IT environmental range and data centre cooling analysis

Assessment of the impact of IT inlet temperature and humidity ranges on data centre cost and overall energy consumption

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May 2011
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1. Document Information

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<td>Minor edits</td>
<td>03 May 2011</td>
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<td>01 May 2011</td>
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<td>Review copy</td>
<td>Added impact of raising upper dew point</td>
<td>27 April 2011</td>
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<tr>
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<td>Amended upper dew point limit for class 2</td>
<td>26 April 2011</td>
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<td>Added 2.7 and 4.11 Impact of increased intake</td>
<td>25 April 2011</td>
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2. Summary

This paper reports the results of an analysis of IT equipment intake temperature and humidity ranges in data centres. The analysis has assessed a set of operating ranges to determine the impact on the IT equipment and data centre energy consumption. In the process a number of key results were obtained which challenge much of the conventional wisdom on data centre efficiency and cost and a few useful rules of thumb identified.

2.1 Impact of expanding environmental ranges

This paper demonstrates that in most of the world there is no significant reduction in overall energy consumption or operating cost available from increasing the IT equipment environmental range from the existing ASHRAE Class 2 (up to 35°C and 80% relative humidity or 21°C dew point) to the ETSI environmental range (up to 45°C and 80% relative humidity no dew point limit).

If the upper dew point limit for the increased to be in the range of 25°C this substantially reduces the requirement for mechanical cooling to control temperature and humidity in direct air economised (fresh air) data centres even within the temperature bounds of the existing Class 2 range. This would represent a significant additional opportunity for data centre operators to build and operate no-chiller data centres which use adiabatic cooling of external air although the data centre capital cost benefits should be balanced against the IT equipment failure and wear-out rate impacts of increased humidity.

2.2 The problem is the data centres and not the IT equipment

The issue of data centre cooling energy overhead is primarily due to the design and operation of data centres and not the IT equipment environmental ranges. The cooling efficiency of the data centre is dominated by the temperature difference between the coldest point in the cooling system and the external climate. Increasing the temperature of this coldest point through the use of best practices such as air flow containment yields multiple benefits.

2.3 Chiller hours is not a useful measure of performance

Chiller or economiser hours are not, on their own, useful measures of the energy efficiency or cost savings available to a data centre. This analysis finds that there is a strong relationship between the economiser hours a well designed data centre achieves and the efficiency of the mechanical cooling when it is operating due to reduced delta-T and reduced load fraction. This results in a non-linear relationship between chiller hours and annual energy consumption or operating cost with much of the benefit achieved by the point where chillers are only used for 5 months of the year.

2.4 Chiller-less data centres

The complete elimination of mechanical chillers (compressors) is of little benefit from an energy consumption or operational cost standpoint. The major benefit of this type of design is from capital cost reduction in the chillers and supporting electrical equipment capacity and not operational cost or energy consumption.

2.5 Increased temperatures should not cause large increases in IT energy consumption

Modern servers with variable speed fans and effective cooling designs show only small (1%-5%) annual increases in IT energy consumption when operated 5°C below the maximum rated intake temperature. IT equipment with compromised cooling design through poor form factor or unnecessary power density represents an issue but this should be addressed through publication of effective power consumption against intake temperature data. It may also be expected that publication of this data for IT equipment product lines may lead to further improvements in higher intake temperature performance if vendors find that customers are selecting equipment based on its energy consumption at elevated intake temperatures.
2.6 Economiser performance available within existing ranges
In many regions it is possible to build a data centre which operates entirely within the existing ASHRAE Class 1 (up to 32°C and 60% relative humidity or 17°C dew point) without mechanical cooling. It is possible to operate a data centre within the ASHRAE Class 2 (up to 35°C and 80% relative humidity or 21°C dew point) without chillers for the majority of the year in most of the world if design best practices are implemented properly.

2.7 Wide humidity ranges are optional
High humidity is a major concern for IT equipment reliability as moisture ingress can damage key components within the server, particularly in combination with high temperatures.

Most of the world is able to operate a well implemented indirect air side or direct water side economiser system within the existing ASHRAE Class 1 recommended humidity range (5.5°C dew point to 60% relative humidity and 15°C dew point) with minimal mechanical cooling and humidity control cost.

