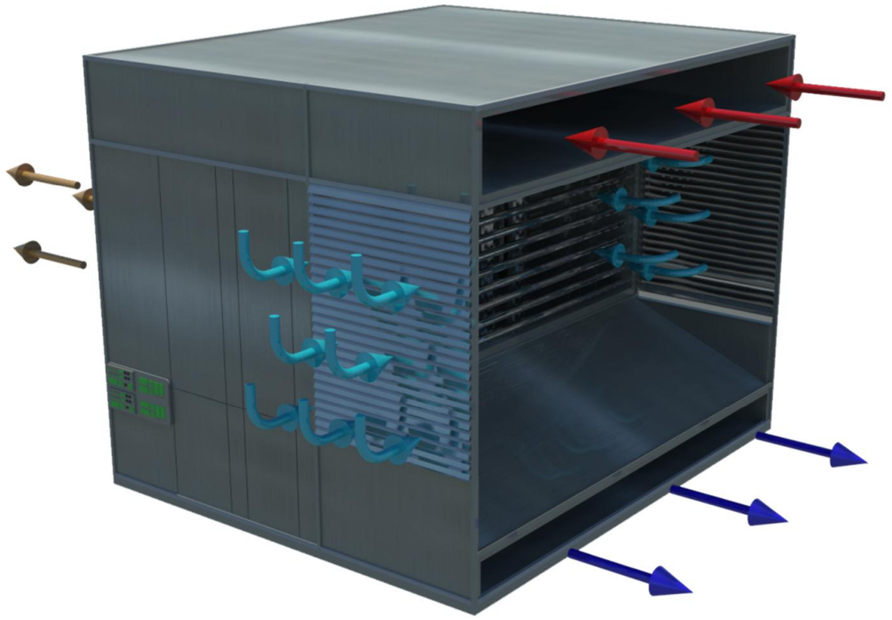
Excool – Data Centre

Cooling Product Comparison Report

Desktop Study

Job No: 1003780

Date: October 2011



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Contents

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Executive Summary

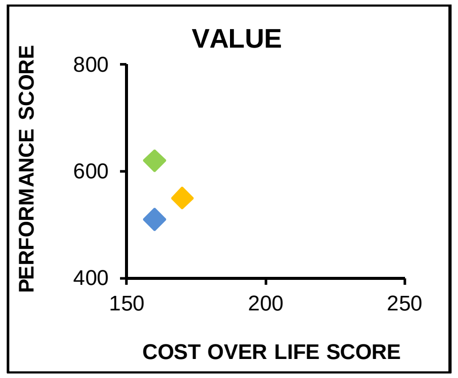
This document presents a comparison of three cooling technologies as applied to a data centre in the London Heathrow region. The cooling systems considered are, Indirect Air Optimisation with Excool, Direct Air Optimisation, and the traditional Chilled Water system methodology.

The product comparison was carried out with the aid of a selection matrix. Reference throughout this document will be made to this process. The true benefit of the matrix and weighting system is that the sensitivity of any particular factor can be tested and retested, once the relative weighting of each category has been agreed upon.

For the purpose of this evaluation the comparison of cooling technologies have been assessed under two different weighting scores, one obtained from the perspective of a stereotypical data centre Developer and the other an End User type Client. The weighting scores for each Client type reflect the respective needs and requirements of each, for example a Developer will place more emphasis on Programme and Capital cost, whereas an End User will consider Environmental and Cost Over Life as more important elements. The final recommendations were made by comparing the performance versus the product cost over life scores for each cooling option.

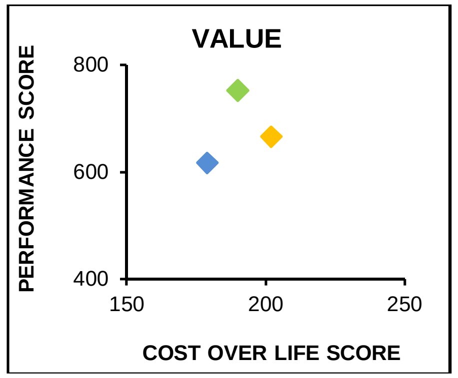
The evaluation process has confirmed the **Indirect Air Optimisation with Excool** technology for the geographical region as the best performing option across the different categories, scoring the highest in performance score for both Client variations.

With regards to the cost over life score, the best performing option varies according to the different client types and so there is no distinct winner. However, if the cost over life score is summated with the performance score, IAO with Excool remains the clear winner.



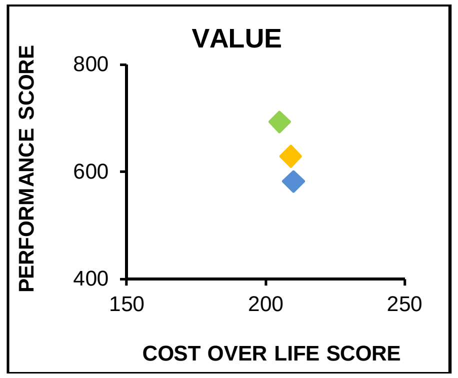
(a) Control Group Uniform Weighting

Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	1
2	Direct Air Optimisation	2
3	Chilled Water	3



(b) Data Centre Developer

Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	*1*
2	Direct Air Optimisation	*2*
3	Chilled Water	*3*



(c) Data Centre End User

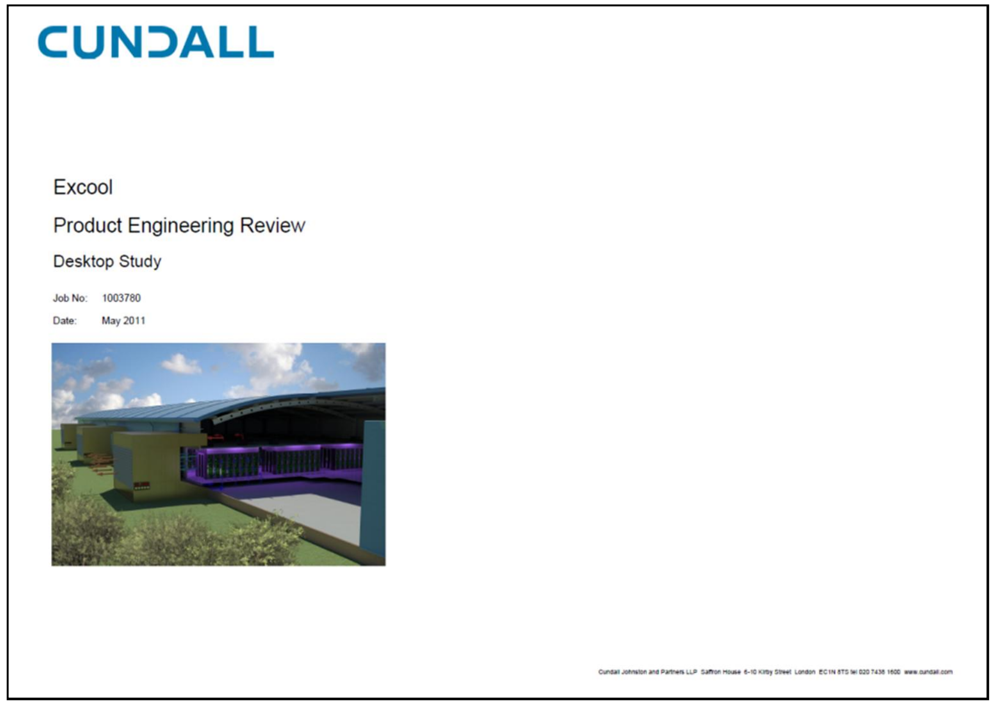
Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	*1*
2	Direct Air Optimisation	*2*
3	Chilled Water	*3*

Figure 10.1: Performance versus Cost over life score and system ranking for the three cooling options considered. Comparisons are made under Weighting Scores defined for three scenarios: (a) Control Group, (b) Data Centre Developer type Client, and (c) Data Centre End User Client.

Pre-Amble

This report makes a high level assessment of the Excool product and the cooling technology in comparison to other recognised methods. Parallel to this, an independent engineering review of the Excool technology has been carried out. This is available through a desk top study for registered and approved users only. For more information please contact Mark Collins, Director of Excool (mark.collins@excool.co.uk).

Following a careful review, Revision C introduces some amendments to the sizing and selection of plant for the Chilled Water solution, for a more practical implementation of this option.



CUNDALL

Excool

Product Engineering Review

Desktop Study

Job No: 1003780

Date: May 2011

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Excool unit Product Engineering Review available to registered users only.

Product Comparison

1.0 Objectives

The objective is to carry out a systematic comparison between the two more established data centre cooling methodologies (Direct Air Optimisation and the traditional Chilled Water solution) and Indirect Air Optimisation with Excool.

The comparison has been conducted through a review and scoring procedure across a series of categories namely, Resilience, Technical Performance, Cost Over Life, Environmental and Programme. Each category will contain a number of subcategories that will be scored from 0 to 10 according to its performance. The total score across each category is obtained by applying a Client weighting to each score according to its perceived relative importance.

The weighting factors that have been applied to each category have a significant impact upon the outcome of the evaluation process. These represent the client's priority of needs, although it is important that they are reviewed and fully understood by all parties concerned, so that the balance of the evaluation correctly reflects the project requirements. An initial comparison of the cooling technologies was made under a Control Group, to assess the sensitivity of the scored categories on system performance, without any applied weightings.

To differentiate between the needs of prospective Clients, an assessment of the cooling technologies is made based on the requirements of a Data Centre Developer and an End User type Client, and so two different weighting score are considered. The weighting scores for each Client type reflect the respective needs and requirements of each, for example a Developer will place more emphasis on Programme and Capital cost, whereas an End User will consider Environmental and Cost Over Life as more important elements.

The final part of this study is to rank the three systems based on the total score, and present the recommendations for the preferred cooling technology, for each type of Client.

A summary table of the Client weightings for the different categories are presented in the Appendix, along with the comparison matrices for the different Client weightings considered.

2.0 Operational Assumptions

In order to make a fair comparison, a number of assumptions are taken with regards to a generic data hall that would form the basis for this study.

- Data centre is based in London, Heathrow Region;
- 1MW IT data hall load – approximately 1400W/m² power density;
- N+1 plant configuration throughout;
- Data hall net floor area of 700m²;
- Supply air conditions to fall within ASHRAE 2008 TC 9.9 recommendations;
- Data hall is 100% loaded;
- Air management systems to be employed within the data halls such that the option can be evaluated under the most efficient operating mode.

3.0 Description of Cooling Technologies

The following part gives a brief summary of the main principles behind the three cooling technologies considered in the comparison matrix.

3.1 Indirect Air Optimisation with Excool

Indirect Air Optimisation (IAO) with Excool is a modular solution. The concept works by removing the heat from the data hall return air and rejecting it through to external via a Heat Exchange System (HES). The return air from the data hall is therefore cooled down to a suitable temperature for re-delivery into the data hall. The Excool unit has been developed and manufactured by IPT/Excool.

This scheme is presented in Figure 3.1. The advantage of this scheme is that the data hall would remain a fully sealed environment, isolated from the external ambient air, such that there is no moisture/pollutant carry over into the data hall. The air-to-air HES will act as an intermediary providing sensible heat transfer between the data hall return air and ambient intake air. The system of adiabatic sprays preceding the HES are designed to lower the dry bulb (db) temperature of air, and so increase the effectiveness of the HES in cooling down the warm return air from the data hall to the desired supply temperature.

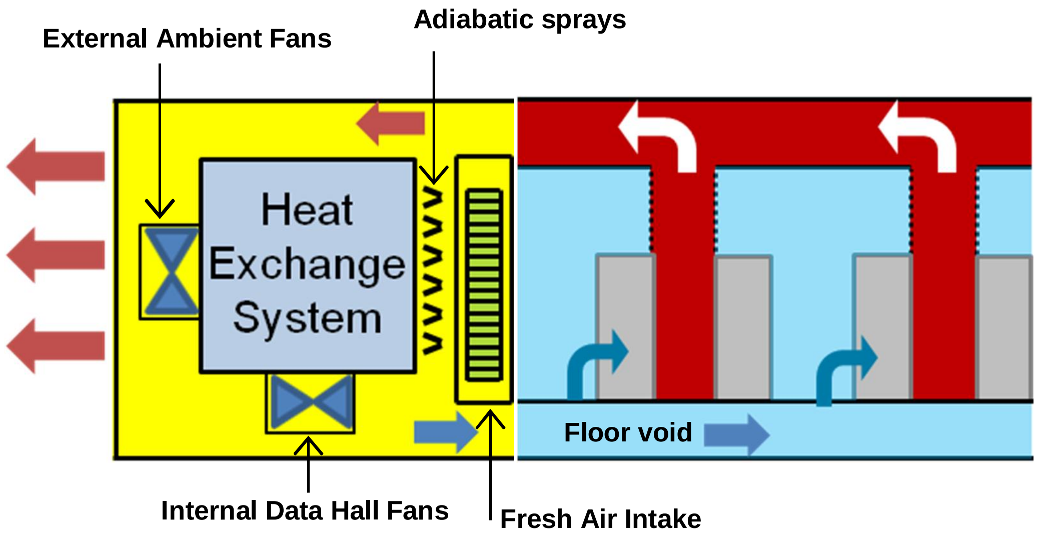


Figure 3.1: The application of Indirect Air Optimisation with Excool to a data hall with Hot Aisle Containment.

