Ark Continuity - Continuously Delivering high integrity data centres

Free-Cooling Vs Cold-Aisle set-point

Two trends in Data Centre power efficiency compared

Dr Ian F Bitterlin

PhD BSc(Hons) BA DipDesInn MCIBSE MIET MBCS MBIFM MIEEE

Publication: May 2010 | **Reference** 2010/05/004

WHITE PAPER 2010

Ark Continuity delivers high integrity data centres for Government and Corporate occupiers. Ark is now building its data centre campus at Spring Park, Wiltshire with the first phase opening in November 2009. The facility will be one of the most secure, available and sustainable in Europe.

This document is one in a series of white papers prepared by Ark Continuity. If you would like further information, please contact Ark Continuity on 0845 389 3355 or visit www.arkcontinuity.co.uk

Head office: Hartham Park, Corsham, Wiltshire, SN13 0RP

Free-Cooling Vs Cold-Aisle set-point

Two trends in Data Centre power efficiency compared

Background

The pressure on data-centre power efficiency improvement is increasingly being affected by two trends, one well established, so called 'free-cooling', and the other less so, the possibility of increased server air inlet temperature. This paper explores the relationship between the two in the context of the typical ambient temperatures found in the UK.

Free Cooling

To remove the heat from the traditional large data-centre facility involves air-to-water heat transfer inside the sealed room (Computer Room Air Conditioners, or CRAC's) with a chilled water circuit transporting (pumping) the heat outside where air or water-cooled chillers use a refrigeration cycle and electric motor driven compressors. Electric fans are used inside the room and outside on the condenser coils. The traditional chilled water temperatures were 6°C cold 'flow' and 12°C hot 'return'.

As the temperature in northern climes is often colder than say, 12°C, and the cost of electrical energy rose, it quickly became a standard energy saving feature to utilise the external ambient air temperature to cool the 'hot' water rather than run the compressor motor. Thus 'free-cooling' coils and circuits were added to the chilled water pipe-work system.

A simplified version of such a scheme is shown in Figure 1. Clearly the cooling is not 'free' as the system still requires pumps and fans but, as we shall illustrate, the compressor motor is the largest power consumer in the system. When the conditions are suitable the valves (in this simplified model) divert the hot water to the free-cooling coil and fans blow ambient air to reduce the 'hot' water temperature to the required 'cold' water temperature for return to the CRAC units, thus avoiding using the chiller and its compressor altogether.

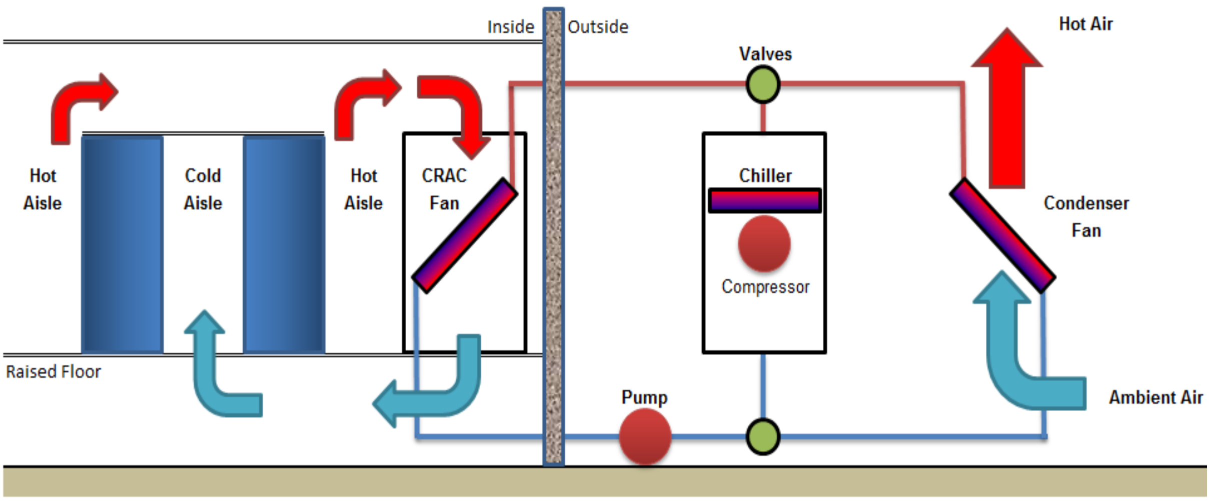


Figure 1

Approach Conditions

Thermodynamic theory is not needed to understand the concepts in this paper but one factor must be understood: If you want to reduce the temperature of the water entering a radiator by blowing colder air across it then the bigger the radiator surface area and the slower the flow, the better. To keep this within practical limits the radiator and flow-rate etc are designed for a particular set of temperature differences – so called, 'approach' conditions. Although sounding complicated, this is very simple and an example is the best way to demonstrate it:

A practical set of approach conditions is to achieve a temperature delta of 2°K. For example, if the 'hot' water is at 12°C and it is required to cool it to 6°C then the air blowing over the heat-exchanger must be at 4°C, i.e. 2°K lower than the chilled water temperature required.