The major benefit of increased upper humidity bounds is an improvement in the available performance of direct air side economiser systems such as those popular with large Internet operators building no-chiller “chicken coop” type facilities. In these designs substantial capital cost may be eliminated and increased upper humidity bounds increase the number of climate regions in which direct air side economised no-chiller facilities are effective.

2.8 Minimised mechanical cooling energy and cost
It is possible, through the implementation of design best practices and the utilisation of the full operating ranges of existing IT equipment to operate data centres with minimal cooling energy consumption and cost across most of the world’s climate regions.

This analysis finds that the majority of the energy and operational cost efficiency benefit for data centres is achieved when the data centre is able to operate for 8 months per year using economised “free” cooling and 4 months per year requiring mechanical cooling. This means that even locations such as Singapore and Riyadh show significant opportunity for free cooling when a suitably tailored cooling design is operated effectively.
3. Objectives

There were a series of objectives for the research carried out to provide the analysis data on which this paper is based.

3.1 Issues in the industry

At present much of the discussion within the data centre industry about what environmental range IT equipment should be operated within is dominated by extreme and opposing viewpoints which leaves operators unwilling to change their present control ranges. This resistance to change has left most data centre operators with higher energy consumption and operating cost than necessary.

Common examples of these opposing extreme viewpoints are;

“You cannot exceed 25°C or your IT equipment fan power will exceed the cooling energy saving” vs. “We can and should eliminate chillers from the data centre, the silicon runs at 80°C so no IT equipment should need any mechanical cooling”

“Servers that can run efficiently at higher than 22°C are too expensive” vs. “Eliminate the capital cost of chillers”

This analysis seeks to understand the relationships between these factors and where the overall most effective choice for each operator lies, somewhere in between these extremes.

3.2 Selection of a minimum expected range

The EU Code of Conduct on Data Centres is currently scheduled to change the minimum expected environmental range for IT equipment purchase from the ASHRAE Class 1 range to the proposed ETSI EN 300 019 Class 3.1

The ASHRAE class 1 range has upper limits at 32°C for temperature and 60% RH and 15°C dew point for humidity whilst the suggested ETSI range requires 45°C intake and 80% RH with no specific humidity limit. A range of concerns have been raised with this large change in required IT equipment operating range including;

- Additional capital cost and physical size
- Additional embodied energy due to increased size
- Reduced device efficiency due to restricted component clock speed (required to achieve cooling targets)

A specific tension exists within the Code of Conduct Best Practice Working Group between operators with “traditional” data centres and those wishing to move to a design with no chillers installed.

This analysis is intended to provide evidence to guide the selection of a new minimum expected operating range.

3.3 Identify the impacts of reducing annual mechanical cooling hours

Given that the average efficiency with which data centres deliver electricity to IT equipment is currently around 50%¹ (a PUE of 2.0) there exists a view that the mechanical cooling is the major part of this overhead, “one Watt of cooling for every Watt of IT” is a commonly heard phrase.

This leads to the view that each eliminated chiller hour is equal and therefore the goal is to eliminate mechanical cooling entirely from the data centre.

¹ The Code of Conduct participant average is 56%, a PUE of 1.8, see http://re.jrc.ec.europa.eu/energyefficiency/pdf/CoC/DC_Stakeholder%20Meeting.%20London%2010%20November%202010/Bertoldi%20London%20Nov%202010.pdf
4. Findings

Many of the findings of this paper were not expected at the beginning of the analysis resulting in a number of additional elements of investigation to further investigate the impact or opportunity represented by the finding.

4.1 Associated papers

This paper is a summary of the analysis activity, more detailed presentation and analysis of the data is available in the associated papers.

4.2 Available savings from eliminating chillers

This paper concludes that there is no 50% efficiency gain available through eliminating chillers. Chillers are generally less than 20% of total data centre energy consumption, whilst the remainder of the losses are elsewhere in the cooling system in devices such as water pumps and fans. In a well operated data centre in most climate regions it is possible to reduce the mechanical cooling losses to less than 5% of the overall energy consumption.

