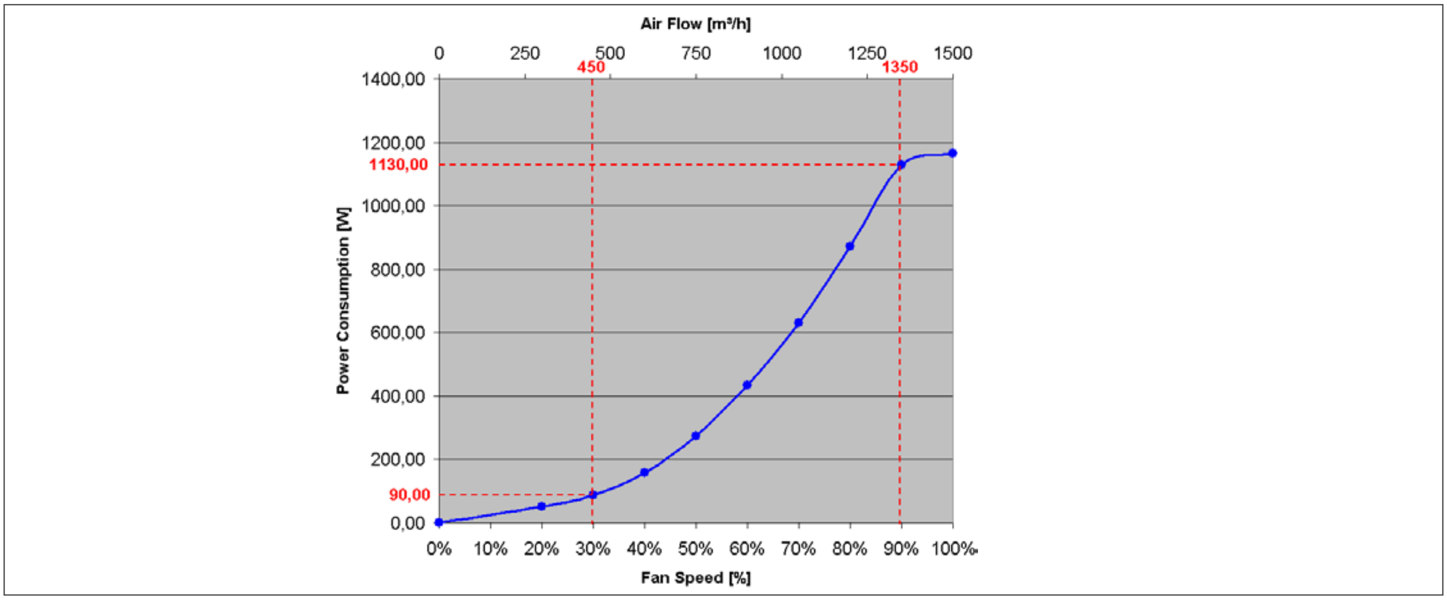

Figure 8: Characteristic curve of a typical EC fan

At least three of these devices must be used to provide the required air volume. In the simplest case these run without any fan control at full speed. The most power is consumed in this configuration.

The annual power requirements were calculated with the calculated power requirement from the calculation software.

Parameters of the high precision air conditioning units	
Inlet fluid temperature	15 °C
Outlet fluid temperature	20 °C
Unit inlet air temperature	35 °C
Unit inlet air relative humidity	25%
Annual power requirement = power x no. of CRAC units x 24 x 365 [kWh]	

	No control
Number of high precision air conditioning units	3
High precision air conditioning units speed	100%
Annual power requirement	131,663 kWh
Annual power costs	€19,749

With speed control the fans still run at almost full speed with pressure control; with temperature control depending on the air requirement, which is relatively low, with only approx. 70%. With the heavily non-linear fan characteristic curve this results in much lower energy requirement.

Full load operation MODE	Pressure control	SmartAisle™ temperature control
Number of high precision air conditioning units	3	3
High precision air conditioning units speed	98%	67%
Annual power requirement	126,407 kWh	45,990 kWh
Annual power costs	€18,961	€6,899

As in practice a redundancy of n+1 is practically always planned, at least 4 high precision air conditioning units would be used, which are operated speed-controlled in parallel operation. This reduces the energy requirement significantly; there continues to be a very big difference between the two control modes.

