Analysis of data centre cooling energy efficiency

An analysis of the distribution of energy overheads in the data centre and the relationship between economiser hours and chiller efficiency

Liam Newcombe
May 2011
1. Summary

This paper is an additional resource to the main paper “IT environmental range and data centre cooling analysis”. Please read that paper for the main conclusions.

There are a number of common beliefs within the data centre industry regarding the benefits and costs of various efficiency improving changes to the data centre. This paper attempts to provide a better understanding of the impacts of some of these actions, specifically what energy savings are available and where there are other negative impacts associated with the change.

This paper examines which parts of the data centre are actually responsible for the energy overheads and are therefore effective targets for energy and cost reduction. Specifically this paper deals with:

- whether eliminating mechanical cooling from data centres is necessary or desirable
- the relationship between chiller hours and chiller efficiency
- whether increasing economiser hours is always an improvement
- the efficiency, capital and operational cost impacts of chiller elimination
- the opportunity for a hybrid control range in re-circulating air facilities

1.1 One watt of cooling for every watt of IT load

The adage of “1 Watt of cooling for every Watt of IT power” is neither applicable to a modern design data centre nor does it indicate that there is 1 Watt of chiller energy for every Watt of IT power in an older data centre.

This paper presents the argument that the majority of the cooling overhead power is present in the other elements of the cooling system, the CRAC unit fans, water pumps and dry cooler or cooling tower fans, not the chillers.

In a well configured, economised and air flow contained data centre the reduction in chiller operating hours, cooling load when operating and improvement in efficiency should result in the chiller representing an overhead of less than 5% of the IT energy consumption. Given these changes in chiller energy consumption the overall data centre cooling efficiency is frequently dominated by fan and pump power consumption and not mechanical chillers.

1.2 Should reducing chiller hours be the major objective?

There is some momentum behind efforts to increase the IT equipment temperature and humidity range to allow a greater number of hours per year where the data centre runs “economised” or without mechanical cooling. This is based on the belief that an hour where the data centre is economised is substantially more efficient than an hour where the data centre is operating on mechanical cooling.

The analysis of energy consumption in sections 4 demonstrates there are common cases where attempting to achieve greater economiser hours will increase the cooling overhead rather than reduce it.

1.3 Impacts of reducing required chiller hours

The analysis in section 6 identifies the relationship between reducing chiller hours, energy consumption, operational cost and capital cost. As data centre design and operation is improved, reducing the requirement for mechanical cooling there are three distinct stages of benefit:

Major efficiency gains

There is an initial region where there are significant energy efficiency and operating cost benefits where required chiller operation is reduced from 12 through to 4 months per year. In this region the Coefficient of Performance of the chillers is also important and the additional capital expenditure for more efficient chillers is likely to be recovered in operating cost.
Minimal benefit region
From 4 months to 2 months per year of chiller there is a notable stagnation region where the additional benefits of fewer chiller hours are small. In this region more benefit will be achieved through carefully managing the pump and fan energy consumption of the cooling system.

Chiller capacity reduction region
The final region is where mechanical cooling capacity may be reduced or eliminated, this has little energy efficiency benefit but can yield substantial capital cost savings due to not only reduced chiller cost but also upstream electrical capacity.

1.4 Humidity ranges and humidity control
There is substantial concern regarding any expansion of humidity control range amongst operators based largely on reliability concerns.

- Humidity should be controlled at the point of air supply to the data hall and not at the CRAC / CRAH units where re-circulated air is cooled due to the difference in required cooling coil temperatures.

- Utilising even the most restrictive ASHRAE Class 1 recommended 5.5°C dew point to 15°C dew point and 60% relative humidity range would remove the humidity control energy overhead for most sites.

- In a data centre with minimised make up air exchange wider operating humidity ranges than the Class 1 allowable only show significant benefits for direct air economised (fresh air) data centre designs. These benefits are primarily capital cost benefits through the elimination of stages of the data centre cooling system including the mechanical cooling and the electrical equipment capacity required to support the mechanical plant.
2. Document Information