As an example of this the chart in Figure 1 below shows the energy consumption of a 500kW IT capacity data centre which achieves an annual PUE of 1.8 over one year. This data centre has no economiser, no air flow containment and relies on mechanical chillers providing a low temperature chilled water loop at all times for cooling.

![Attributed Overall Energy](chart.png)

**Figure 1 Annual energy consumption broken down by device**

In this case 3.1GWh of electrical power is delivered to the IT equipment over the year and a further 2.7GWh of energy is lost as data centre overhead in the mechanical and electrical infrastructure. Of these losses only 900MWh is consumed by the chillers, a further 1.36GWh is lost in the pumps and CRAC units.

Reduction of the "one Watt of cooling for every Watt of IT load" requires a series of actions targeting a range of energy losses within the cooling system, not simply elimination of the chillers. These practices are all identified within the Code of Conduct Best Practices.
4.3 Only moderate expansions of existing ranges are required

The constraint on data centre efficiency is not due to the IT equipment intake ranges but instead lies in the design and operational settings of many of the data centres housing the IT equipment.

This paper suggests that by selecting IT equipment capable of operating within the ASHRAE Class 2 range (up to 35°C and 80% relative humidity or 21°C dew point) most data centres will be able to operate with minimal chiller hours.

No justification was found for increasing the minimum expected IT environmental range for all operators within Europe beyond 35°C intake. The secondary effects on IT equipment cost for the majority of European operators coupled with the lack of cooling energy saving suggests that those operators in particularly hot or dry parts of southern Europe should be considered as a special case. Note that data centres in dry regions are particularly disadvantaged by not being able to use adiabatic cooling.

**Annual Chiller Hours (Dry Cooling) Class 2**

![Annual Chiller Hours (Dry Cooling) Class 2](image)

*Figure 2 Annual European chiller hours for ASHRAE Class 2 IT range – Dry cooling*

As shown in Figure 2 above when the data centre is designed and operated effectively the hours per year during which any mechanical cooling is required are minimal. Three different types of cooling economiser are represented, direct air side (fresh air), indirect air side and indirect water side. With the exception of the hottest dry climates such as Seville, Athens and Palermo all of these locations are in the range where there is no substantial additional energy efficiency or operational cost saving to be achieved through further reduction of chiller hours.

Figure 3 below shows how this is further reduced through the use of adiabatic cooling, it should be noted that in some areas water availability is an issue and adiabatic cooling is not a realistic option. A significant part of the adiabatic cooling chart is the indicated opportunity for reduced or eliminated mechanical cooling capacity for the cooler parts of Europe in all three economiser designs and for all of Europe using the adiabatically cooled indirect air side economiser.

*Note that these charts are based on Typical Meteorological Year data and should not be used to size the cooling system of a data centre which should consider peak in addition to typical operating conditions.*
Rest of the world
As the Code of Conduct is used by and has impact upon data centres outside Europe it is also important to consider the impact in other climate regions. This is shown in the charts below:

**Chiller Hours (Dry Cooling) Class 2**

As for the European climate zones the adiabatically cooled indirect air design shows strong opportunity for capital cost savings through reduction or elimination of chiller capacity. For the majority of the climate regions the chiller hours are sufficiently low to have delivered most of the operational energy and cost savings with only Riyadh showing significant need for mechanical cooling.
Figure 5 Annual world chiller hours for ASHRAE Class 2 range - Adiabatic cooling

Figure 4 and Figure 5 show two notable issues when the broader range of climate types are included;

a) There is a subset of very hot climates (Group B arid and semi-arid) such as Riyadh where significant chiller hours are likely to be required due to the external temperature and the lack of available water for adiabatic cooling. Note that even in these conditions more than half of the hours per year can be economised and the major chiller efficiency gains have already been delivered, most regions are into the range of chiller capacity reduction or elimination.

b) There is a second subset of warm and wet climates (Group A tropical – megathermal) such as Mumbai, Hong Kong and Singapore where the combination of external temperature and humidity present an issue for direct air side economiser systems but which are well served by an indirect air or direct water side economiser design which is not subject to the IT device maximum humidity constraints.