If you try to reduce the approach conditions to, say, 1°K, then the heat exchanger size and cost rises disproportionately.

In reality the calculations (and linked to the thermodynamic performance of standard components and assemblies) are complex but the principle remains simple – you need a temperature difference to transfer heat and 2°K is a practical design point.

Server Inlet Temperature

All of the IT hardware OEMs (IBM, HP, Dell, Sun, etc) participate, cooperate and contribute to ASHREA (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers) and it's Technical Committee 9.9. In 2009 ASHREA relaxed both the temperature & humidity limits from the rather draconian 22±1°C, 50%RH±5% to the less stringent and 'greener' boundaries of 18-27°C and 30-80%RH.

Allied with this relaxation is the growing trend to manage the air-flow in a much more confined manner, simply put; not allowing precious chilled air to return to the CRAC's unless it has been through the IT load. Aisle containment, blanking plates and hole stopping etc, are all a part of this new 'technology' and can be studied in depth in the 'best-practice' section of the 2009 EU Code-of-Conduct on Data-Centre Efficiency.

In this way the emphasis has shifted from a 'room' SLA of 22°C – achieved by feeding 17-19°C air into the plenum and taking 22-24°C back into the CRAC's - to a more definable 'cold-aisle' SLA.

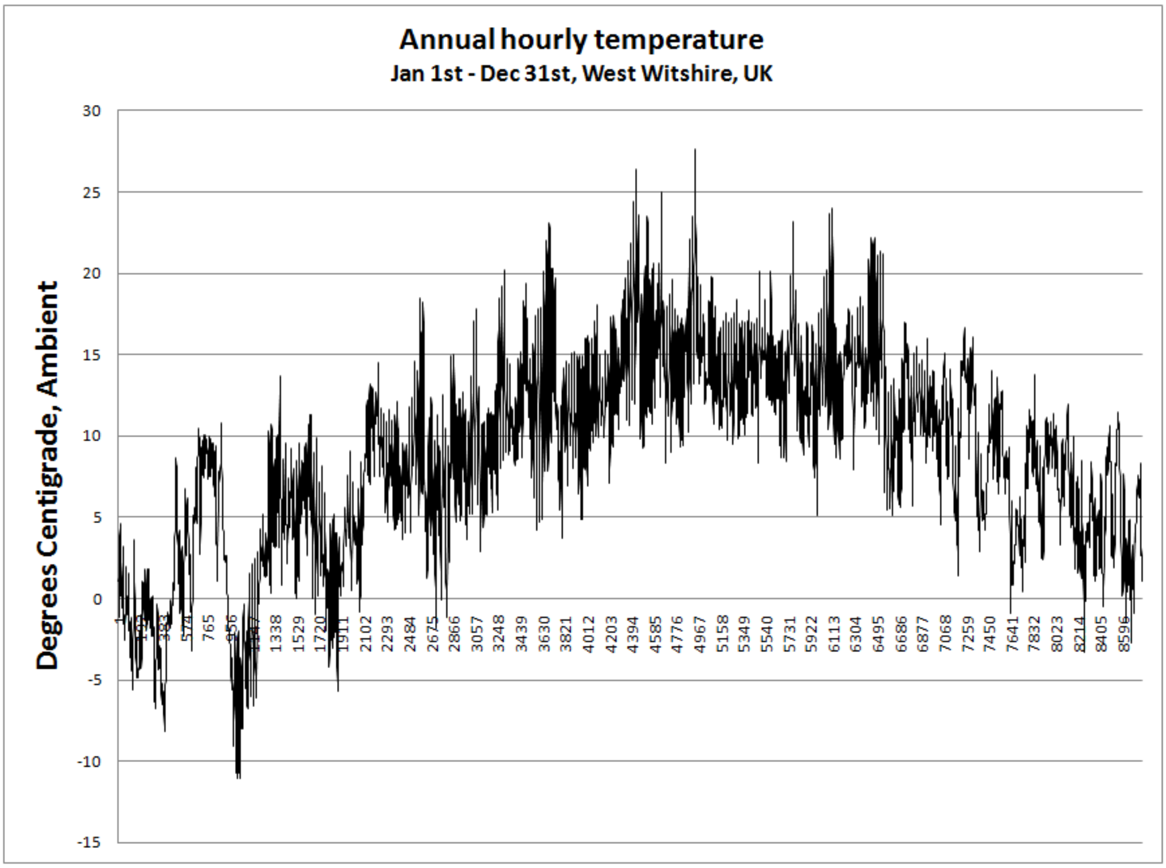
So far (May 2010) there is more talk about raising server inlet temperatures than temperatures actually going up but the trend is gaining a lot of momentum as the cost of cooling is recognised as a major element apart from the IT hardware itself.