The section in Figure 3.1 shows the configuration of a typical Excool module in IAO, and its application to a data hall with hot aisle containment. The Figure above shows air delivered into the floor void; however, the arrangement can be configured with delivery directly into the space (in the absence of a floor void) via a uniform supply wall Grille. Each Excool unit consists of a number of modules that are fitted with external and internal plug fans (ECDC motor driven) with integral speed control, thus allowing for potential energy savings with small reductions in fan speed.

3.2 Direct Air Optimisation

Although implemented by a number of industry leaders, to date, the numbers of fully complete data halls that adopt Direct Air Optimisation (DAO) as the primary cooling technology have been limited. End Users such as, Microsoft, Google and Yahoo have all employed this technology within their latest facilities. In addition, there are a number of modular solutions such as the HP FlexDC, BladeRoom scalable solution and the COLT modular data centre that provide a form of DAO.

The DAO method moves on from the concept of closed circuit cooling, to drawing in fresh air directly into the data hall and rejecting the warm air to atmosphere. This type of solution has been made possible as a result of the relaxed AHRAE 2008 TC 9.9 guidelines. In the present case, the idea of a modular side entry solution with hot aisle containment is explored as shown in schematically in Figure 3.2. Bespoke DAO solutions can be provided by a number of manufactures, to name a few, Trane, Airedale, Dalair, Saiver, Mcquay and RMI.

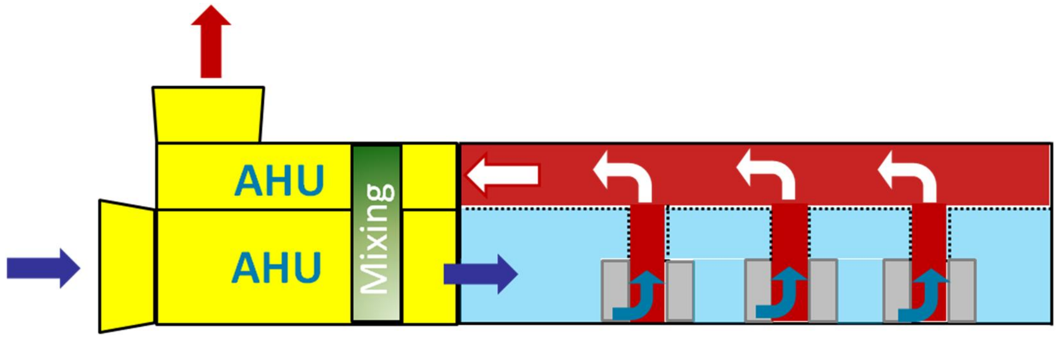


Figure 3.2: Fresh Air Cooling in Direct Air Optimisation by Side Entry.

In the application of DAO, the fresh air can be mechanically distributed through to the data hall through a low resistance by-pass duct, which offers a reduced static pressure for the fans to overcome, resulting in reduced fan input power. Of course, this does not shy away from the fact that the ambient air will need to be filtered with DAO systems before being delivered into the data hall. During summer the air may require some additional form of adiabatic cooling or dehumidification through a refrigeration component. In winter time, the moisture content of the ambient air may be low, and so a combination of mixing and adiabatic cooling would be required. The maintenance of filtration components is also an element that requires consideration, in addition to the performance of the system during periods of low air quality (i.e. local fire/smoke).

Perhaps one of the most significant shortcomings of the DAO approach is the requirement for a backup cooling system, which would be called upon in an emergency situation, such as in the event of external events generating significant airborne contaminates or operation of the data hall fire suppression system, where the system will operate in a close loop mode.

3.3 Chilled Water System

The traditional approach more common in data centres today, is that of a dedicated Chilled Water (CHW) system solution, with chillers serving as the main refrigeration element and pumps for flow distribution. The system comprises of a number of air-cooled free-cooling chillers, a CHW network with primary and secondary pumps, and Computer Room Air Conditioning (CRAC) units. There are other considerations such as the pump rooms and water treatment plant.

The purpose of the chilled water (CHW) distribution system is to deliver the required cooling to a number of elements on site, including the cooling to the supporting UPS switchrooms, but most importantly to the data hall ring which feeds the CRAC units that service the IT cabinet heat loads. The CRAC units will operate in full recirculation mode inside a sealed environment (usually located within a corridor outside of the technical data hall space), by removing heat from the room return air and rejecting this heat into the CHW system. This traditional concept with CRACs, chillers and pumps is demonstrated schematically in Figure 3.3.

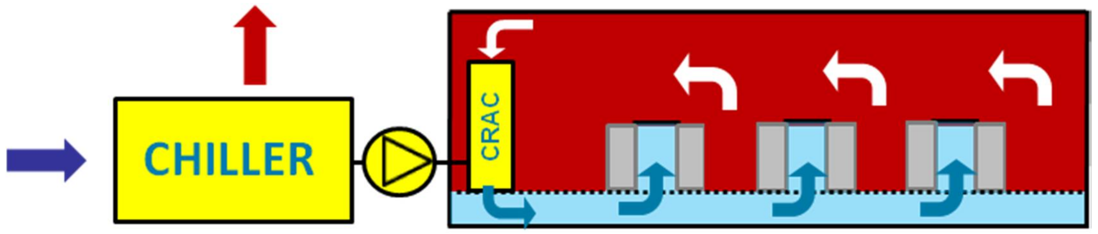


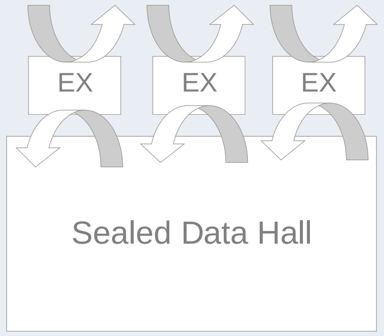
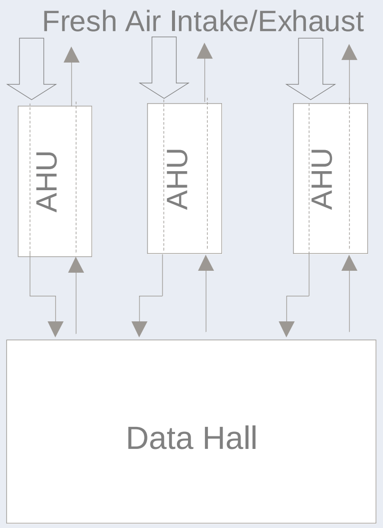
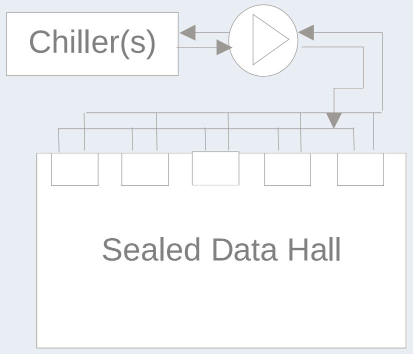
Figure 3.3: Chilled Water Cooled Data Hall

A number of different Chiller technologies are available. In the case of free cooling air cooled Chiller, its Energy Efficiency Ratio (EER) will vary according to the ambient conditions and so the energy consumption of the Chiller is a function of the ambient conditions. In simple terms, during the colder months the EER may peak and so the power input to the Chiller compressors will be significantly less than in the summer months. This type of Chiller offers significant energy savings over standard air cooled chillers. Chillers are available from a variety of manufacturers namely, Trane, Mcquay, and Airedale. Bespoke CHW system pumps and pump rooms can be manufactured by Armstrong and Grundfos.

The data hall CRAC units can be fitted with EC plug fans. The variation of power consumption versus volumetric flow for this type of fan motor follows the cube law relationship, therefore, the installation of EC fans can benefit from a major reduction in power consumption, especially for low speed applications. GEA Denco, Emerson and Stulz, form just a few of the manufacturers that offer CRAC unit solutions.

4.0 Summary of system configuration

The following table presents details of the system configurations, for the considered cooling technologies, in light of the operational assumptions in Section 2.

Ref.	System Description	System Components	Typical Configuration	Project Requirements	Comments
1	**Indirect Air Optimisation** Manufacturers: IPT/Excool	Excool Unit(s); Fans/Sprays/Heat Exchange System Water distribution system including water treatment components and associated pumping; Water storage tanks. Separate AHU for data hall pressurisation		4no. Excool units to represent N+1 for data hall cooling; 2no. smaller Excool units to represents N+1 for UPS room cooling; 2no. bulk water storage tanks each sized to deliver the emergency water consumption.	Plant footprint is significantly reduced and data hall remains a closed system. Requirement of air management systems (particularly suited to hot aisle containment) in the data hall to operate at 24/36ºC supply return conditions. No refrigeration. Significant water storage
2	**Direct Air Optimisation** Manufacturers: Trane, Dalair, Saiver, Mcquay, RMI	Bespoke Air Handling Unit(s) with the following components: Intake/exhaust Attenuator; Filters; Supply Fans; Exhaust Fans; Adiabatic Coil; DX system; By-pass duct; Mixing duct; Water distribution system including water treatment components and associated pumping; Water storage tanks.		5no. bespoke air handling units to represent N+1 for data hall cooling; 10no. external DX condensers (two per AHU) for data hall cooling; 2no. air handling units with fully modulating economisers and DX back-up for UPS room cooling to represent N+1; 2no. bulk water storage tanks for evaporative cooling/humidification of ambient air.	Design of large bespoke air handling units, integrating backup cooling plant. Requires careful consideration to the modes of operation according to ambient conditions. Requirement of air management systems (particularly suited to hot aisle containment) in the data hall to operate at 24/36ºC supply return conditions. Servicing of filtration components.
3	**Chilled Water** Manufacturers: *(Chiller)* Trane, Mcquay, Airedale *(Pumps)* Armstrong, Grundfos, *(CRAC units)*, Emerson, GEA Denco, Stulz.	Free cooling air cooled Chillers; Chilled water distribution network; Primary pumps; Secondary pumps; Plant room for water treatment, pumps and pressurisation systems; CRAC units; Separate AHU for data hall pressurisation		3no. free cooling air cooled chillers to represent N+1; 3no. primary pumps and 3no. secondary pumps to represent N+1; 12no. CRAC units to represent N+1 for data hall cooling; 2no. CRAC units to represent N+1 for UPS room cooling.	Most common tried and tested cooling technology for data centres. Increased plant space. Increased energy consumption. More components with servicing requirements. Raised accessible floor for airflow distribution.

5.0 Resilience

5.1 Reliability

The following definition taken from BS4778 provides a context for Reliability; '***Reliability is the ability of an item to perform a required function under stated conditions for a stated period of time***'.

The following paragraphs are taken from British Standard 5760: Part 0: 1986

System Reliability
A chain is as strong as its weakest link. In systems all components affect the reliability with the weakest causing the most system failures; often just a few components causing the most trouble. Reliability analysis of systems at the design stage can identify such potential failures so that re-design can reduce or identify them. If this analysis is used with a target reliability performance the result can be used to limit analysis and redesign. A useful measure of target reliability is ***Mean Time Between Failures (MTBF)***.

System Maintainability
Mean Time To Repair (MTTR) *and repair rate are used in much the same way as MTBF and failure rates. The implication is that repair times vary even for narrowly defined work and that they have a statistical distribution.*
To take account of preventative maintenance a figure for ***Mean Time for Preventative Maintenance (MTPM)*** *is also required.*

System Availability
The concept of availability combines reliability and maintainability. For example, steady state or long-term average availability may be defined as;

$$\textbf{\textit{Availability}} = \frac{\mathbf{MTBF}}{\mathbf{MTBF+MTTR+MTPM}} \qquad [5.1]$$

To evaluate the reliability of each of the considered cooling technologies the MTBF for the primary system components were obtained using data from the Alion System Reliability Centre [1]. Independent data from [1] was used as opposed to manufacturer specific data, to retain an unbiased evaluation.

For Direct Air Optimisation the individual MTBF for a typical AHU and a DX system were considered. The most critical component of the AHU is the operation of the fan, this aside the performance of the different components, humidifiers, the backup cooling system (external Condenser), and notably the filters.