A full set of charts is available in the accompanying documents;

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Table 1 Analysis output available

4.4 Impact of raising the upper dew point humidity limit

The combined low capital cost and high operating efficiency of direct air side economisers, where external air is supplied to cool the IT equipment with minimal conditioning provides an attractive choice for data centre operators. A number of large scale cloud and social networking operators have deployed data centres using this design.
The major constraint on this type of cooling system is the upper humidity limit, specifically the upper maximum humidity ratio\(^2\) set by the upper dew point specification. This increase in allowable humidity affects only the Direct Air economiser type, the performance of the indirect air and indirect water are unchanged.

**Annual Chiller Hours (Adiabatic) Class 2 Ext**

Comparison of Figure 3 with Figure 6 above for Europe shows that this extension of the upper dew point limit allows almost all of Europe to operate without requiring any mechanical cooling in a typical year. Comparison of Figure 5 with Figure 7 shows that only unusually hot and wet world climates still require mechanical cooling with this extended range.

**Chiller Hours (Adiabatic) Class 2 Ext**

\(^2\) The ratio between the mass of water vapour to the mass of air as opposed to relative humidity which is a measure of what proportion of the maximum amount of water vapour in air at the given temperature
4.5 Capital cost vs. energy efficiency vs. operational cost
No significant tension was found between IT equipment capital cost and energy consumption or power cost efficiency. In most of the world the selection of an operating IT environmental range for a data centre is not a question of trading off capital cost of either the data centre or IT equipment against operating cost and energy consumption.

This analysis demonstrates that in most of the world it is possible to operate with a negligible mechanical cooling energy whilst using relatively conservative IT operating ranges.

4.6 Dynamic management of IT equipment supply air temperature
Whilst only minor changes are required to the selected operating ranges major changes are required to the design and operational approach of many data centres. The goal of these changes is the reduction of the temperature difference between the IT equipment intake and the coldest point in the cooling system.

Many concerns have been raised regarding any increase in the supply temperature to IT equipment in the data centre, the two major issues being the increase in IT equipment energy consumption and an impact on the IT equipment reliability.

The first step in addressing this concern is to allow the data centre to vary the supply air temperature based upon the current external conditions. This allows the data centre to supply relatively cold air to the IT equipment for most of the year and only make use of the upper parts of the temperature range when necessary in order to limit the extent of the exposure to increased temperature.

The second step is to implement air flow containment to minimise the temperature differential between the coldest part of the cooling system and the IT equipment intake. Air flow containment provides a stable and consistent IT intake temperature removing the need to operate the data floor several degrees colder to deal with “hot spots”.

The chart below shows the number of hours that an indirect air side economised data centre would spend at each IT intake temperature in a Typical Meteorological Year.3

Figure 8 Achieved IT intake temperature hours - London indirect air side economiser

3 A Typical Meteorological Year is a set of 8760 hours of temperature and humidity data which is assembled from many years of observed data for a location. The composite TMY provides a single year of data which represents the medium term climate that will be experienced at the location. It does not provide for evaluation of peak temperatures and should not be used to size cooling systems. The TMY is used here for energy and cost evaluation. See http://www.nrel.gov/docs/fy08osti/43156.pdf for more information on how the data is derived.
Note that with adiabatic cooling this indirect air economiser achieves 8,550 hours per year (out of 8,760) at 22°C IT intake and has a single worst hour at 26°C intake. It should be noted that in an existing hot / cold aisle data centre in London operated at low supply temperatures the lack of air flow containment and consequent “hot spots” are likely to result in substantially more IT device hours spent at 26°C every year than an adiabatically cooled data centre with no chillers.

The full set of these charts for all of the analysed locations is available in the associated documents.

4.7 Reducing chiller hours
At a simple level the task for a data centre operator is to increase the lowest temperature in the cooling system. In many current data centre designs, such as that shown in Figure 9 below the coldest point in the cooling system is far below the target IT equipment intake temperature. This is due to the combination of hot and cold air remix allowed by failure to contain air flow coupled with the delta T introduced at every change of heat transfer medium. In this example there is potentially unnecessary delta T where chilled water is used to transfer heat from the supply air to the chiller plant, in other designs there are more stages of heat exchanger and change of medium.