Version History

<table>
<thead>
<tr>
<th>Version</th>
<th>Description</th>
<th>Version Updates</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0.0</td>
<td>Public review</td>
<td>Version number incremented</td>
<td>04 May 2011</td>
</tr>
<tr>
<td>0.0.8</td>
<td>Review copy</td>
<td>Paul Latham review comments</td>
<td>04 May 2011</td>
</tr>
<tr>
<td>0.0.7</td>
<td>Working copy</td>
<td>Additional content, general updates</td>
<td>01 May 2011</td>
</tr>
<tr>
<td>0.0.6</td>
<td>Working copy</td>
<td>Separated analysis of cooling efficiency from IT</td>
<td>25 April 2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>range analysis</td>
<td></td>
</tr>
<tr>
<td>0.0.5</td>
<td>Working copy</td>
<td>Locations, conclusions and charts updated,</td>
<td>04 April 2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>added &quot;contribution to energy overhead&quot;,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;separating temperature and humidity targets&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and &quot;chiller efficiency improvements&quot;</td>
<td></td>
</tr>
<tr>
<td>0.0.4</td>
<td>Working copy</td>
<td>Data updated</td>
<td>28 March 2011</td>
</tr>
<tr>
<td>0.0.3</td>
<td>Working copy</td>
<td></td>
<td>13 March 2011</td>
</tr>
</tbody>
</table>

Release History

<table>
<thead>
<tr>
<th>Version</th>
<th>Description</th>
<th>Authoriser</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0.0</td>
<td>Public review</td>
<td>Liam Newcombe</td>
<td>04 May 2011</td>
</tr>
</tbody>
</table>
3. Contribution to energy overhead

To determine the energy efficiency improvements available from reducing or eliminating mechanical cooling it is first necessary to understand the contribution of each device to the data centre energy overhead. In this section a series of data centre models are used to provide a representative view of the efficiency improvements available through reduction or elimination of cooling energy overhead.

3.1 Old chilled water data centre – London

The first data centre is an old design chilled water data centre located in London with the following major characteristics:

- 500kW design IT power and cooling capacity
- No air flow containment – hot / cold aisle layout only requiring low air supply temperature (15°C)
- Low chilled water loop temperature (10°C)
- No economisers, all cooling load handled by chillers
- Air cooled chillers (working to the external dry bulb temperature)
- Fixed speed drive fans in Computer Room Air Conditioning units
- Fixed speed pumps for chilled water system
- Targets a 22°C target IT intake temperature

This site achieves an annual average PUE of 1.85 which is reasonable for a site of this type in the London climate.

Figure 1 below shows the annual energy consumption of the data centre broken down by the major elements of infrastructure. Note that although the PUE is only slightly below two the annual chiller energy consumption is less than one third of the IT energy consumption.

Including the water pumps the annual chiller system energy consumption is 1.22 GWh. Compared with the 3.1 GWh of IT energy consumption the chiller system components represent a 40% overhead on top of the IT energy consumption or a 0.4 contribution to the annual PUE.

![Attributed Overall Energy](image-url)
3.2 Newer chilled water data centre – London

The second example uses the same basic data centre as above but in this case the site has been designed as a contained air flow economised data centre. The same types of mechanical and electrical devices have been used but the control scheme has been changed to take advantage of the improved air flow design and a set of free cooling coils has been added to provide an indirect water side economiser;

- 500kW design IT power and cooling capacity
- Free cooling coils (air cooled – dry bulb)
- Additional set of water pumps for free cooling coils
- Increased chilled water loop supply temperature (17°C to 22°C)
- Improved chiller CoP through increased evaporator temperature
- Air flow containment
- Variable speed drive fans in Computer Room Air Conditioning units
- Variable speed pumps for chilled water system
- Maintains a 22°C target IT intake temperature
- Allows IT intake temperature to rise to 27°C before requiring mechanical cooling

Due to these changes in the implementation the site is able to operate fully economised up to 17°C external temperature and partly economised up to 27°C however the control scheme is set to transition completely to chillers at 20°C for the reasons explained in section 4. This results in the site achieving around 1,100 chiller hours per year, of which 550 occur in the transitional region where most of the load is taken by the economisers. These changes in the control scheme coupled with the addition of the free cooling coils has reduced the annual average PUE to 1.37.

![Attributed Overall Energy](image)

*Figure 2 Overall energy consumption - new chilled water data centre - London*

Note that in this design the distribution of overheads has changed, the chillers now operate not only for fewer hours but at lower load for much of their operating hours resulting in an annual chiller energy consumption which is now less than the data centre lighting. Both the water pumps and cooling fans for the free cooling also consume more energy than the chiller. In this improved design the total energy consumption of primary pumps, chillers, free cooling pumps and fans on the free cooling coils is 0.24GWh, an 8% overhead on top of the IT energy consumption.
3.3 Newer chilled water data centre – Rome
The third annual analysis moves the indirect water side economised design to Rome to examine how it performs under the much warmer climate.