For Chilled Water, the individual MTBF values for a typical Chiller, Pump, CRAC unit, and Valve were considered. The most critical components, in this option, are the primary refrigeration elements of the Chiller (i.e. the evaporator and condenser circuits, as well as the heat rejection fans). In addition, the operation of the system pumps in distributing water throughout the chilled water circuit and the operation of the CRAC units in servicing the data hall heat load are all contributing factors to overall system reliability.

The key components within the Excool system which may pose a risk to the operation of the data hall are, the adiabatic spray pumps, the internal data hall fans, the external ambient fans, and the HES. The adiabatic spray pumps are installed per bank of 4 modules, and are only required for a number of hours during the year, where the db temperature exceeds 21ºC. In the present case considered each unit will consist of 7 modules each with multiple data hall fans and ambient fans. The likelihood of an entire unit being offline due to fan or pump failure is reduced, due to its modularity. For example, owing to the power distribution philosophy, 4 out of 7 modules may be brought offline to replace a faulty fan, which represents approximately 57% of an entire unit.

The figures stated for the systems reflect intrinsic failures and do not represent the consequences of a site power failure on the equipment or that which occurs as a result of human error.

In summary, the Chilled water system consists of more critical plant with an associated failure rate, and so an increased likelihood that any one of the identified components may fail over a given period. Both the cooling technologies in IAO and DAO consist of a reduced quantity of critical plant; therefore the likelihood of failure in the air optimized options is reduced.

Ref.	System Description	MTBF	Availability
1	Indirect Air Optimisation with Excool	Fan: 50,000 h Pump: 87,000 h	0.99952 0.99972
2	Direct Air Optimisation	AHU: 47,000 h DX system: 113,000 h	0.99949 0.99978
3	Chilled Water	Chiller: 50,000 h Pump: 87,000 h CRAC unit: 47,000 h Valves: 90,000 h	0.99952 0.99972 0.99949 0.99973

MTBF Figures were taken from average typical equipment values for Power Generation/Heating Ventilation and Air Conditioning [1]. The total MTTR + MTPM was taken as 24 hours for all components.

An availability calculation for the system as a whole has not been conducted due to the scope of this report. The scores below are based on the individual components and taking an objective view.

Reliability Rating

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	7
3. Chilled Water	6

5.2 Ease of Maintenance

The following part describes the maintenance requirements for the primary components in the systems considered.

Indirect Air Optimisation with Excool

The impact of maintenance procedures on the data centre is reduced due to the modularity of the units, i.e. components can be maintained across a bank of modules thus reducing the likelihood of an entire unit being offline. Should a fan require replacing, part of the unit (3 or 4 modules from a total of 7) will need to be shutdown and brought offline at a time of convenience, for maintenance purposes. The fan and motor bearing are sealed for life.

A total of 4 visits per year for inspection and maintenance are required. The main components that require maintenance are:

- Fresh air intake filters;
- Maintenance of spray nozzles;
- Water filters;

Separate maintenance is required for the water distribution system to the unit sprays. All other items are required to be inspected and replaced as required.

Direct Air Optimisation

The main components of the system that require maintenance are the AHU air intake filters, due to the high grade of filtration required and the continuous exposure to air particles and pollutants. The fan and motor bearing are sealed for life. A total of 4 visits per year for inspection and maintenance are required. The following outlines further maintenance requirements:

- Visual check of coils;
- Evaporative cooler;
- Visual check of fans;
- Filter change if required;
- Damper actuators;
- Motors
- DX system checks;
- Refrigeration filters;

Separate maintenance is required for the water distribution system to the unit adiabatic coil.

Chilled Water

The main components of the Chilled Water option that require maintenance are the Chillers, CRAC units, Pumps. These are outlined below:

- CRAC units (4 visits per year)
    - Check air filters;
    - Check functionality ;
    - Check valves fully open and fully closed;
    - Check fan ramp up and ramp down;

    - Piping connections;
    - Coil filters.
- Chillers (2 visits per year)
    - Refrigerant check;
    - Water leaks;
    - Check functionality of onboard pumps;
    - Controllers;
    - Refrigerant filters;
    - Electronically check the Chiller valves;
    - Temperature settings.
- Pumps (2 visits per year)
    - Pump functionality;
    - Check pump seals;

In summary, Indirect-Air-Optimisation with Excool offers the simplest maintenance procedure in comparison to the other options; however, this does depend on the level of maintenance required for spray nozzles required for adiabatic cooling. In addition, the water storage system also requires maintenance.

For Direct-Air-Optimisation, the greatest maintenance requirement will be associated with the DX cooling component and air filters. The annual filter change is increased especially given the grade of filter that is likely to be specified to maintain ISO Class 8 particles count per m³, as defined by the clean room standards 14644-1, due to the fact that a large volume of fresh air is required for delivery into the data hall for primary cooling. The individual requirements for maintenance across the different components in the Chilled Water option result in an overall greater annual maintenance activity, and so this option receives the lowest score.

Ease of Maintenance Rating

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*6*
3. Chilled Water	*4*

5.3 Historic Operation

The following describes briefly, the technology behind the considered options and its track record.

Indirect Air Optimisation with Excool

The Excool system operates under a combination of the adiabatic and evaporative cooling processes. The main components of the system are the adiabatic sprays, the HES, and the fans. The adiabatic sprays supress the dry bulb temperature, and the evaporative process occurs in the HES. As with Direct air Optimisation, this system comprises a number of concepts that have are well established over time. Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into the surrounding air, cools an object or a liquid in contact with it. When considering water evaporating into air, the wet bulb (wb) temperature, as compared to the air's db temperature, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect.

Perhaps the factor that sets this option apart from other air optimised solutions is that there is no moisture carry over through the HES into the data hall supply air stream, and therefore the challenges faced by other air optimised schemes are not apparent here.

Due to its relatively recent introduction in 2010, to date there are no complete data centre installations with Excool and as such the product has no proven track record, although feasibility and scheme design are under way across a number of different sites. Although the Excool product consists of a number of established components at its core, the control system (software) has not been tested, which is impacted on the score.

Direct Air Optimisation

A typical air handling unit takes advantage of a combination of several different proven technologies, such as blowers/fans, heating/cooling elements, filters, dampers, humidifiers, mixing chambers and heat recovery devices. Each of the aforementioned components have been developed over time through research and development (R&D) and have an established track record. It is common to find fresh air supply air handling units used for pressurisation of data halls, delivering 1-3 m^3/s into the space.

At present there are no ‘plug and play’ DAO solutions available on the market for data centre cooling, designs are often bespoke through manufacturers such as Airedale, Trane, and Dalair. A number of different implementations have been explored which are largely dependent on spatial availability and the form of the building, these are: 1) the top entry solution whereby all AHU/cooling plant are housed on the roof of the facility and air delivered into a room that employs a sealed hot aisle containment strategy, and 2) the side entry solution whereby air is delivered into the space from a wall zone (Figure 3.2). A third less frequent solution has also been implemented whereby air is delivered via a large floor void or plenum which is then used to pressurise a system of enclosed cold aisle.

Chilled Water

Commercially there are four different types of compressors used in Chiller systems. These are reciprocating compression, scroll compression, screw-driven compression, and centrifugal compression. All are mechanical machines that can be powered by electric motors, steam, or gas turbines. The first centrifugal water chiller was patented by Willis Carrier in 1921. The design of the first centrifugal compressor was similar to the centrifugal blades in a water pump, however, the component has developed considerably over the past decades. In general, chiller systems work in a cycle; the refrigerant passes through an evaporator, compressor, condenser, and an economiser expansion valve before being pumped back into the evaporator.

Today there are several manufacturers that offer plant for utilisation into a chilled water cooled data centre, such as Trane, Carrier, Emerson, Denco, and Armstrong. In general the technology through R&D has a proven track record, and the unit sales of this type of system generally outweigh the other options considered here. The development of powerful Chiller technology has allowed for the design of modern data centres with highly concentrated server clusters, particularly, racks of blade servers. However, it is well known that chillers typically consume the largest percentage of a data centre’s electricity and significant portions of annual energy budgets.

It must be noted that in today’s market many data centres use this type of system, and so it achieves the highest score.

Historic Operation Rating

1. Indirect Air Optimisation with Excool	*1*
2. Direct Air Optimisation	*7*
3. Chilled Water	*10*

5.4 Design Life

The design life of the different systems is dependant on the maintenance regimes adopted. The figures presented in the table below have been obtained from the manufacturers of the individual components.

Ref.	System Description	Design Life	Comment
1	Indirect Air Optimisation with Excool	Excool unit with sealed Plug Fans and Pumps: 25 years+	All items corrosion proof. Design life can be maintained as long as servicing procedures are carried out. Product refurbishment governs design life
2	Direct Air Optimisation	AHUs with back up DX condenser systems: 20 years +	Based on the *Trane* selection. Product refurbishment governs design life
3	Chilled Water	CRAC units: 12 years Chillers: 15 years Pumps: 15 years	CRAC unit design life based on *Denco.* Design life driven by the bearing life. Pump design life based on *Armstrong*.

Design Life Rating

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*7*
3. Chilled Water	*5*

6.0 Technical Performance

6.1 Load Handling

The Load Handling performance may be in part assessed by considering the power input and associated Coefficient of Performance (COP) for the primary components of the different cooling technologies.

Note that the COP can vary with the external ambient conditions, but also the unit loading, and the number of plant in operation, i.e. if one AHU is down for maintenance, then the resultant COP of the operational units may be affected. For the analysis in the table below, a plant operating philosophy of N+1 is considered throughout.

Ref.	System Description	Cooling Capacity (kW)	No. Required of units @ N+1	Power Input per unit (kW)		Unit COP	
				Max.	Nom.	Worst	Best
1	Indirect Air Optimisation with Excool	370 kW for 7-module unit	4	22	7.4	12	42 (at 5°C ambient)
		Smaller Excool unit for UPS room	2	7.4	1.48	12.9	39
2	Direct Air Optimisation	250 kW bespoke design AHU with back-up DX cooling system for data hall	5	121	14	2.07	18 (Fan only operation)
		Packaged AHU with fully modulating economiser for UPS room	2	36	8.2	2.7	11.8 (Fan only operation)
3	Chilled Water	650 kW for free cooling air cooled Chiller	3	213	89	3.05	25 (at 5°C ambient)
		Primary Pumps	3	4	4	N/A	N/A
		Secondary Pumps	3	6	6	N/A	N/A
		CRAC units for data hall	12	7	7	N/A	N/A
		CRAC unit for UPS room	2	7	7	N/A	N/A

The figures quoted in the table are spot values based on London weather data. The nominal power input data is based on an average external ambient temperature of 11°C for London Heathrow. The maximum power input is based on a maximum external temperature of 32°C based on TRY weather data. The IT load is assumed to be fixed at 1000 kW, as per the assumptions in Section 2.

The Indirect Air Optimisation with Excool achieves a higher COP throughout the year in comparison to the other options. The main contributors to energy consumption are fan power and pumping power to serve the adiabatic sprays, note that the latter is nominally required at db temperatures greater than 21ºC. The analysis shows that the Excool unit can achieve its maximum COP at 5°C ambient, but can generally achieve a COP of at least 33 at ambient db temperatures of 11ºC or less, which accounts for a considerable number of annual hours according to Figure 6.1.

With Direct Air Optimisation, the AHUs may achieve more efficient performance levels where the external ambient conditions fall within the ‘Mixing’ and ‘ASHRAE Class 1’ zones (see Figure 6.2), which accounts for approximately 57% of the year, where no additional treatment is required. For 37% of the year the supply air conditions may be achieved by further mixing and adiabatic humidification (evaporative cooling), and during the other 6% of the year the back-up mechanical cooling system will be required. In these cases, the supply fans in DAO must overcome the increased static pressure through the humidifier and cooling coil, and so the benefits of the low static by-pass duct are not utilised. During an emergency mode of operation in full recirculation mode with the backup cooling system delivering the entire load, the unit COP will fall to its lowest level of 2.07. The best COP of 18 is achieved when the unit fans are in sole operation (i.e. no refrigeration through the DX system).