It can be seen quite clearly that the IT equipment intake temperature would have to be increased to over 50°C to allow this facility to operate without chillers for the entire year.

![Wasted Delta-T – Traditional data centre](image)

Figure 9 Cooling system temperatures and wasted Delta-T

The significance of this issue is that it directly affects the energy efficiency of the data centre through restricting the duration for which the data centre may operate in economised mode and increasing the work required of the mechanical cooling when it does operate.

Figure 10 below shows how the behaviour of data centre cooling system changes as the cooling system temperature is increased, either through optimisation of the cooling system or IT intake range. As shown this initially yields a transitional region where the chiller is supplemented by some free cooling, as the optimisation of the data centre continues the free cooling system is able to deal with a full typical year as the difference between the cooling system lowest temperature and the external air temperature is eliminated.

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4 Delta-T a difference in temperature between two parts of the system, in this case the difference in temperature at each heat exchange step in the cooling system
4.8 Stages of optimisation

Analysis across the range of cooling system designs, climates and IT equipment operating ranges has identified a series of distinct stages in the cooling optimisation. These are indicated in Figure 11 below where the non-linear relationship between chiller hours and energy consumption and operating cost is shown.

The vertical axis for the chart is labelled in annual chiller operating hours. These are reduced as the external temperature at which the data centre can operate economised is increased. This may be through improvement of the infrastructure design, increasing the maximum IT intake temperature or both.

**Figure 10 Transition from mechanical to free cooling with increasing operating temperature**

**Figure 11 Impact of reducing chiller hours**
Initial reduction of chiller hours
The first stage and the most important from an energy efficiency perspective is the initial reduction of chiller hours from a traditional data centre which relies entirely on mechanical cooling through to one which uses chillers for less than 4 months per year.

As the chiller hours are reduced the annual chiller energy consumption is subject to a beneficial combination of effects;

1. The operating hours are directly reduced
2. For some part of the operating hours the economiser system deals with part of the load, reducing the working load on the chillers
3. The chiller may be specified to work at a lower delta-T thereby improving the achievable efficiency

This combination of effects results in a rapid reduction in the annual chiller energy as chiller hours are converted into economiser hours. This provides direct and significant operational cost and energy efficiency benefits.

Limited benefit region
Below 4 months per year the additional energy savings of the chiller are relatively small due to the combination of effects described above.

In this region energy and cost savings are more likely to be achieved through analysis of fan and pump energy in the cooling system as these are likely to exceed the chiller energy consumption. The advantages of cooling and economiser systems with fewer heat transfer stages such as indirect air or direct water side economisers are important in this region as each transfer stage typically involves additional fans or pumps which consume energy.

Reduction or elimination of chiller capacity
The final region is where the combination of external climate, data centre infrastructure design and IT operating range allow the operator to reduce the installed mechanical cooling capacity or eliminate it entirely.

There is little energy efficiency benefit in this region and in some cases it is possible that the site could operate more energy efficiently with a chiller.

For further discussion of the opportunity for zero chiller data centres please see the maps produced by Robert Tozer\(^5\) and presented at the November 2010 Code of Conduct meeting.

4.9 The benefit of eliminating chillers is primarily capital cost and IT capacity
There will be some operators for whom the elimination of large parts of the traditional cooling infrastructure is a priority; however the major advantage of these no chiller (compressor) cooling designs is not energy efficiency but reduced capital cost of the mechanical cooling plant and the electrical infrastructure required to power it.

Whilst in some areas these operators may have to spend slightly more on IT equipment with a broader operating range this is balanced against the capital savings in the data centre infrastructure rather than the operating cost.

This release of electrical system capacity may be used either to directly reduce the capital cost of the data centre or to increase the critical IT load capacity of the site where utility feed capacity is the constraint.

It is notable that this release of electrical infrastructure capacity occurs in two distinct phases, firstly through improved chiller efficiency reducing the required chiller electrical power as the

working delta-T is reduced and secondly through the reduction or elimination of mechanical cooling capacity.