Ambient Conditions in the UK

The further North you are located, the higher the altitude your facility is and the further you stay away from within the London/M25 'temperature island effect' the colder the temperature will be.

For the purposes of this paper we are going to use actual temperature data from the South West.

However if we just take minimum, maximum and average temperatures it doesn't tell us much about the opportunity for free-cooling operation. For the full year hourly data-set shown in Graph 1 the average is 8.82°C, the minimum is -11.10°C and maximum +27.60°C.



Graph 1

Clearly the opportunity for free-cooling is great, but how great?

Free-Cooling Vs Cold-Aisle Temperature?

Looking at Figure 1, and bearing in mind the temperature delta that needs to be considered for the heat exchange approach conditions, it should be clear that the higher the cold-aisle temperature is, the higher the chilled water temperature can be. As a direct result, the higher can be the external temperature for 'free-cooling' operation.

Table 1 summarises a simplified set of data that shows this relationship.

The table starts with a version of the traditional room set-point (of average 22°C) and shows that free-cooling operation is available for 68.4% of the year (compressor running for only 31.6%) – which clearly demonstrates why the additional investment in free-cooling plant has become 'standard practice' in large facilities.

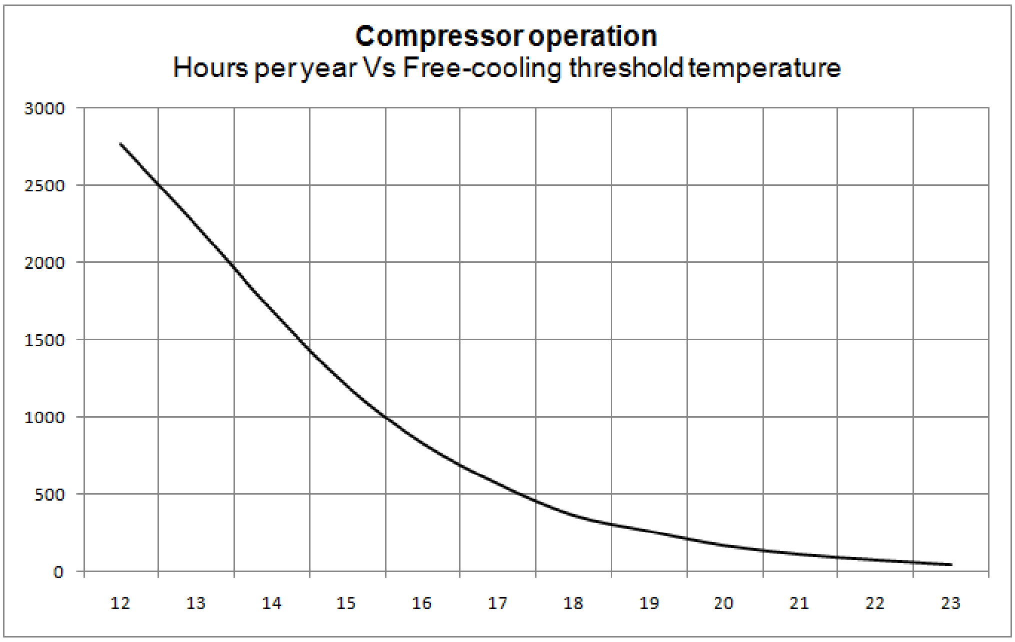
Typical temperature relationships & hours of free-cooling						
Cold Aisle °C	Hot Aisle °C	Water Cold Feed °C	Water Hot Return °C	Free-Cooling Threshold °C	Compressor Hours per year	Annual %age
17	27	15	21	12	2768	31.6%
18	28	16	22	13	2244	25.6%
19	29	17	23	14	1692	19.3%
20	30	18	24	15	1199	13.7%
21	31	19	25	16	828	9.5%
22	32	20	26	17	564	6.4%
23	33	21	27	18	361	4.1%
24	34	22	28	19	258	2.9%
25	35	23	29	20	165	1.9%
26	36	24	30	21	108	1.2%
27	37	25	31	22	72	0.8%
28	38	26	32	23	41	0.5%

Note! ASHREA TC9.9 upper limit for server inlet temperature = 27°C

Table 1

Table 1 ends with the 27°C upper limit set by ASHREA TC9.9 and shows that free-cooling could be available for 99.2% of the year (just 72 hours per year of compressor operation).