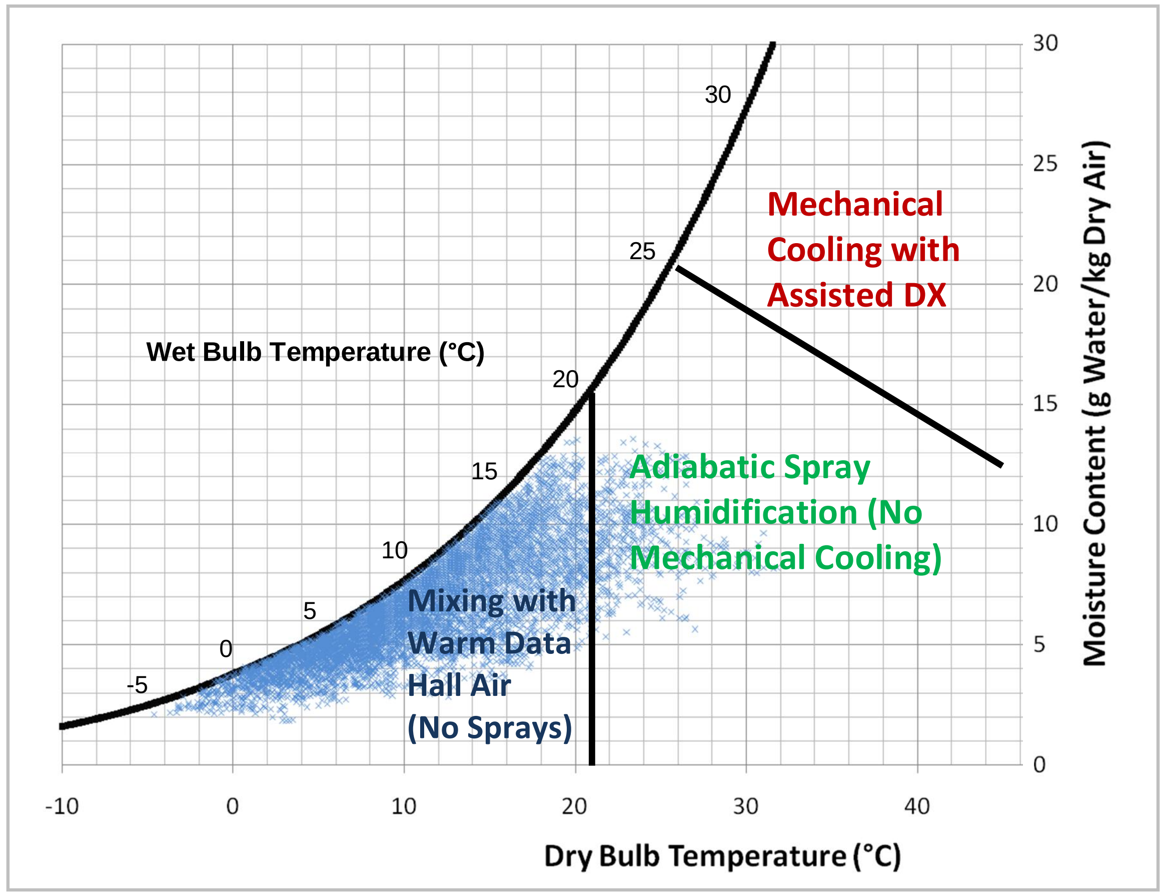


Figure 6.1: TRY Weather Data for London and the Implications of Applying Indirect Air Optimisation with Excool in this Region.

The free cooling air cooled chillers can achieve a peak COP of 25, at an ambient air temperature of 5ºC or less; this occurs for only a fraction of the year. Note that for the majority of the year the Chiller is operating in partial free cooling/partial mechanical cooling mode. The overall power input requirement (and so the energy consumption) for the Chilled Water option is generally higher that the other systems not least because of the contributions by the secondary plant such as CRAC units and pumps. The input power requirements for the secondary plant are fixed and only vary with the IT load in the data hall.

For the purposes of consistency, the supporting infrastructure that is designed to cool the UPS rooms is common to the particular cooling system, i.e. for IAO a smaller Excool unit is considered, whereas for DAO the UPS rooms are cooled via a packaged AHU with economiser. For the Chilled Water option, additional CRAC units are installed within the UPS room that tap off the common CHW system.

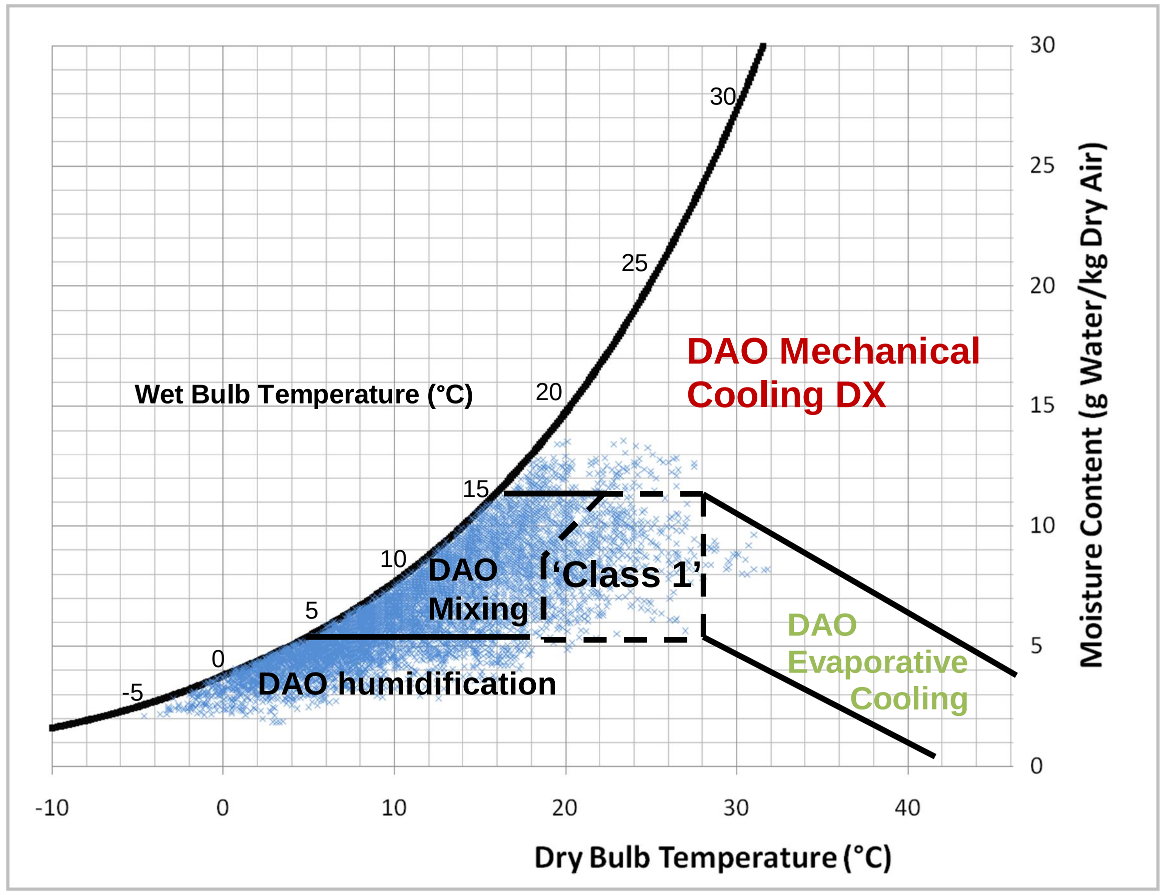


Figure 6.2: TRY Weather Data for London and the Implications of Applying Direct Air Optimisation for Data Hall Cooling in this Region. The Data is Plotted on a Psychrometric Chart that is Overlaid with the ASHRAE 'Class 1' Zone.

The system operation at low load and system turn down capabilities are also considered when assessing load handling.

The selected Excool units for data hall cooling in IAO comprise of 7-modules, and each module consists of a number of external ambient and internal data hall fans. Given the small size of these fans the units can be turned down to achieve a minimum flow to cater for low load operation, and still achieve 24°C, at little energy expense. Similarly the fan operation can be staged in response to load increase.

For data hall cooling with DAO the AHUs consist of 8 supply fans and 8 exhaust fans, and so a fair turn down can be achieved by ramping back the fans during low load operation. The specific performance at low load is dependant on the application of either cold aisle containment with a large floor void or hot aisle containment with delivery directly into the room. The best performance is generally achieved with the latter, especially at low load, as there is no requirement to maintain a pressurised floor void in that scenario.

Ref.	System Description	Turn Down
1	Indirect Air Optimisation with Excool	5% (for oversupply purposes)
2	Direct Air Optimisation	10%
3	Chilled Water	20%

The turn down figures quoted refer to global operation of the system

There are limitations in terms of operation at low load with a Chilled Water. This is attributed to the minimum turn down of the Chiller components mainly the compressor, the system pumps, as well as data hall CRAC units.

Load Handling Rating

1. Indirect Air Optimisation with Excool	*9*
2. Direct Air Optimisation	*8*
3. Chilled Water	*6*

6.2 Tolerances

The system tolerance rating may be assessed in terms of the ability to maintain a stable thermal environment within the data hall given the variations in ambient conditions and changes in plant loading. According to ASHRAE 2008 TC 9.9, the server air inlet conditions must adhere to the range 18-27ºC, with a maximum rate of change of 5°C and 5% relative humidity (rh) per hour.

Indirect Air Optimisation with Excool

During summer months the units adiabatic sprays may be required incrementally to achieve the supply air conditions (Figure 6.1). Furthermore, during the colder winter months, the units reuse the data hall warm return air to achieve the 24°C supply air condition. To achieve the close band of operating temperatures the application of Excool is best served with hot aisle containment, although it is also possible to implement cold aisle closure schemes with this option. This option provides a better control of the thermal conditions, due to the fact that the data hall remains sealed and no fresh air is introduced directly into the space via the Excool unit.

Direct Air Optimisation

Unlike IAO, the selected AHUs in the DAO are responsible for treating the humidity, temperature and the quality of the supply air (Figure 6.2). As a result a significant strain is placed on the various components inside the AHU to meet the ASHRAE 2008 recommended rates of change within the data hall. Therefore, given the tolerance of the AHU components, it is likely that the thermal conditions in the data hall may fluctuate slightly with the external ambient.

Chilled Water

For the CHW system option the thermal conditions within the data hall will be similar to that of Indirect Air Optimisation with Excool, due to the fact that both follow the principles of a sealed data hall.

Tolerance Ratings

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*6*
3. Chilled Water	*8*

6.3 Flexibility of Use

The flexibility of use may be assessed by considering applicability to cooling the diverse range of IT equipment, data hall pressurisation and flexibility of operating parameters.

Diversity in Delivering Cooling to the IT Equipment

Both IAO with Excool and DAO are recognised as air cooling technologies (i.e. they rely on air as the cooling medium), and so the implementation of such systems in data halls where high density water cooled racks are installed may require additional consideration. In both cases, a separate chilled water system technology will be required to maintain flexibility of the cooling strategy in the data hall. The Chilled Water technology has been commonly applied in several instances to serve data halls containing air cooled and water cooled equipment. In these instances the load consumed by the direct cooled cabinets is deducted from the air cooled capacity of the CRAC units, to maintain balance in the CHW system.

Data Hall Pressurisation

The pressurisation of the data halls with respect to their surrounding corridors (to minimise dust ingress) is dealt with intrinsically by the DAO system, and so in contrast to the Chilled Water option, a separate AHU is not required. In the case of IAO, the Excool unit may be configured with an additional module for fresh air supply/pressurisation of the data hall, which emulates that of the standalone AHU in the Chilled Water option, and is required to run continuously throughout the year.

Flexible operation

A chilled water cooled facility often operates at a fixed water supply/return condition, which is used to size the system terminal units such as Fan Coil Units and CRAC units. Although the CRACs are fully adjustable in their air temperature set points, the influence of the changing parameters on the downstream water side plant i.e. heat exchangers and chillers, needs further consideration once a system has been commissioned. Subsequently, both air optimised technologies are less dependant on the downstream plant and offer greater flexibility of operating parameters after commissioning.