**Quantifying the benefit**

As an example of the economic benefit available from elimination of the chiller plant in a data centre, where the climate allows this the chart in Figure 12 below shows the full cost of each delivered kWh of power to the housed IT equipment. The same basic data centre design is used in both analyses but the Economised design is only able to support 500kW of IT critical load as so much of the electrical capacity is allocated to the mechanical plant whilst the No Chiller design is able to reallocate that electrical capacity, increase the installed UPS capacity and support 800kW of IT capacity for only a small increase in capital cost.

**Cost per delivered IT kWh**

![Cost per delivered IT kWh](chart)

*Figure 12 Cost per delivered kWh of Economised vs No Chiller data centre*

This reallocation of electrical capacity produces a very substantial reduction in the true cost of supporting the IT equipment in the no chiller data centre. Note that although there is a reduction in the fixed and variable energy overheads in the data centre the majority of the benefit here is reduced capital and maintenance costs.

**4.10 Operators should require IT vendors to supply power vs temperature data**

One of the major concerns preventing data centre operators from using the currently available IT equipment ranges is a potential increase in the energy consumption of the IT equipment. Increased inlet temperature can increase the total power of an IT device through a number of effects but the major issue is cooling fan power.

This analysis shows that for most modern IT equipment the feared increase in IT equipment intake power is relatively low and can be easily mitigated through operating the data centre below the maximum rated intake temperature of the installed IT equipment.

**IT device power vs temperature data**

Data centre operators should require their equipment vendors to provide data on the change in device power with changes in intake temperature. The data should include total device power at a minimum resolution of 5°C over the range 20°C to the upper limit of the operating range as shown in Table 2 below.

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6 See the analysis of Code of Conduct reporting data associated document
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<td>225 Watts</td>
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*Table 2 Example IT device power by intake temperature data*

Note that this is the data for the generic ASHRAE Class 2 server used in the analysis.

**Total Device Power**

*Figure 13 Example IT device power by intake temperature data*

**Load and temperature**

Operators should also note that the response to intake temperature of most servers also depends upon the applied workload. If the servers are run at less than full load the fan power rise will occur at a higher temperature if at all. Servers may also be throttled through the use of power control technology to control power during high intake temperature periods.

**4.11 Selecting operating temperatures and IT equipment**

The nature of the cooling design and fan power consumption in most IT devices is such that the power consumption will be relatively flat up to a certain “knee-point” temperature where there is a distinct change in power consumption. An operator with mechanical cooling available should in most cases select an upper normal operating limit and IT device combination such that this rapid increase region is avoided.

**Helpful rule of thumb**

If the data is not available for all of the IT devices in a data centre a useful rule of thumb is to set the upper operating temperature 5°C below the maximum rated temperature of the IT equipment as the last 5°C is commonly the region of significant cooling fan power.

**Temperature excursions**

Selecting IT equipment capable of operating 5°C above the design maximum supply temperature in the data centre may also provide for some operating flexibility in terms of reduction or elimination of mechanical cooling capacity by using the additional allowable intake temperature to deal with infrequent high temperature events.

Note that the determination of required chiller capacity should be made on peak temperature data and not the Typical Meteorological Year data used in this analysis.

4.12 Impact of increased intake temperatures on IT energy consumption

To provide some context for the available cooling system energy savings it is necessary to also understand the impact of the increased operating temperature range on the annual IT energy consumption.

A hybrid range is used for this analysis based on the intake temperature suggestions in section 4.11 above and the humidity control suggestions below in section 4.13. IT equipment which meets ASHRAE Class 2 which is capable of 35°C is operated in a data centre with the target intake temperature set to 22°C and the upper limit set to 32°C, 3°C short of the 35°C the equipment is capable of. Also, the humidity is constrained to an upper bound of 60% relative or 15°C dew point.

**Annual Chiller Hours (Adiabatic Cooling) Hybrid**

![Figure 14 Annual chiller hours for hybrid environmental range](image)

Figure 14 and Figure 15 show the annual effect of this hybrid range on the chiller hours and the IT equipment energy consumption. It is immediately notable that mechanical cooling is almost eliminated in the typical year with indirect air or indirect water side economiser technology. The direct air side economiser is substantially constrained by the upper humidity limits.