![Attributed Overall Energy](image)

**Figure 3 Overall energy consumption - new chilled water data centre - Rome**

This change in the external climate has increased the annual average PUE to 1.42. As shown in Figure 8 above this is primarily in additional chiller energy consumption as would be expected with the site now requiring chillers for 3,800 hours per year. However 1,100 of these hours are with the chillers only working at part load to supplement the economiser.

In the warmer climate of Rome the total energy consumption of primary pumps, chillers, free cooling pumps and fans on the free cooling coils has risen to 0.38GWh, a 12% overhead on top of the IT energy consumption.
4. Are economiser hours always good?

There is a common misconception that it must always be more efficient to use “free cooling” if there is any economised cooling capacity available. Unfortunately the energy profile of economised cooling systems is both non zero and quite complex and considerable care must be taken in the optimisation of a data centre to minimise chiller hours. It is important 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 term “free cooling” is quite misleading as economised cooling is not free, there are relatively significant capital and operational cost impacts in addition to the energy consumption of the pumps and fans required by many designs.

4.1 Example of early economiser shutoff

To illustrate this issue a water cooled data centre has been modelled in both an effective configuration where the highest efficiency is achieved at all external temperatures and an overly aggressive tuning of the economiser set points which results in considerable reductions in the achieved efficiency through the transitional region where both economiser and chiller are active.

This data centre is a 500kW IT capacity chilled water design similar to the example data centres used in section 3. This data centre is capable of operating entirely on economised cooling up to 15°C external temperature, the delta-T on the chilled water loop would allow for some economised cooling to occur up to 25°C external.

Correctly configured

The DCIE plot in Figure 5 below show the achieved efficiency of the data centre against both IT electrical load and external temperature. In this case the entire cooling load is handled by the economiser up to 15°C external temperature at which point the control systems shut off the economiser and hand load over to the chillers within 2°C producing the neat step down in efficiency from ~ 75% to 70% as the data centre moves over to mechanical cooling.

DCIE Chart - Chilled water date centre - Correct economiser shutoff temperature

Figure 4 DCIE plot for data centre with correctly configured economiser

1 Data Center Infrastructure Efficiency (what percentage of the total utility power reaches the IT equipment)
Poorly tuned economiser

Figure 5 below shows the cooling system 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 efficiency chillers producing a visible crevasse in the DCIE plot.

Figure 5 DCIE plot for data centre with economiser mis-configuration
5. Increasing the lowest temperature in the system

During the analysis of the achievable energy efficiency for any data centre design there is one key factor which stands out as a diagnostic of the achievable energy efficiency. This is the temperature difference between the coldest point in the cooling system and the external air temperature. Whilst the cooling system low point temperature is set through the combination of any number of design decisions elsewhere such as the IT intake temperature range and whether chilled water or DX cooling is utilised the resulting temperature sets quite a hard upper bound on the achievable energy and cost efficiency.

5.1 Wasted delta-T

Once an IT intake temperature range has been set for a data centre it is possible to work down through the required temperatures in the cooling system. Figure 6 shows the temperatures in a traditional hot and cold aisle data centre with indirect water side economiser.

The IT intake range is 20°C to 25°C but due to the lack of air flow containment and consequent mixing of cooled supply air with hot return air this requires a supply air temperature from the CRAC units in the range of 12°C to 15°C. To achieve this supply air temperature the chilled water loop must be operated in the range of 7°C to 12°C. Finally, due to the 5C approach temperature of the plate heat exchanger separating the CRAC chilled water loop from the dry cooler glycol loop in economised cooling mode the water from the dry coolers must be in the range of 2°C to 8°C. This design has a wasted delta-T of 18°C and therefore is only able to run economised for a few hours per year with minimal cost or energy savings.

5.2 Improving cooling efficiency

To improve the opportunity for economised cooling of the data centre shown in Figure 6 the operator needs to raise the external temperature at which the data centre can reject heat to the external air.

This could be achieved through increasing the allowable IT intake temperature, for example to the upper limit of ASHRAE Class 2, 35°C. However, in this compromised data centre design this would only result in the ability to run economised cooling at up to 18°C external temperature whilst having a potentially significant impact upon the energy consumption and reliability of the IT equipment through extended periods at high intake temperatures.