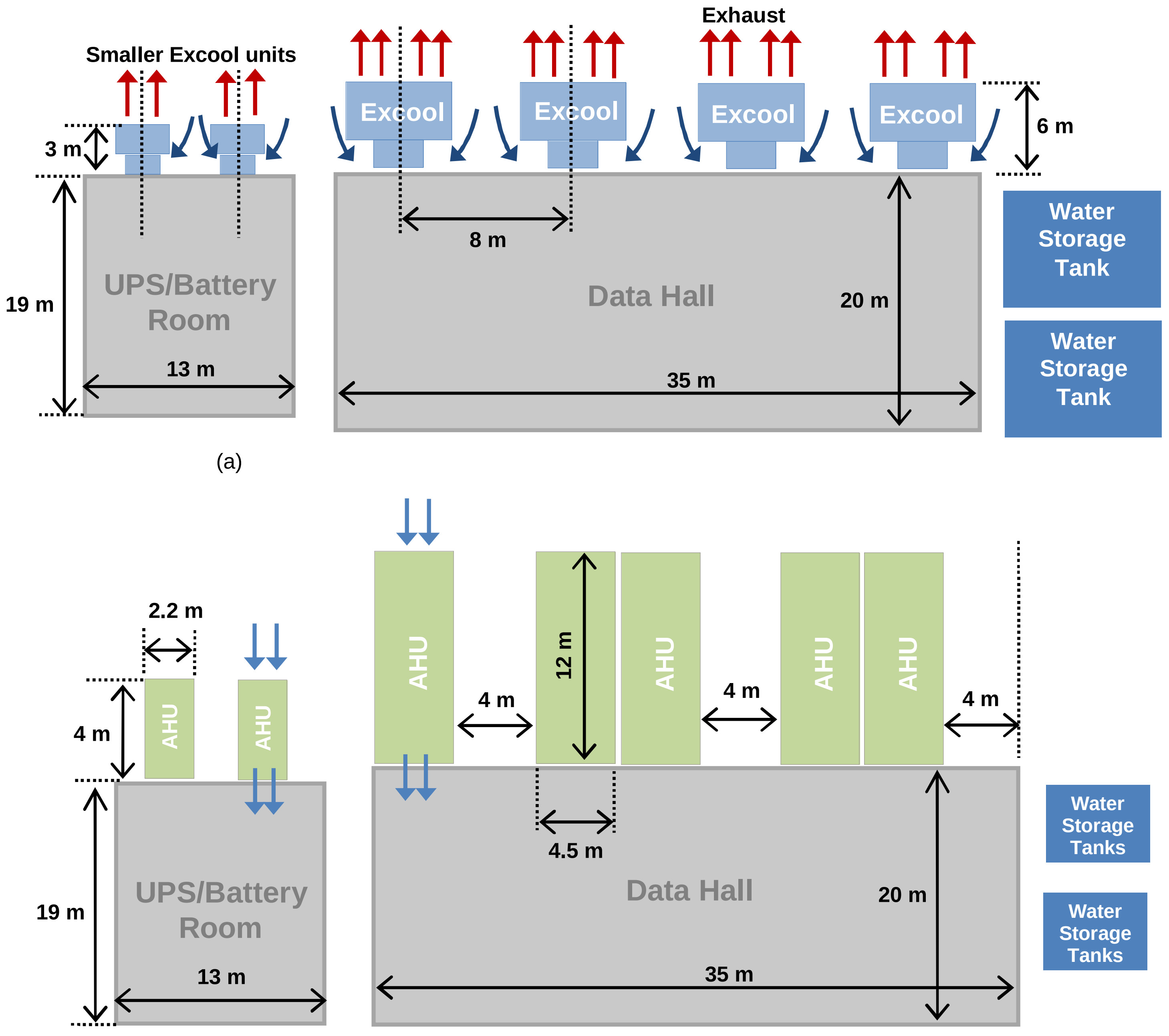
In summary, the chilled water system scored higher on the basis that the system can be adapted to serve both air cooled and water cooled IT equipment.

Flexibility of Use Rating

1. Indirect Air Optimisation with Excool	*5*
2. Direct Air Optimisation	*5*
3. Chilled Water	*7*

6.4 Spatial Take

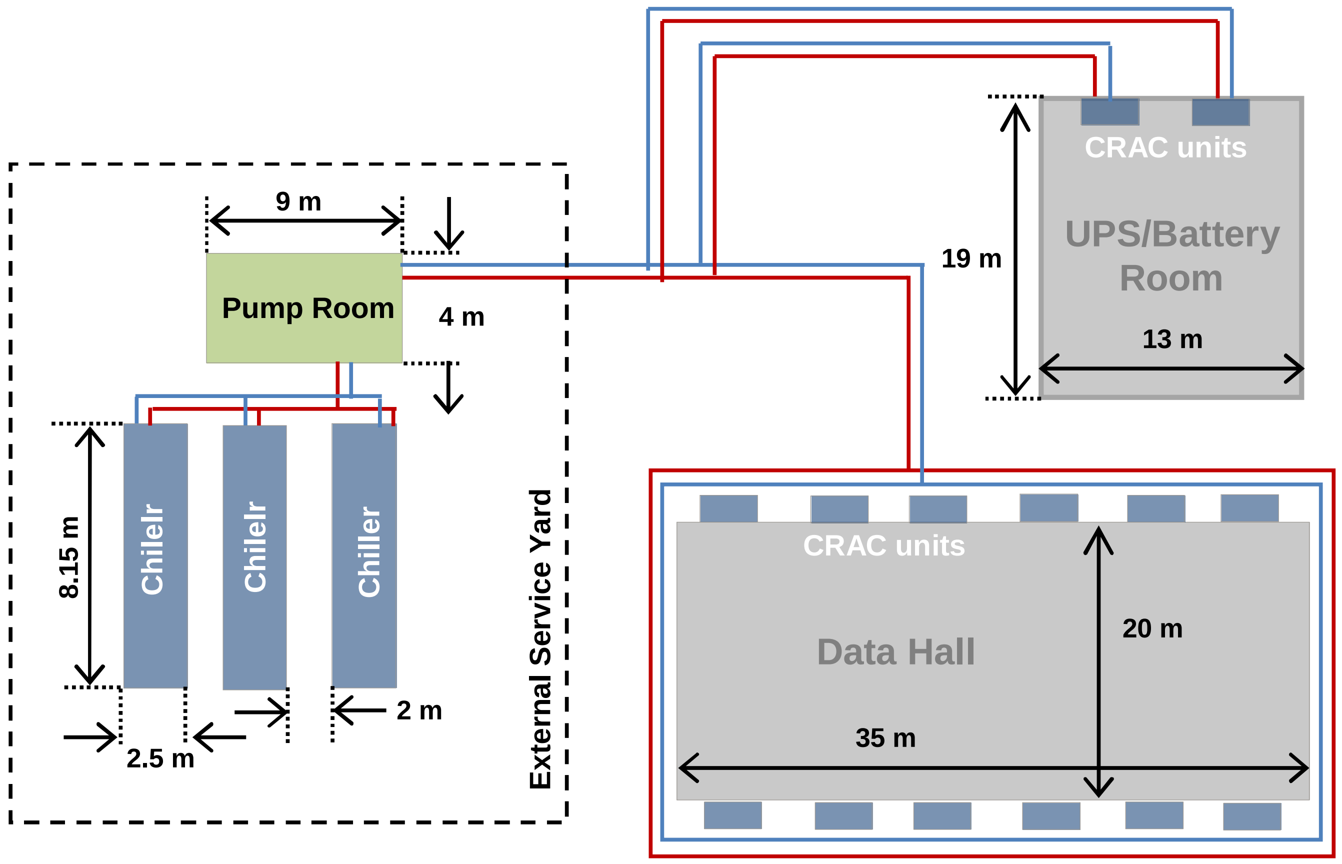
To assess the spatial take of the three cooling strategies considered, a hypothetical layout of the main cooling plant is shown in Figure 6.3(a-c). As shown in Figure 6.3(a) and 6.3(b) both air optimised solutions require dedicated water storage. However the spatial coverage of the cooling plant for Indirect Air Optimisation is significantly reduced due to the size and reduced number of Excool units in comparison to AHUs. In DAO, the supporting electrical infrastructure (i.e. Generators) to accommodate the back-up mechanical cooling systems will account for an increased Spatial Take in comparison to IAO. The removal and possible replacement of filters and coils in DAO requires a minimum clearance of 4m, for this option, between the air handling units, as shown in Figure 6.3(b).



(a)

(b)

Figure 6.3: For Caption See Head of Figure.



(c)

Figure 6.3: Typical Cooling Plant Arrangement to Deliver 1MW of Cooling Across a 700m² Data Hall for: (a) Indirect Air Optimisation, (b) Direct Air Optimisation, (c) Chilled Water. Note that the dimensions given are typical as obtained from manufacturers.

The Chilled Water solution requires considerable space for the chillers, pump room, and distribution pipework that are to be coordinated through to a central distribution ring. The plant is to be arranged in an external service yard with adequate clearances for access and maintenance. The CRAC units are typically installed outside the IT space, within a corridor. It is worth noting that the inefficiencies of the Chilled Water solution compared to the two air optimised technologies can result in the requirement for larger UPS and Power Generation plant, which adds to the spatial take. On the other hand, the Chilled Water solution can be implemented across non uniform or unconventional building shapes that would otherwise not accommodate the air only systems considered here.

In summary, although the physical dimensions of the Excool units would take less space than the DAO solution using AHU's, the requirements for water storage for adiabatic cooling also needs to be taken into account, which are considerable.

Spatial Take Rating

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*8*
3. Chilled Water	*5*

6.5 Contamination Risk

The contamination risk may be assessed in terms of the risk that the cooling system places on the data hall.

The Direct-Air-Optimised systems draw air directly into the data hall and so put emphasis on filtration, humidification and refrigeration of this air throughout the year. During periods of low air quality, i.e. local fire/smoke, the AHU controller will shut the unit fresh air dampers and revert to closed loop DX cooling. However, on detection of such an event this does not stop filters/components from becoming contaminated, and so affecting the data hall air quality. As a result, given the tolerances of these components, the likelihood of a contaminant entering the data hall is higher than the other options considered.

For both Indirect-Air-Optimisation with Excool and the Chilled Water solution, the data hall operates as a sealed system. In these cases the fresh air supply/pressurisation will be via a standalone AHU with heating, cooling, humidification elements, and filtration to adhere to the ISO 14644-1 cleanroom standards (Figure 6.4). It should be noted that this AHU is subject to the same contamination issues as DAO, although it could be shut down, which would result in a loss of the pressurisation regime.

For a typical data centre it is common to design filtration components to satisfy ISO Class 8, which limits that maximum particle count per m³ to 3,520,000. The Excool system is complete with water filtration, automatic drain down and automatic purge systems. Therefore, the water is filtered for Micro-organisms and treated with a scale inhibitor before entering the high pressure pump.

Class	**maximum particles/m³**						**FED STD 209E equivalent**
	≥0.1 µm	**≥0.2 µm**	**≥0.3 µm**	**≥0.5 µm**	**≥1 µm**	**≥5 µm**	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

Figure 6.4: ISO Cleanroom Standards 14644-1.

Contamination Risk Rating

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*4*
3. Chilled Water	*7*

7.0 Cost Over Life

7.1 Capital Cost

The costs are for guidance only and relate to specific projects and manufacturers components. For Indirect Air Optimisation with Excool, the costs relate to 4no. Excool units for data hall cooling, 2 no. smaller Excool units for UPS room cooling, and 4 water storage tanks in an 2N arrangement. In the case of Direct Air Optimisation, these refer to 5no. AHUs for data hall cooling, associated water storage, and 2no. smaller packaged AHU systems for UPS room cooling. The Chilled Water option refers to a system with 3no. free cooling air cooled chillers, 14 CRAC units for data hall and UPS room cooling and a packaged pump room with secondary pumps, primary pumps, buffer vessels, and water treatment plant. The table below details the capital cost of the key cooling plant for each of the options considered.

Ref.	System Description	Main Cooling Plant	Capital Cost per unit (£)	Total Cost (£)
1	Indirect Air Optimisation with Excool	7-module Excool unit (×4)	£194k	£776k
		Smaller Excool units (×2)	£42k	£84k
		AHU (x1)	£25K	£25K
		Water storage for 4no. tanks	£5k for water tank £4k for pumps £2k for water treatment £4k for pipework = £19k	£76k
				£961k
2	Direct Air Optimisation	Bespoke AHUs (×5)	£175k	£875k
		Smaller AHUs (×2)	£21k	£42k
		Water storage for 5no. tanks	£4k for water tank £2k for pumps £2k for water treatment £3k for pipework = £11k	£55k
				£972k
3	Chilled Water	Chillers(×3)	£132	£396k
		CRAC units (×14)	£18k	£253k
		Pumps + Pipework	£400k	£400k
		AHU (x1)	£25K	£25K
				£1,074k

Although the cost figures for the mechanical elements of the different options are similar, the increased power requirements for DAO and Chilled Water will result in the requirement of a larger electrical support infrastructure (larger Generators and UPS plant), the upshot of which is a greater spatial take and increased capital costs for these options. Note that when calculating the cost of the Chilled Water option, the costs associated with the water distribution pipework etc. have not accounted for.

Capital Cost Rating

1. Indirect Air Optimisation with Excool	*6*
2. Direct Air Optimisation	*6*
3. Chilled Water	*4*

7.2 Maintenance Costs

The maintenance costs presented in the table below relate directly to the maintenance procedures discussed in Section 5.2, for each of the considered systems.

Ref.	System Description	Main Cooling Plant	Annual Maintenance Cost per Component (£)	Total Annual Cost of Maintenance (£)
1	Indirect Air Optimisation with Excool	7-module Excool unit (×4)	£2.5k	**£10k**
		Smaller Excool units (×2)	£1k	**£2k**
		AHU (x1)	£1.5K	**£1.5K**
		Water storage (×4)		
		- Water tank + pump	£500	
		- Replacing UV lamps	£500	**£4k**
2	Direct Air Optimisation	AHU (×5)	£3k	**£15k**
		Smaller AHUs (×2)	£1.5k	**£3k**
		Water storage (×4)		
		-Water tank + pump	£500	
		-Replacing UV lamps	£500	**£4k**
3	Chilled Water	Chillers(×3)	£2k	**£6k**
		CRAC units (×14)	£600	**£8.4k**
		Pump room (×1)	£ 2k	**£2k**
		AHU (x1)	£1.5K	**£1.5K**

Figures are manufacturer specific, for chillers these are based on CRACs are based on Denco, the pump room is based on Armstrong. The figures for the AHU are based on Trane.