The base power draw of the server (as shown in Table 2 and Figure 13) at 20°C is 202 Watts. Servers in the direct and indirect air economised designs operate between 202 Watts and 203 Watts annual average power draw due to the short exposure to increased intake temperature delivered by the dynamically managed IT intake temperature.
The indirect water design carries notably more penalty at 203 Watts to 207 Watts, a 2.5% increase in energy consumption for almost complete elimination of mechanical cooling. In Seville, Rome, Athens and Palermo it would be worth carefully selecting to reduce the peak power consumption at elevated intake temperature.

Figure 16 below shows the same analysis for the worldwide locations and also for dry cooling. Whilst there are some notable constraints for locations such as Riyadh where adiabatic cooling is not a realistic option there are other locations whose results are quite surprising. Singapore, for example will only require 144 hours of chiller in a typical year with the penalty of an average 210 Watts server power consumption, a 5% increase in IT energy.

It is clear from the results that where water is available at reasonable economic and environmental cost adiabatic cooling has substantial advantages over dry cooling for economised data centres.

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### Figure 15 Annual server power for hybrid environmental range

<table>
<thead>
<tr>
<th>Location</th>
<th>Direct Air</th>
<th>Indirect Air</th>
<th>Indirect Water</th>
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<tr>
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<tr>
<td>Palermo</td>
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</tr>
</tbody>
</table>

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### Figure 16 Annual chiller hours and server power for hybrid environmental range - world locations
These charts are available for all of the examined IT environmental ranges and with more detailed discussion in the accompanying documents.

4.13 Selecting a humidity control range
Each operator should select the temperature and humidity ranges separately for each data centre based on their risk profile, data centre design and local climate.

The issue of high relative humidity applies only to operators who wish to operate external air cooling. The achievable performance of direct air side economisers is constrained by the allowable humidity range.

Direct air side – external air cooling
As shown in the detailed analysis, where the operator is willing to allow for large excursions in IT equipment intake humidity, particularly high humidity direct air side cooling can offer the best performance with the least capital and operational cost overhead. The achievable performance of direct air side systems is dominated by the allowable humidity, specifically the upper humidity set points constrain both the ability to adiabatically cool intake air and may require mechanical cooling to reduce intake air humidity.

Frequent high IT intake humidity is known to cause a range of reliability issues for the IT equipment, some of which accumulate over exposure time. The selection of direct air side cooling is highly dependent upon the operator’s site risk profile.

Re-circulated air cooling
To minimise operating energy consumption and cost, allowing temperature excursion is more important than allowing humidity excursion. It is not necessary to allow large changes in relative humidity, as these can be avoided at relatively low energy cost through the use of indirect air or direct water side economisers.

Under several of the assessed ranges indirect air (or direct water) side economisers actually outperformed direct air side economisers due to these restrictions whilst also being able to maintain well controlled IT humidity. (This is shown in Figure 3 and Figure 5)

4.14 Eliminate CRAC / CRAH humidity control
There are two reasons to eliminate humidity control at the CRAC / CRAH units in the data centre.

Firstly once the cooling system is optimised the air cooling units will no longer be cold enough to perform dehumidification and the cooling system temperatures should not be compromised simply to allow this.

Secondly, given the impact of high humidity on IT equipment reliability and in particular the combined impact of high humidity and high temperature, there is an opportunity to leverage the primarily recirculating air of the indirect air or water side economiser designs to maintain a relatively narrow humidity control range whilst allowing for a more progressive temperature control range.