Graph 2 illustrates the relationship between the temperature that free-cooling is available and the hours run per year of the chiller compressor:



Graph 2

Rule-of-thumb: Free-cooling is available at external ambient temperatures of 'Cold-Aisle - 5°K'.

Emergency conditions

Normal practice in design (for the UK climate) is to take an ambient temperature peak of 35°C but it would be tempting to take these hourly temperature figures (with the peak at 27.6°C) and base a design on them instead. This would, of course, be wrong since each year there is the potential for some kind of abnormal event where a temperature excursion of above 30°C is possible, even for just an hour or two. The UK record of 34°C was set a few years ago not far from the example data-point location, in Gloucester.

The design problem that we face is that to base the plant on 35°C ambient and then have it run in 8.8°C annual average with a peak of 27.6°C results in oversized cooling plant often operating away from its optimum energy efficiency point.

The design conclusion must be that, even at a 27°C cold-aisle set-point, the compressor plant has to be installed although it will only run for less than 100h/annum.

To minimise the installed power-grid capacity and maximise the return on investment on the emergency diesel generators it is suggested that to run the compressors (with the full IT load, a very rare condition) requires the diesels to start.

Power saving and carbon-footprint

Table 2 illustrates the cost of running the cooling system for the whole range of cold-aisle temperatures from 17-27°C.

Annual Power Consumption per MW of IT load							
Cold Aisle °C	Compressor Motor h/annum	CRAC kWh 50 VA/kW	Pump kWh 15 VA/kW	Compressor kWh 220 VA/kW	Condenser kWh 50 VA/kW	Total Energy MWh	Cost £000's £0.10/kWh
	8760	438,000	131,400	1,927,200	280,000	2,777	£ 278
17	2768	438,000	131,400	608,960	193,760	1,372	£ 137
18	2244	438,000	131,400	493,680	157,080	1,220	£ 122
19	1692	438,000	131,400	372,240	118,440	1,060	£ 106
20	1199	438,000	131,400	263,780	83,930	917	£ 92
21	828	438,000	131,400	182,160	57,960	810	£ 81
22	564	438,000	131,400	124,080	39,480	733	£ 73
23	361	438,000	131,400	79,420	25,270	674	£ 67
24	258	438,000	131,400	56,760	18,060	644	£ 64
25	165	438,000	131,400	36,300	11,550	617	£ 62
26	108	438,000	131,400	23,760	7,560	601	£ 60
27	72	438,000	131,400	15,840	5,040	590	£ 59

Table 2

The first line of Table 2 shows the cost of running a traditional cooling system without any form of free-cooling and this can be directly compared to the '17°C' line to show the benefit of just fitting free-cooling plant but not raising the room set-point from the classic 'average' 22°C SLA (where the air is supplied into the plenum at around 17°C).

The maximum annual saving to be made (from the traditional 22°C SLA with no free-cooling to 27°C cold-aisle with free-cooling) per MW of IT load is in the order of 2,190MWh, £220k and 1,200 Tonnes of CO_2 from the UK power-generation fuel mix. This is the equivalent of 400 'average' UK car-years, every year.

The annual saving to be made (from the traditional 22°C SLA with free-cooling to 27°C cold-aisle with free-cooling) per MW of IT load is in the order of 780MWh, £78k and 425 Tonnes of CO_2 from the UK power-generation fuel mix. This is the equivalent of 140 'average' UK car-years.

Conclusions

For the UK ambient temperature profile it is clear that pushing the server inlet temperature up (in conjunction with free-cooling plant) progressively reduces compressor operation to less than 100 hours per year. This improves the PUE[1], saves energy and operational expenditure, as well as reducing maintenance costs and, ultimately, the carbon-footprint of the facility.

End

[1] PUE = Power Usage Effectiveness, see Dr Bitterlin's previous white paper "Exploring the concept of comparative PUE" at www.arkcontinuity.co.uk