Normal operation MODE	Pressure control	SmartAisle™ temperature control
Number of high precision air conditioning units	4	4
High precision air conditioning units speed	78%	52%
Annual power requirement	94,258 kWh	29,784 kWh
Annual power costs	€14,139 €	€4,468 €

In many cases today additional high precision air conditioning units are planned in to further optimise energy efficiency. This results in a further significant reduction in energy costs. A coordination of additional investment costs and saved operating costs is required to optimise investments. This would also result in the following further savings.

Efficient operation MODE	Pressure control	SmartAisle™ temperature control
Number of high precision air conditioning units	6	6
High precision air conditioning units speed	54%	37%
Annual power requirement	49,932 kWh	19,447 kWh
Annual power costs	€7,490	€2,917

Highly efficient operation MODE	Pressure control	SmartAisle™ temperature control
Number of high precision air conditioning units	8	8
High precision air conditioning units speed	42%	33%
Annual power requirement	35,741 kWh	20,323 kWh
Annual power costs	€5,361	€3,048

The cost-effectiveness of this method is studied closer in another white paper.

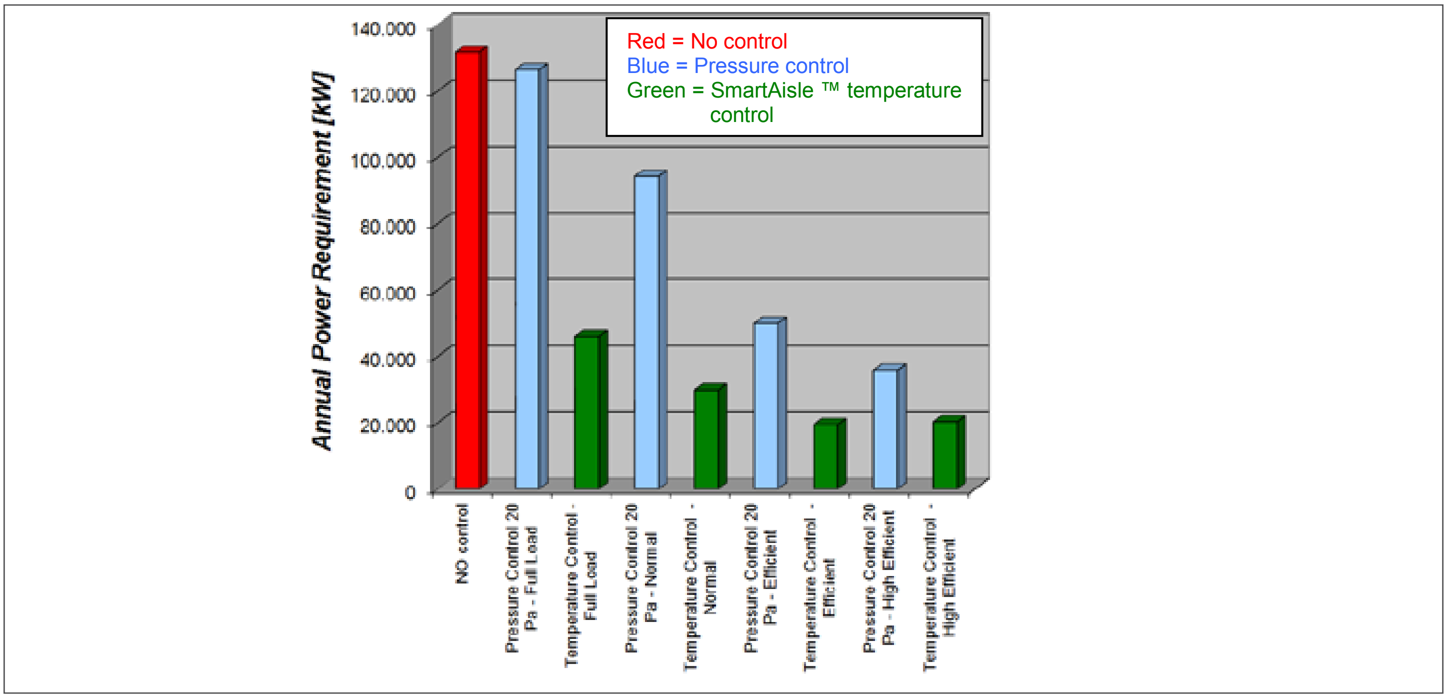

Figure 9: *"Annual power requirement" results*

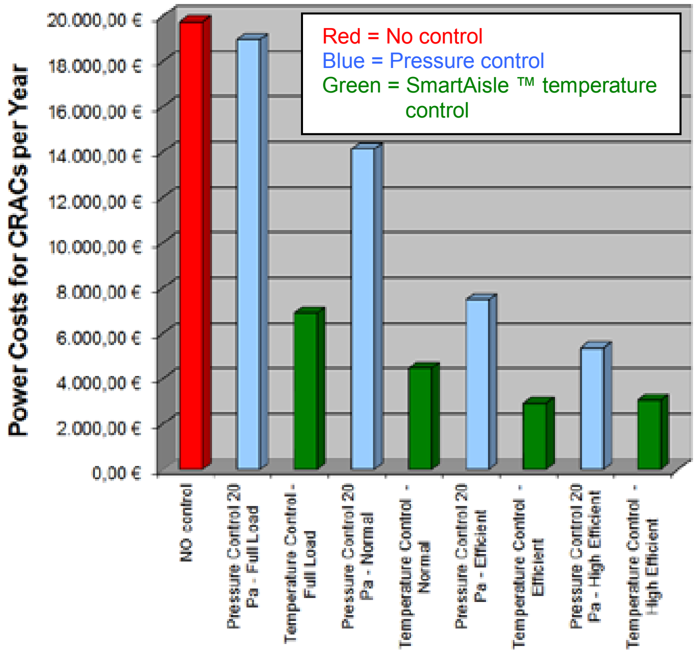

Figure 10: *"Annual power costs" results*

POWER REQUIREMENT/POWER COSTS RESULTS

For operating the high precision air conditioning units, less than half of the power is required for the SmartAisle™ temperature control compared with the pressure control! This applies to all 4 modes:

- Full load operation
- Normal operation
- Efficient operation
- Highly efficient operation

SUMMARY AND ASSESSMENTS

A modern and energy-efficient data center should have high precision air conditioning units with speed-controlled fans.

	Pressure control	SmartAisle™ temperature control