Alternatively the operator could eliminate some of the unnecessary delta-T in the design and operation of the facility as shown in Figure 7 and select a more moderate IT intake temperature range such as 22°C to 30°C. This will both substantially increase the available economiser hours and also reduce the intake temperature of the IT equipment over most of the year.

---

Figure 6: Wasted Delta-T in a traditional data centre

---

2 The difference between two temperatures
Figure 7 Wasted Delta-T in an indirect air economised data centre
6. Chiller efficiency improvements

In recent years there has been a substantial improvement in the efficiency of mechanical chillers available to data centre operators. This has occurred for several reasons; including the change in relative importance of capital cost and energy efficiency as decision factors for purchasing chillers allowing manufacturers to optimise for this parameter. In this section the impact of supply temperature changes on chiller performance is discussed.

6.1 Improved efficiency through reduced delta-T

Improvements in data centre design designed to allow for greater economiser hours have also impacted the achievable efficiency of the mechanical cooling in the data centre. The changes required to improve economiser operation increase the supply temperature and therefore reduce the required delta-T for the chiller.

6.2 Traditional data centre

Figure 8 shows a set of temperature ranges for an existing chilled water data centre design which relies on a hot / cold aisle layout. Note how far below the required IT intake temperature range the evaporator side of the chiller is required to operate to make up for the inefficiencies in delivery of cooled air to the IT equipment.

In this case the IT equipment has an operating target of 20°C to 25°C intake but due to the failure to contain the airflow and prevent remix the temperature of the supply air from the CRAC units needs to be between 12°C and 15°C. These CRAC units are fed by a chilled water loop which must be between 7°C to 12°C to provide the required supply air temperature meaning that the evaporator of the chiller must be between 3°C to 8°C to maintain the required chilled water supply temperature.

For the air cooled chiller to reject heat to the external air the condenser side of the chiller must be hotter than the maximum external temperature meaning that the condenser temperature is likely to be set to operate between 35°C and 45°C. This gives a delta-T across the chiller in the region of 40°C.

Cooling system temperatures – traditional data centre

Figure 8 Cooling system temperatures - traditional data centre

3 Whether this is a fixed or variable temperature depends upon the dry cooler control scheme, it is common to leave this as a fixed temperature to reduce fan power consumption at the dry coolers.
6.3 Contained air flow data centre

In a contained air flow data centre many of these inefficiencies are eliminated, substantially reducing the required delta-T as shown in Figure 9. In this case there is no chilled water loop and the air flow containment substantially increases the supply air temperature required to maintain the IT equipment intake temperature. Under this design the evaporator side of the chiller can operate between 13°C and 19°C to meet the same IT equipment intake range resulting in the chiller delta-T being only 30°C.

**Figure 9 Cooling system temperatures - contained air flow data centre**

Figure 10 shows another economised design which is intended to operate economised for the majority of the year where the chillers are only used to constrain the temperature peaks. In this case the supply IT intake temperature is limited to within the Class 1 allowable range and the evaporator temperature can be as high as 22°C to 25°C meaning that the chiller has a working delta-T of only 20°C, half that of the chiller in Figure 8.

**Figure 10 Cooling system temperatures - Class 1 allowable contained air flow data centre**
6.4 Impact on chiller efficiency

This reduction in the required chiller delta-T directly affects the achievable efficiency as the work performed by the chiller is directly related to the difference in temperature across it.

The theoretical efficiency limit for a chiller is given by

\[
COP = \frac{T_{\text{evaporator}}}{T_{\text{condenser}} - T_{\text{evaporator}}}
\]

Using this some estimations of the impact of the reduced delta-T on chiller efficiency\(^4\) are shown in Table 1 below:

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Contained air flow</th>
<th>Class 1 allowable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator temp</td>
<td>2°C ( 275K )</td>
<td>12°C ( 285K )</td>
<td>22°C ( 295K )</td>
</tr>
<tr>
<td>Condenser temp</td>
<td>40°C ( 313K)</td>
<td>40°C ( 313K )</td>
<td>40°C ( 313K )</td>
</tr>
<tr>
<td>Delta T</td>
<td>38°</td>
<td>28°</td>
<td>18°</td>
</tr>
<tr>
<td>CoP(^5) limit</td>
<td>7</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Realistic CoP</td>
<td>5</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Realistic efficiency</td>
<td>80%</td>
<td>86%</td>
<td>92%</td>
</tr>
</tbody>
</table>

\(^4\) Indicative values based on data from multiple vendors for multiple types of chiller

\(^5\) Coefficient of Performance – the number of Watts of cooling delivered for each Watt of power consumed by the chiller

Note that this increase in the efficiency of the chiller also has an impact on the required compressor power for the chiller which reduces the required upstream electrical capacity and potentially the capital cost of the chiller.