Note that for both IAO and DAO the maintenance requirements for filters/dampers necessitate four annual visits, and to this end the costs represent the maintenance fee per component, as well as the requirement of one filter change per system, be it an air filter for an AHU or water filter in the Excool option.

Note that for all the cases the maintenance costs do not consider that which may be associated with human mistreatment of components or replacement plant costs, but associated wear and tear. For the chilled water option additional maintenance checks may be incurred for the system valves, chilled water pipework, and other smaller support components.

Maintenance Cost Rating

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*6*
3. Chilled Water	*8*

7.3 Energy Consumption Cost

The annual energy consumption associated with the different cooling options is presented in the break down format in the table below, and is based on the key operational assumptions presented in Section 2.0. The data has been gathered using TRY weather data for the London region.

1		2		3	
Indirect Air Optimisation with Excool		Direct Air Optimisation		Chilled Water	
Per module (kWh)	11,208	**DX Cooling (kWh)**	324,660	**Free cooling Chiller (kWh)**	1,349,958
No. of Modules	28	**Fans (kWh)**	797,386	**Primary and Secondary Pumping (kWh)**	284,086
Excool Data Hall Consumption (kWh)	235,373	**Humidifier (kWh)**	0	**Data Hall CRAH Fan Power (kWh)**	569,400
		Pumping for Adiabatic Sprays (kWh)	8,130		
UPS Switchroom Cooling (kWh) ***Small Excool unit***	11,844	**UPS Switchroom Cooling (kWh)** ***Smaller packaged AHU***	89,220	**UPS Switchroom CRAC Energy Consumption (kWh)**	87,600
Total Annual Running Cost of Cooling Plant (£)	**£30,193**	**Total Running Cost of Cooling Plant (£)**	**£80,480**	**Total Running Cost of Cooling Plant (£)**	**£151,211**

For all items the figures presented are estimates based on manufacturer's specific selections and psychometric calculations. The cost of electricity is taken at £0.066 per kWh.

Indirect Air Optimisation with Excool

For the Excool unit, the energy consumption associated with refrigeration is zero, which is reflected in the total annual running cost of £30,193. The figure of 11,208 kWh per module is attributed to the unit fans and pumps feeding the adiabatic sprays. The cooling to the UPS switch rooms is through 2No. specially selected smaller Excool units, which accounts for 11,844 kWh.

Direct Air Optimisation

The annual energy cost of applying a DAO system in the London region falls between that of IAO and the Chilled Water solution. The main contributors are the system fans which consume 797,386 kWh on an annual basis to maintain a 12°C temperature difference across the data hall. Note that the fan energy consumption is based on a Specific Fan Power (SFP) of 1.0 for AHU operation within 'Class 1' and 'DAO mixing mode' of Figure 6.2, and SFP of 1.8 (minimum for Part L compliance) for operation the other zones. There is also a small contribution from the DX cooling elements. For the most energy efficient solution an adiabatic AHU has been selected such that mixing and adiabatic humidification are used to treat ambient data points in the 'DAO humidification' zone of the psychrometric chart presented earlier in Figure 6.2. As a result there is no direct humidification through a humidifier, and so the water consumption for this option is reduced. The pumping energy for the evaporative cooling process is obtained using data from the manufacturer applied to the London TRY weather profile.

Chilled Water

Figure 6.5 presents the annual energy consumption variation for the free cooling air cooled Chiller in the London region. The calculation is based on two chillers operating at part load, delivering a gross CHW load of 633 kW each (third Chiller to remain on standby). Note the considerable savings incurred in the winter months with the free cooling air cooled Chiller, offering a pay back period of approximately 1 year over a standard air cooled Chiller.

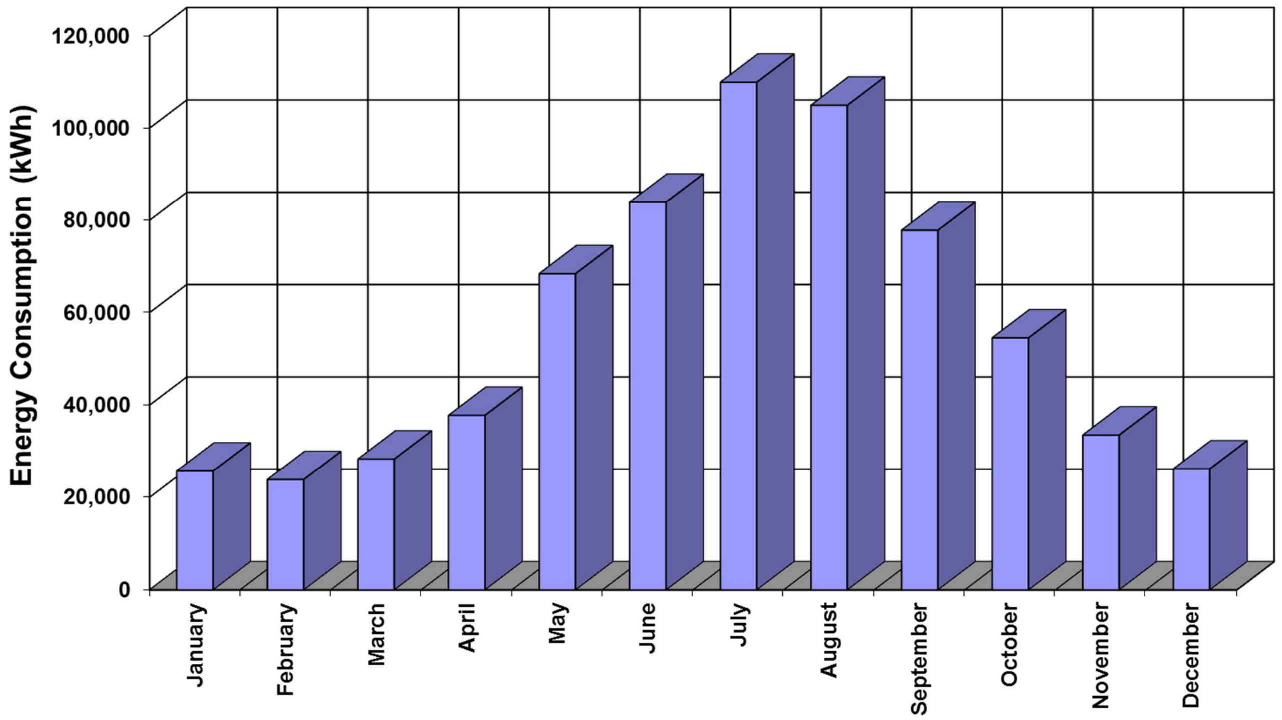


Figure 6.5: Annual Variation of Energy Consumption for the Free Cooling Air Cooled Chiller for the London region (Data Plotted for a Single Chiller).

Energy Consumption Cost Rating

1. Indirect Air Optimisation with Excool	*10*
2. Direct Air Optimisation	*7*
3. Chilled Water	*5*

7.4 Water Consumption Cost

The water consumption cost figures in the table below have been derived using the water consumption analysis in Section 8.2.

Ref.	System Description	Water Consumption for Data Hall (m³)	Annual Cost (£)
1	Indirect Air Optimisation with Excool	1468	1952
2	Direct Air Optimisation	400	532
3	Chilled Water	Negligible	Negligible

Water consumption cost is based on a figure of £1.33/m³.

Water Consumption Cost Rating

1. Indirect Air Optimisation with Excool	*3*
2. Direct Air Optimisation	*7*
3. Chilled Water	*10*

7.5 Related Building Costs

Indirect Air Optimisation with Excool

The Excool units will be supported typically on a concrete upstand in an external compound and abut the building external envelope; builderswork would then be required to form an opening in the envelope to allow a supply and return duct to be connected.

To permit the Excool to operate in the event of a loss of water supply, water will need to be stored on site, this can be stored in either above ground water tanks or buried tanks, the later requiring a greater amount of builderswork.

Direct Air Optimisation

In essence the same applies as Excool

Chilled Water

This type of system generally requires a significant amount of builders works and secondary support. chillers typically if located in an external compound will need to be elevated off the ground to allow air flow via some form of secondary support steel system. From the chillers, CHW pipework would then need to be supported along its entire length to a pump room, this built room would be dedicated to the function of pumping. The chilled water would then be pumped to CRAC units via supported pipework. The CRAC units would need to be supported above a raised floor on plinths and holes cut into the data hall wall (if located external to the data hall) to allow the air flow to / from the CRAC to the IT equipment.

Where as the Excool require water to be stored to allow continuous operation in the event of a loss of mains water, a CHW system may deploy a chilled water buffer in much the same way. This buffer vessel would have the same implication as the cold water storage vessel for the Excool unit.

Related Building Costs Rating

1. Indirect Air Optimisation with Excool	*6*
2. Direct Air Optimisation	*8*
3. Chilled Water	*5*

8.0 Environmental

8.1 Carbon Emissions

The Carbon Reduction Commitment (CRC) was announced in the 2007 Energy White Paper published by the UK Government and forms a mandatory scheme aimed at improving energy efficiency and cutting emissions in large public and private sector organisations. The long term aim of the CRC is to cut carbon emissions by 80% of the 1990 levels by 2050. The most effective way for data centre industry to achieve this goal is to encourage user/operators responsible for emissions to reduce their energy consumption and adopt efficiency measures.

Different metrics are generally used in order to classify the efficiency of data centres. The metrics referred to in this assessment are defined below.

Power Usage Effectiveness (PUE) and Carbon Usage Effectiveness (CUE)

The Power Usage Effectiveness (PUE) [2] is the ratio of total energy consumption over IT load. The Carbon Usage Effectiveness [3] is the product of the PUE and the Carbon Emissions Factor, thus termed the CUE. These equations are shown below in (1), (2).

$$PUE = \frac{Total\ Energy\ Consumption}{IT\ Energy\ Consumption} \qquad (1)$$

$$CUE = PUE\ \times\ CEF\ \ (CEF = Carbon\ Emission\ Factor) \qquad (2)$$

The Carbon Emission Factor for the United Kingdom is taken to be 0.517 kgCO^2/kWh. Source: National Calculation Methodology (NCM) modelling guide (for buildings other than dwellings in England and Wales) 2010 Edition.

Ref.	System Description	PUE	CUE (kgCO^2/kWh)
1	Indirect Air Optimisation with Excool	1.1 to 1.2	0.57 to 62
2	Direct Air Optimisation	1.15 to 1.3	0.59 to 0.67
3	Chilled Water	1.4 to1.7	0.72 to 0.88

PUE and CUE Emissions figures are estimates and are dependant on the specific system configuration.

The figures for PUE quoted in the table above are estimates, but generally representative of those that may be achieved for the different options considered.

An accurate evaluation of the PUE was outside the scope of this study as it involved specific sizing and selection of electrical plant, i.e. UPS, Transformers, and other site specific equipment. Note the significantly reduced PUE estimate for the Indirect Air Optimisation solution with Excool, as oppose to the Chilled water solution.

Carbon Emissions Rating

1. Indirect Air Optimisation with Excool	*10*
2. Direct Air Optimisation	*7*
3. Chilled Water	*5*

8.2 Water Usage

The Green Grid has produced a metric for the water consumed by a data centre; this is known as the Water Usage Effectiveness (WUE) [4].

The metric for water usage in the data centre is defined in the equation (3) below.

$$WUE = \frac{Annual\ Water\ Usage}{IT\ Equipment\ Energy} \qquad (3)$$

The units of WUE are litres/kilowatt-hour (l/kWh)

The WUE metric is calculated using the data presented in Section 7.4. Note the increased WUE metric for Indirect Air Optimisation solution with Excool as oppose to the Chilled Water and DAO cooling technologies, which is attributed to the predicted water Figures.

Ref.	System Description	WUE (l/kWh)
1	Indirect Air Optimisation with Excool	0.167
2	Direct Air Optimisation	0.046
3	Chilled Water	Negligible

<ins>Indirect Air Optimisation with Excool</ins>

For Indirect air optimisation with Excool the water consumption is governed by operation of the adiabatic sprays. The annual variation of water consumption for this option is presented in Figure 8.1.

The data indicates an annual water consumption of 1468 m^3 for a typical 1000 kW data hall in the London region, based on spray activation at 21ºC db. Note that this is a maximum that is required for the 24ºC supply air condition. Should the supply air condition be relaxed further within the ASHRAE recommended bounds, to say 26ºC, (i.e. spray activation at 23ºC as oppose 21ºC db), the predicted annual water consumption figure is reduced by half to approximately 800 m^3.