The feasibility of this was analysed and the dehumidification load modelled for a range of geographic locations. This is described in detail in the associated paper “Analysis of data centre cooling efficiency” but at a summary level the site is constrained to four air changes per hour of make-up air and all humidity control on the CRAC / CRAH units is disabled. All humidity control is moved to the make-up AHU and intake air is restricted to a 14°C dew point to constrain it below the ASHRAE Class 1 recommended 60% relative humidity at the minimum 22°C IT intake temperature. Adiabatic humidification is used to maintain the internal humidity above the

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8 Computer Room Air Conditioner or Computer Room Air Handler, the air cooling device serving the IT cooling load
9 External conditioned air supplied to replace air in the building
minimum 6°C dew point lower limit. The number of hours per typical year where it is necessary to reduce the intake humidity for the selected locations is shown in Figure 17 below;

![Humidity Control Hours](image)

*Figure 17 Humidity control hours worldwide locations*

The analysis then determined the required make up air volume and a Coefficient of Performance of 5 assumed for the DX cooler in the AHU to estimate the annual energy consumption of the intake humidity control. This is shown in Figure 18 below converted to the PUE overhead contribution of this make up dehumidification.

As shown the humidity control penalty is relatively small, particularly in dry arid, temperate and continental climate regions and operators may wish to trade this energy penalty for the reduction in IT equipment failure rate.

![Dehumidification PUE Contribution](image)

*Figure 18 Dehumidification PUE contribution worldwide locations*

The elimination of humidity control components and controls from CRAC / CRAH units should also represent a worthwhile capital and operational cost saving for the data centre operator.
4.15 Economiser hours are not always more efficient than chiller hours

In the optimisation of a data centre to minimise chiller hours considerable care must be taken to avoid a number of common configurations where the economised cooling mode actually consumes more energy than switching over to mechanical cooling. This is particularly common in designs with modern, high CoP chillers.

The two DCIE\textsuperscript{10} plots in Figure 19 below for a 500kW IT load data centre show this issue. In the plot on the left the free cooling economiser is active up to 15°C external temperature at which point the control systems shut off the economiser and hand load over to the chillers relatively quickly producing the neat step down in efficiency from ~ 75% to 70% as the data centre moves over to mechanical cooling.

In the plot on the right the system has been mis-configured in an attempt to decrease the cooling energy consumption and cost by allowing the free cooling coils to continue operating and sharing cooling load with the mechanical chillers in a transitional region from 15°C to 22°C. Unfortunately the additional water pump power of running both chiller primary and free cooling coil pumps coupled with the full fan power of the free cooling dry coolers when they are unable to achieve their target water return temperature is substantially higher than the energy penalty of handing load over to the high CoP chillers producing a visible crevasse in the DCIE plot.

\textit{Figure 19 Economiser operation problem DCIE plots}

\textsuperscript{10} Data Center Infrastructure Efficiency (what percentage of the total utility power reaches the IT equipment)
5. Associated documents

The following papers provide a more detailed presentation and discussion of the analysis results;

**European IT environmental range analysis**
Detailed analysis and presentation of the impact on chiller hours and IT device energy consumption for European climate locations.

**Achievable IT intake temperature hours for European cities**
A supplement to the European IT environmental range analysis providing detailed charts of the achieved IT intake temperature distribution for each of the assessed economiser types in each of the assessed European cities.

**World IT environmental range analysis**
A supplement to the European IT environmental range analysis providing detailed output from the analysis of chiller hours and IT device energy consumption for worldwide climate locations.

**Achievable IT intake temperature hours for World cities**
A supplement to the World IT environmental range analysis providing detailed charts of the achieved IT intake temperature distribution for each of the assessed economiser types in each of the assessed World cities.

**Analysis of data centre cooling energy efficiency**
This document describes the analysis of the distribution of cooling energy overheads in the data centre and the underlying relationship between economiser hours and chiller operating efficiency in more detail. The energy cost of make-up air dehumidification analysis is also presented.

**Code of Conduct Environmental range reporting analysis**
6. Acknowledgements

This analysis used Typical Meteorological Year weather data for the locations shown sourced from:

i. The ASHRAE IWEC data sets for Europe, Asia and Pacific regions, [www.ashrae.org](http://www.ashrae.org)


The Prognose data centre modelling software was used to perform analysis of the achieved DCIE, attributed annual energy consumption and cost per delivered kWh of the sample data centres see [http://www.romonet.com/content/prognose](http://www.romonet.com/content/prognose).

This paper was prepared with input and assistance from:

i. Stephen Worn of Data Center Dynamics [www.datacenterdynamics.com](http://www.datacenterdynamics.com)

ii. Paul Latham of the BCS Data Centre Specialist Group