6.5 Adiabatically cooled chillers

This reduction in chiller delta-T can be taken even further in designs where the chillers are cooled to the wet bulb temperature through the use of traditional open cooling towers or temperature dependent water spray onto dry coolers. In this case it is possible for the working chiller Delta-T to drop below 10°C resulting in substantial reductions in both energy consumption and compressor power.
7. Relationship between chiller hours and chiller efficiency

One of the more interesting outcomes of this analysis is the direct link between reducing chiller hours and increasing chiller efficiency which results in a non-linear energy and cost reduction with reducing chiller hours. This occurs due to the tendency of designs which optimise economiser hours to also allow a low chiller working delta-T.

7.1 Chiller vs. economiser hours

The basic method of reducing chiller hours or increasing economiser hours for a data centre is, as described in section 5 above, to increase the low point temperature and thereby reduce the overall temperature difference across the cooling system. The general impact of this is shown in Figure 11 below:

![Chiller vs Economiser Hours](image)

Figure 11 Chiller vs economiser hours with increasing cooling system temperatures

At the left hand extreme the red area indicates that the entire cooling load of the data centre is handled by the mechanical cooling all year. This is the least efficient mode of operation.

As the cooling system is improved the delta-T reduces to the zero economiser hours point where the economised part of the cooling system, shown in purple, is able to deal with a worthwhile part of the cooling load. Note that although some of the cooling load is handled by the economiser there is no point at which the chillers shut off completely.

As this improvement continues there are an increasing number of hours where only economiser cooling is required shown by the blue area. At zero chiller hours the data centre is able to operate without requiring mechanical cooling for a full Typical Meteorological Year.

7.2 Utilisation of chiller capacity

The reduction of chiller operating hours will clearly have an impact on the chiller energy through the year as the chiller will be operating for less time but this is not the only effect. Figure 12 below shows that the average load on the chillers, as a fraction of their capacity, also reduces as chiller hours are reduced. This is due to an increasing proportion of the cooling load being handled by the economiser system.

![Proportion of chiller capacity used](image)

Figure 12 Proportion of chiller capacity used vs. chiller hours
7.3 Impact on chiller efficiency

As discussed in section 13 above, the reduction in chiller hours is achieved through reducing the overall Delta-T of the cooling system. The increase in supply temperature which allows for more economiser hours also allows the mechanical chillers to operate at a higher evaporator temperature, thereby reducing the delta-T between evaporator and condenser. This is illustrated in Figure 13 below:

![Chiller Working Delta-T](image)

*Figure 13 Chiller working delta-T vs. chiller hours*

This reduction in the working delta-T of the chiller allows for an increase in the operating efficiency of the chillers when they are required.

7.4 System level impact

Bringing these effects together there is a multiple impact where reducing the chiller hours also reduces the load on the chillers during the hours where they operate and reducing the delta-T across the chiller allowing them to operate at a higher COP\(^6\). The combined effects of this are illustrated in Figure 14 below:

![Chiller Annual Energy Consumption](image)

*Figure 14 Chiller annual energy consumption vs. chiller hours*

The chart shows the composite effect of reducing chiller hours. Note that this is averaged across a broad range of economiser designs and climate regions. As the chiller hours reduce the average cooling load on the chillers for the hours during which they operate also reduces, whilst the energy consumed to deliver the cooling load is also reduced by the improvement in chiller efficiency. This results in a triple gain where the chillers deliver a smaller load more efficiently for fewer hours per year.

The overall outcome of this is that energy and cost savings are far from linear with reducing chiller hours, most of the available benefit occurs between 12 and 4 months of chiller per year with very little energy or cost benefit available below 4 months per year (2,920 hours) of chiller operation.

---

\(^6\) Coefficient Of Performance, the number of Watts of cooling for each Watt of power used by the chiller
### 7.5 Reducing chiller capacity

The outcome in section 7.4 does not mean that there is no further benefit to data centre operators in reducing mechanical cooling below 4 months per year. A secondary impact of the changes in data centre design that allow for fewer chiller hours is that there is a substantial range of temperatures at which only part of the cooling load must be handled by the chillers as some of the required cooling load is delivered by the economiser system.