<ins>Direct Air Optimisation</ins>

The water consumption in Direct Air Optimisation is attributed to primarily the evaporative cooling and adiabatic humidification. The annual variation of water consumption for this option is presented in Figure 8.2.

In comparison to the Indirect solution, the water consumption figure here is considerably reduced, as the majority of energy consumption is through fan power, and refrigeration elements. The analysis indicated an annual water usage of 400 m^3 for the data hall.

<ins>Chilled Water</ins>

The water consumption in a typical Chilled Water system data hall is attributed to the treatment, dosing, flushing elements and buffer vessels which are all a function of the system size. Even so, for the system considered here the typical figures are negligible in comparison to the other options.

The water consumption profiles in Figures 8.1 and 8.2 are obtained from psychrometric analysis using the London weather profile.

Water Usage Rating

1. Indirect Air Optimisation with Excool	*3*
2. Direct Air Optimisation	*7*
3. Chilled Water	*10*

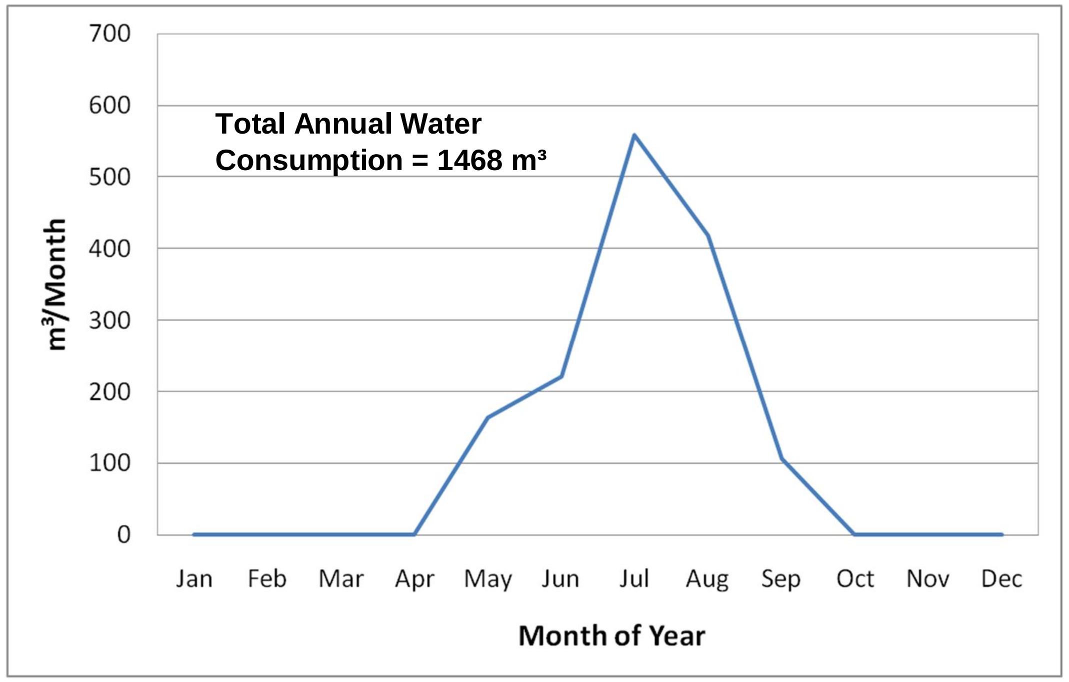


Figure 8.1: Typical Annual Water Consumption profile for an Indirect Air Optimisation solution with the Excool application in London, to achieve the 24°C supply condition into the data hall.

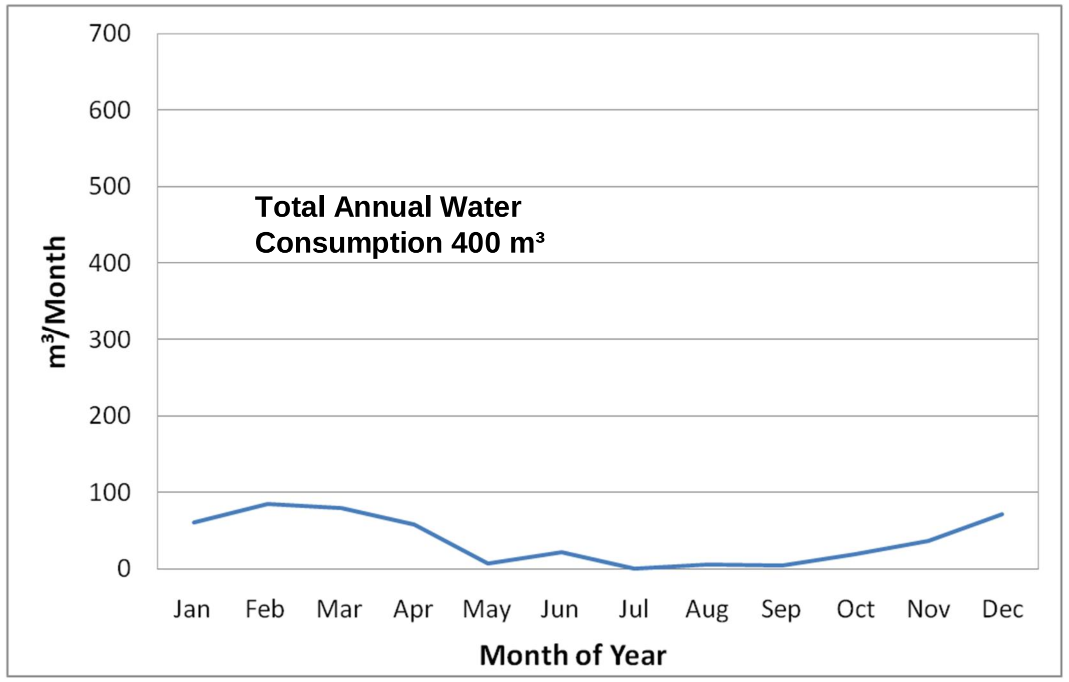


Figure 8.2: Typical Annual Water Consumption profile for Direct Air Optimisation Application in London, based on Manufacturer's data.

8.3 Manufacture

The systems considered generally require a high level of primary natural resources, and there is no evidence to suggest that any of the systems utilise recycled materials.

In the case of Indirect Air Optimisation with the Excool unit, the manufacturing process is relatively a low energy procedure as it is predominantly an assembly exercise. The AHU and condenser plant in DAO are often a bespoke design solution, physically larger than the Excool units and so will consume more raw materials.

The traditional solution with chillers, CRAC units and chilled water system pumps consists of more plant, spread across a wider assortment of manufacturers. In addition to this the fabrication of pipework and pump rooms to serve the chilled water distribution network. For this reason the usage of raw materials and associated wastage is greater than the other options considered.

Manufacture ratings

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*7*
3. Chilled Water	*4*

8.4 Noise Emissions

The location considered in the London Borough of Hillingdon (Heathrow) may be close to residential properties and so noise pollution is a factor that needs to be considered. The maximum noise level that may be exhibited in the vicinity of any residential property is taken as 47dB(A). For assessment of this parameter, the primary noise producing plant that sit in the external zones are considered.

<u>Indirect Air Optimisation with Excool</u>

The Excool units use ECDC fans and are therefore inherently quiet. The units are quieter than the Chiller systems and can be attenuated locally. The manufacturer has quoted a sound pressure level of 58 dB(A) measured at 10 m from the units.

<u>Direct Air Optimisation</u>

The noise producing elements in a typical Direct Air Optimisation solution are the AHU fans and external condensers. Based on the manufacturer’s data, the sound pressure level from the AHU supply and exhaust fans (measured inside the casing) are 89 dB(A) and 88 dB(A), respectively. The back up cooling system consists of 2no. external condensers per AHU. The rated peak sound pressure from a single condenser is 98 dB(A). If refrigeration is required, the load per AHU may be shared between the two condensers and so the resultant noise level per condenser reduced. The psychrometric analysis has shown that in the absence of any emergency mode operation the back up DX cooling system may be online for no more than 6% of the year. However, acoustic treatment may still be required to limit the noise breakout.

<u>Chilled Water</u>

The dominant noise producing element in a data centre incorporating a chilled water system is the system chillers. Within a free cooling Chiller the noise producing elements are the compressors and fans, which will operate in different modes depending on the ambient conditions throughout the year. It is normal for the manufacturer to incorporate an acoustic package within their Chiller in acknowledgement of the noise levels, to minimise the impact on the design. For a typical free cooling air cooled Chiller, a sound power level of 53 dB(A) @ 10m can be expected from the unit during normal operation, and 65 dB(A) @ 10m from the unit during Max free cooling. A typical Chiller and pipework configuration may be designed such that it is housed on a supporting gantry. In these instances it is important to take into account tonal noise elements from the interconnecting pipework. In this light, the residential limit of 47dB(A) in the vicinity of any residential property may need to be lowered by 5dB(A) to 45 dB(A).

A breakdown of the manufactures noise data for the Excool units, AHU supply/extract fans and its associated external condensers, as well as a typical free cooling Chiller are presented in the table below:

Ref.	System Description	Total Sound Pressure dB(A)
1	Excool	58 dB(A) @ 10 m
2	AHU Supply Fan	Attenuated to 65dB(A)@1m
	AHU Exhaust Fan	Attenuated to 65dB(A)@1m
	External Condenser	66 dB(A) at 10 m
3	Chiller (NSB 3402A EXF0F2T6AK)	53-65 dB(A) @ 10 m

Noise data is based on specific selections from the manufacturer. The AHU supply/extract fans and external condenser are based on data from Trane.

Although Chilled Water can be acoustically treated, it has high spatial requirement for this treatment and can be expensive to implement.

Noise Emissions Rating

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*5*
3. Chilled Water	***3***

8.5 Disposal

In all cases considered, the manufacturers have confirmed that where possible wastage material from the manufacturing processes is recycled.

The Excool units are manufactured from a stainless steel base. The inner panels (heat exchangers) are manufactured from composite materials and the outer panels from aluminium with foam insulation. All components are recyclable.

The air handling units in DAO contain a number of components that may be recycled (i.e. copper tubing, cabling and electric motors), and also those that will need to be disposed of safely.

When a Chiller reaches its end of life, decommissioning is available at the factory. During manufacture of the Chiller, the manufacturer will generally collect and divide any waste into material types for recycling to comply with the Waste Electrical and Electronic Equipment (WEEE) directive. Any excess refrigerant gas such as R134a are recovered and disposed in the correct manner. Materials classified as harmful to the environment are contained, monitored and disposed of in accordance with the European regulations.

The air optimised schemes generally consists of fewer components, i.e. the Excool unit, or AHU with a condenser system and so the number of components that may require disposal are reduced. However with the Chilled Water option the system consists of a greater number of components that will require safe disposal or recycling where possible, i.e. intrinsic chiller components, CRAC unit components, chilled water pipework and pumps/pump room components.

Disposal Rating

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*5*
3. Chilled Water	*3*

9.0 Programme

9.1 Procurement

The table below details the estimated lead in times for the plant, based on feedback from the manufacturers.

Ref.	System Description	Component	Quantity	Reported lead in times	Estimated total time
1	Indirect Air Optimisation with Excool	Excool unit for data halls	4	16-20 weeks	4-5 months
		Excool units for UPS room	2	14-16 weeks	
2	Direct Air Optimisation	AHUs for data halls	5	16 weeks to delivery on site for first AHU, 3 week per additional unit. Also 1 week per unit for controls to be fitted	6-7 months
		Condenser	10	8 weeks	2 months
		Packaged AHU for UPS rooms	2	12 weeks	3 months
3	Chilled Water	Chiller	3	8-10 weeks plus 1 week for delivery	2-3 months
		CRAC units	14	8-11 weeks	2-3 months
		Pump/Pump Room	1	6-8 weeks	1-2 months

The plant in direct air optimisation is based on selections from Trane, the CRAC units are based on Denco, and the pumps/pump room are based on Armstrong integrated systems.

With Excool being a relatively new product, the present lead in time for Indirect Air Optimisation is 4-5 months for 4no. units. However this lead in time will reduce over time, as more units are manufactured. The bespoke air handling units in DAO take the longest to procure, not least because of the anticipated research and design development associated with building the first bespoke air handling unit. The primary cooling plant for the Chilled Water option are established components that have overtime undergone optimisations and advances in their respective manufacturing processes, and so offer reduced lead-in times in comparison to the other options.

In the cases tabulated above, factory testing of plant, post manufacture, has been factored in.