Energy costs	**Acceptable energy efficiency** Pressure control produces constant cold air loss through gaps and openings (bushings, foam, etc.).	Best energy efficiency (only half the costs compared with pressure control) With this control the controlling is constantly against a pressure difference of 0 Pascal. This means there is less cold air loss through gaps and openings (bushings, foam, etc.).
Cold air supply for different cold aisles	The cold aisles are mostly supplied with sufficient cold air. An aisle **under-supply** with cold air **cannot be ruled out** with different heat loads. The raised floor area has a differential pressure of at least 20 Pa. This pressure is transferred through perforated raised floor panels to the cold aisle. If an individual aisle has an air requirement higher than 20 Pa,then there is an under-supply of this cold aisle.	Depending on its length, each cold aisle has at least 2 temperature sensors, which are positioned in the air controlling opening. Each cold aisle is monitored individually. The speed is usually controlled after the highest temperature value in all aisles. This guarantees that **no cold aisle is under-supplied**.
Effects on the IT equipment	The pressure control works with a constant differential pressure of at least 20 Pa. This means that the fans in the servers, switches, etc. are subjected to constant pressure. This constant pressure **can** reduce the **IT equipment's service life**.	The temperature control always controls the pressure against 0 Pa. This does not result in any constant over-pressures for the IT equipment. Therefore there **no negative effects**.

FURTHER CONSIDERATION AND OUTLOOK

In comparison with pressure control, the SmartAisle™ temperature control also has higher energy savings for the chillers. These savings will be discussed in a white paper to follow.

REFERENCES

1. Dissertation – Andreas Matthias, 2007. The flow characteristics of labyrinth seals with different operating conditions.
2. Daniel Kennedy, 2012. Ramification of Server Airflow Leakage in Data Centres with Aisle Containment.

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