In many cases it is possible to design a data centre such that the local ambient temperature will never require full chiller capacity and therefore the installed chiller capacity can be reduced. This is illustrated in Figure 15 below with the red region representing the chiller capacity required and the green region representing elimination of chiller capacity.

Note that this is quite sensitive to the type of cooling (dry or adiabatic), the divergence between typical and extreme temperatures in the local climate and the allowable peak operating intake temperature of the IT equipment. Where the facility has been designed to operate 5°C below the maximum allowable IT equipment intake temperature to mitigate IT equipment fan power this also provides worthwhile headroom for chiller capacity reduction or elimination.

![Figure 15 Required chiller capacity vs. chiller hours](image)

Note again that the chart represents an average across a range of cooling designs and climates, a specific analysis should be performed for each site considering the local climate and the operators tolerance for temperature excursions to determine how much chiller capacity may be eliminated.

### 7.6 The benefit of eliminating chillers is primarily capital cost and IT capacity

Given that there is no significant energy efficiency or operating cost benefit to reducing or eliminating chiller capacity the question arises, is it worth it?

The primary benefit of reduced or eliminated chiller capacity is reduced capital cost of the mechanical cooling plant and the electrical infrastructure required to power it. Whilst in some areas 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 16 below shows the full cost of each delivered kWh of power to the housed IT equipment in an example Tier III type data centre.

This is the same basic data centre design used in the chiller energy consumption analyses in section 3. As before the Economised design is able to support 500kW of IT critical load but requires the full chiller capacity to be installed.

By contrast the no chiller data centre is able to liberate a significant amount of utility electrical capacity that was previously allocated to the mechanical plant. This additional capacity is reallocated to the critical power systems, the installed UPS capacity increased and the site is now able to support 800kW of IT capacity for only a small increase in overall capital cost. The impact of this redesign is shown in Figure 16 below;

![Cost per delivered IT kWh](chart.png)

*Figure 16 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.
7.7 Overall impact of chiller hours on energy efficiency and cost
The chart in Figure 17 below summarises the benefits of reducing chiller hours for a data centre.

**Major efficiency gains**
There is an initial region from 12 to 4 months per year of required chiller operation where there are significant energy efficiency and operating cost benefits, in this region the Coefficient of Performance of the chillers is also important and the additional capital expenditure for more efficient chillers is likely to be recovered in operating cost.

![Impact of reducing chiller hours](chart)

**Figure 17 Overall impact of reducing chiller hours**

**Minimal benefit region**
From 4 months to 2 months per year of chiller there is a notable stagnation region where the additional benefits of fewer chiller hours are small. In this region more benefit will be achieved through carefully managing the pump and fan energy consumption of the cooling system.

Cooling systems with fewer stages show a significant benefit in this region, for example replacing an indirect water side economised chilled water and CRAC system with a centralised indirect air side system to eliminate a set of pumps.

**Chiller capacity reduction region**
The final region is where mechanical cooling capacity may be reduced or eliminated. In this region the operating efficiency of the chiller is not a concern but the reduction of mechanical capacity and the required upstream electrical capacity is significant. In this region the chiller COP is again important as the major part of the cost saving is in the “essential” electrical infrastructure delivering power to the mechanical systems.

Operators may choose to eliminate chiller capacity either to reduce the overall delivery cost of IT load in the data centre or to allow for additional IT electrical load in a site where the available utility power feed capacity is constrained, as essential power capacity is reduced it may be reallocated to critical IT equipment power capacity as discussed in section 7.6.
8. Separating temperature and humidity control ranges

As identified in the associated paper “IT environmental range and cooling analysis” the cooling overhead impact of IT intake temperature and humidity ranges can differ substantially depending upon the design of cooling system and the climate in which the data centre is operating. Specifically, in many regions it is possible to achieve zero or minimal chiller hours per typical year using the indirect air or water side economiser design.

This presents an opportunity to the operator to allow a relatively broad IT intake temperature range to achieve free cooling for most or all of the year whilst simultaneously taking advantage of the primarily recirculating air flow to maintain a more conservative humidity control range. This is an attractive option given the impact of high humidity on IT equipment reliability and in particular the combined impact of high humidity and high temperature.

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

1. 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.
2. CRAC / CRAH units which do not contain the mechanical parts or control systems necessary for “close control” humidity offer a capital and maintenance cost saving to the data centre operator
3. 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.

8.1 Controlling humidity at the make-up AHU

Most data centres have two sets of air conditioning equipment, the primary cooling system which re-circulates air within the data hall and a secondary system which provides “make-up air” to the data hall and maintain positive pressurisation. This secondary system may be shared with other areas such as office or support spaces.

Figure 18 Data hall with make-up AHU

7 Computer Room Air Conditioner or Computer Room Air Handler, the air cooling device serving the IT cooling load
As shown in Figure 18 above the majority of the air flow is recirculating within the data hall, cold air is delivered from the CRAC units to the data hall, heated by passing through the IT equipment and then returned through a contained plenum to the CRAC units to be cooled again. Note that this layout does not use the suspended floor for cold air delivery but instead uses most of the room as a cold air supply plenum thus eliminating many air flow issues and the need to carry out CFD analysis of the data centre once it is in operation. The hot aisle is contained and ducted to the ceiling plenum.

A small proportion of the air needs to be replaced both to maintain positive pressurisation of the data floor and to remove pollutants such as CO₂. This task is performed by the make-up Air Handling Unit, the volume of air flow at the make-up AHU is much lower than at the main CRAC units.

The make-up AHU in this example is configured to re-circulate hot return air through an evaporative humidifier to maintain the required minimum humidity ratio (e.g. 6°C dew point) when the external air humidity ratio is too low. The AHU is also equipped with a local DX cooling unit to perform dehumidification of intake air when the external humidity ratio is too high.

The important part of this control scheme is that both upper and lower humidity controls are on humidity ratio and therefore do not vary with temperature meaning that there is no need to attempt to control the humidity of the air already inside the data hall.

8.2 Energy analysis

To assess the energy consumption overhead of maintaining this more conservative humidity range in the data centre by using the make-up air AHUs a simple model was developed.

This model represented a data hall with the following characteristics:

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total data floor area</td>
<td>250</td>
<td>m²</td>
</tr>
<tr>
<td>Total floor to ceiling height</td>
<td>5</td>
<td>m</td>
</tr>
<tr>
<td>Total air volume</td>
<td>1250</td>
<td>m³</td>
</tr>
<tr>
<td>Power density</td>
<td>2</td>
<td>kW / m²</td>
</tr>
<tr>
<td>Total IT power</td>
<td>500</td>
<td>kW</td>
</tr>
<tr>
<td>Racks</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Per rack power</td>
<td>5</td>
<td>kW</td>
</tr>
<tr>
<td>CRAC unit Delta-T</td>
<td>10</td>
<td>°C</td>
</tr>
<tr>
<td>Make up air changes</td>
<td>4</td>
<td>Per hour</td>
</tr>
</tbody>
</table>

*Table 2 Sample data hall properties*

This results in the following air flow requirements for the data hall:

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CRAC air flow</td>
<td>41</td>
<td>m³ / second</td>
</tr>
<tr>
<td>Make-up air flow</td>
<td>1.4</td>
<td>m³ / second</td>
</tr>
</tbody>
</table>

*Table 3 Air flow requirements for sample data hall*
This make up air flow requirement was then applied to the Typical Meteorological Year data used in the main analysis but in this case the sensible and latent cooling power requirements to achieve dehumidification to a 14°C dew point were determined. This dew point was selected as it meets the upper 60% relative humidity target of the ASHRAE recommended range at the minimum supply temperature of 22°C. The hybrid range is shown (in green) against the ASHRAE Class 2 recommended (in red) and allowable (in blue) ranges in Figure 19 below;

![Figure 19 Class 2 and hybrid IT environmental ranges](class2_hybrid_ranges.png)

The number of hours per typical year where it is necessary to reduce the intake humidity for the selected locations is shown in Figure 20 below;

![Figure 20 Humidity control hours for make-up air](humidity_control_hours.png)
A chiller Coefficient of Performance\(^8\) of 5 was assumed for the local DX chiller in the make-up AHU to allow an estimation of the annual energy cost of providing the dehumidification. This is shown in Figure 21 below converted to the PUE overhead contribution of this energy loss.

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)

\(^{8}\) Coefficient of Performance (CoP), how many Watts of heat are removed for each Watt of electrical energy used by the chiller.
9. Acknowledgements

This paper was prepared with input and assistance from:

i. Paul Latham of the BCS Data Centre Specialist Group

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.