Procurement Rating

1. Indirect Air Optimisation with Excool	*5*
2. Direct Air Optimisation	*4*
3. Chilled Water	*7*

9.2 Design

Indirect Air Optimisation with Excool

As a packaged unit, the Excool solution adopts uniformity in design and assembly, i.e. all components are contained within the single entity and supplied by one manufacturer. The units are autonomous in operation and configurable in a modular sense. The number of modules can be configured according to the heat load to be supported in the data hall and the level of required resilience. The primary design element in the development of such a system is not so much the Excool unit itself, but its integration into the building and supporting infrastructure such as a water distribution network for sprays. The Excool units are supplied with run and stand by pumps (to feed the adiabatic sprays) and integrated controls.

This approach does without the need to size specific system components, such as pumps, pressurisation units, coils, condensers, which are onerous design processes associated with Direct Air Optimisation and Chilled Water options.

Direct Air Optimisation

There is no existing standard design, all solutions are bespoke and require some level of R&D. Collaboration is required between the AHU and Chiller manufacturers to design a suitable air handling unit with the appropriate sections for supply, exhaust, mixing chambers and the integration of a back up cooling system.

The air handling units require bespoke controls system which collectively brings together the operation of fans, dampers, adiabatic coil, and assisted mechanical cooling system.

Chilled Water

The data centre chilled water system consists of a large number of components that are linked through a common water distribution network. These components need to be sized and selected so that they can operate in harmony with one another within the network, and for this reason this option presents a more lengthy design process in comparison to Indirect Air Optimisation. Although many data centre developers now adopt standardised Turnkey designs across their sites.

Typically, a system heat load calculation will be carried out to size the number of CRAC units required in the data hall to service the IT heat load. From this calculation the required chilled water flow rate, and Chiller duty can be deduced. Subsequently, the system pumps will be sized to deliver the required flow rate around the chilled water circuit. This will require the design of a pump room with dedicated water treatment plant.

Design Ratings

1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*5*
3. Chilled Water	*5*

9.3 Installation / construction

Indirect Air Optimisation with Excool

The installation involves simply bolting a unit together, connecting ductwork, power and water supply, which can be carried out in one week for the 4no. Excool units. Note that additional time is required for installation of water tanks, pumps and distribution pipework to the Excool units.

Direct Air Optimisation

A complete AHU system with the associated refrigerant pipework, and condensers will take two weeks to install. Additional units may be installed with multiple teams, but as a maximum time frame the manufacturer has indicated an additional two weeks per AHU system.

Chilled Water

The Chillers can be craned in the duration of one day, and pipework and electrics can be connected within one week. The CRAC units come with flanged connections. Assuming that the installed chilled water pipework has matching flanged connections and a readily available power supply, final connections can be carried out within a day by an M&E contractor, once a unit is in position. The pump rooms are usually manufactured as a prefabricated element off-site. The rooms may be delivered to site and positioned onto a specially designed structural gantry via a crane. The install time may be no more than a week given the services infrastructure is in place.

Note that the plant installations may be carried out in parallel, however there is some co-dependency, especially with the coordination of the interconnecting chilled water pipework with the main plant.

Ref.	System Description	Component	Reported installation time
1	Indirect Air Optimisation with Excool	Excool unit	2 week
2	Direct Air Optimisation	AHU	8-10 weeks
		Condenser	
3	Chilled Water	Chiller	5-7 weeks (simultaneous installation of plant)
		CRAC units	
		Pump/Pump Room	
		Pipework	

Installation / construction Ratings

1. Indirect Air Optimisation with Excool	*7*
2. Direct Air Optimisation	*5*
3. Chilled Water	*3*

9.4 Commissioning

The main commissioning activity for the Excool unit will involve the setting of controls and fan speeds, which should encompass a maximum of two days per 7 module unit.

The manufacturer reports that the AHU systems in Direct Air Optimisation can be commissioned in one week, and so it will take a maximum of five weeks to commission the 5no. AHUs. The commissioning of the packaged AHUs for the UPS room may be carried out in parallel with the data hall units.

The Chilled Water solution requires commissioning of the system pumps/pump room and the chilled water system itself. In addition to the individual components, namely the chillers, pumps and CRAC units, will undergo a commissioning process. Pre-commissioning of the chilled water system, i.e. filling the system, will encompass two to three days per Chiller. Checking the Chiller functions will take approximately one day per Chiller. The final commissioning process will also require an additional day per Chiller. The CRAC units can be commissioned at a rate of two to three units per day. Note that these processes are to be carried out with some degree of coordination.

Ref.	System Description	Component	Reported commissioning time
1	Indirect Air Optimisation with Excool	Excool unit	1-2 weeks
2	Direct Air Optimisation	AHU	2-5 weeks
		Condenser	
3	Chilled Water	Chiller	4-8 weeks
		CRAC units	
		Pump/Pump Room	
		Chilled water system	

For reasons relating to the general complexity of commissioning a data centre with a chilled water system (i.e. more elements to commission in comparison to the other cooling technologies), this option has been assigned the lowest score.

Commissioning Ratings

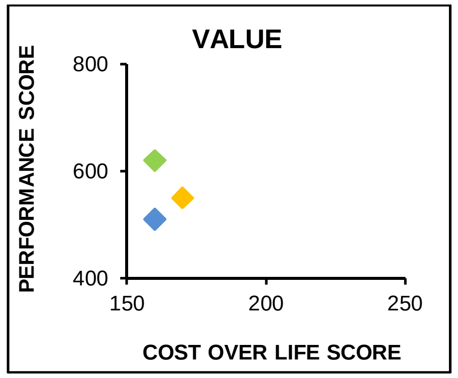
1. Indirect Air Optimisation with Excool	*8*
2. Direct Air Optimisation	*7*
3. Chilled Water	*4*

10.0 Selection Matrix Summary

As a first step the cooling technologies were initially considered under a Control Group with uniform weighting scores, to assess the performance and sensitivity to the different categories.

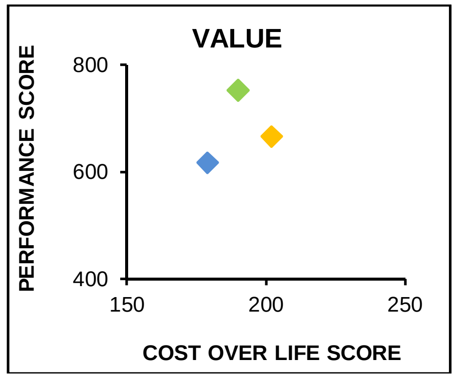
Following this, the options were compared under the two different Client weighting scores, one obtained from the perspective of a data centre Developer and the other an End User type Client. The final recommendations were made by comparing the performance versus the product cost over life scores for each cooling technology considered, across both Client types.

Of the systems assessed and by application of the Client weighting scores and engineering assessment matrices, the following results have been obtained. The charts in Figure 10.1(a-c) have been configured using the latest information available and originate from the selection matrices in Appendix A.



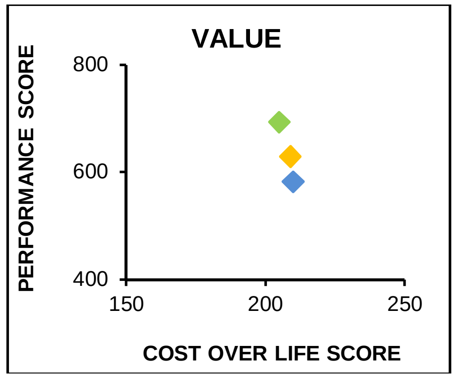
(b) Control Group Uniform Weighting

Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	1
2	Direct Air Optimisation	2
3	Chilled Water	3



(b) Data Centre Developer

Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	1
2	Direct Air Optimisation	2
3	Chilled Water	3



(c) Data Centre End User

Ref.	System Description	Ranking
1	Indirect Air Optimisation with Excool	1
2	Direct Air Optimisation	2
3	Chilled Water	3

Figure 10.1: Performance versus Cost over life score and system ranking for the three cooling options considered. Comparisons are made under Weighting Scores defined for three scenarios: (a) Control Group, (b) Data Centre Developer type Client, and (c) Data Centre End User Client.

Our analysis of the three cooling strategies for the Geographical region with the available information from the manufacturers leads us to recommend ‘Indirect Air Optimisation with Excool’ as the preferred cooling strategy across both Data Centre Developer and End User Client variations.

It can be seen that the Indirect Air Optimisation with Excool achieved the greatest performance score and exceeded the other options by a distinct margin for both Client variations (Figure 10.1b and 10.1c). A similar pattern was observed when considering the cooling options under a Control Group assessment with uniform weightings.

With regards to the cost over life score, the best performing option varies according to the different client types and so there is no distinct winner. However, if the cost over life score is summated with the performance score, IAO with Excool remains the clear winner.

Note that the climate plays a big part in scoring of a number of the categories and so the product comparison scores as well the Client Weightings will need to be revisited when considering other climates/regions. For instance, a Client looking to construct a data centre in Dubai may place more emphasis on spatial constraints and water storage/consumption, whereas in the United States, Programme and Cost over life may take precedence.

11.0 References

1. Typical Equipment MTBF values for Power Generation/Heating Ventilation and Air Conditioning Equipment, Alion System Reliability Centre (2001), http://src.alionscience.com.
2. The Green Grid, Data Centre Power Efficiency Metrics: PUE and DCiE. White Paper #6.
3. The Green Grid, Carbon Usage Effectiveness (CUE): A Green Grid Data Centre Sustainability Metric. White Paper #32.
4. The Green Grid, Water Usage Effectiveness (WUE): A Green Grid Data Centre Sustainability Metric. White Paper #35.

12.0 Appendices

CLIENT WEIGHTING SUMMARY TABLE

KEY CATEGORY	SUB-CATEGORY	CLIENT WEIGHTINGS		
		CONTROL GROUP	DATA CENTRE DEVELOPER CLIENT	DATA CENTRE END USER CLIENT
RESILIENCE	**RELIABILITY**	5	8	9
	EASE OF MAINTENANCE	5	4	9
	HISTORIC OPERATION	5	5	7
	DESIGN LIFE	5	5	7
TECHNICAL PERFORMANCE	**LOAD HANDLING**	5	6	8
	TOLERANCES	5	4	6
	FLEXIBILITY OF USE	5	6	6
	SPATIAL TAKE	5	7	5
	CONTAMINATION RISK	5	6	5
COST OVER LIFE	**CAPITAL COST**	5	9	4
	MAINTENANCE COST	5	6	8
	ENERGY COST	5	4	8
	WATER CONSUMPTION	5	4	7
	RELATED BUILDING COST	5	7	4
ENVIRONMENTAL	**CARBON EMISSIONS**	5	5	8
	WATER USAGE	5	4	7
	MANUFACTURE	5	2	3
	NOISE EMISSIONS	5	7	4
	DISPOSAL	5	3	7
PROGRAMME	**PROCUREMENT**	5	8	5
	DESIGN	5	7	4
	SPEED OF INSTALLATION	5	9	4
	COMMISSIONING	5	9	3

COMPARISON BASED ON A CONTROL GROUP WITH UNIFORM WEIGHTINGS ACROSS THE CATEGORIES

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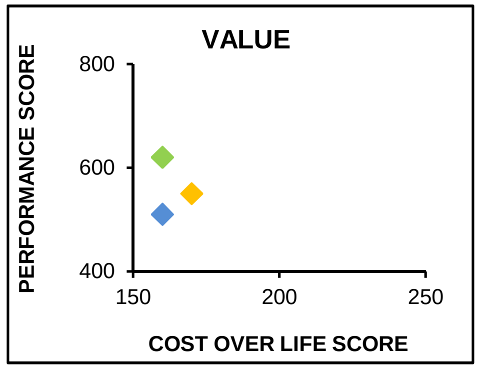
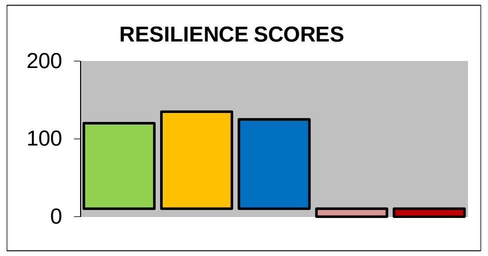
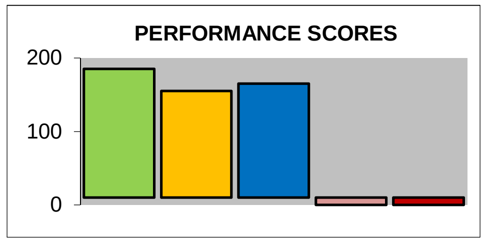
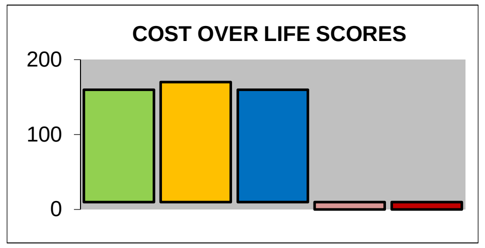
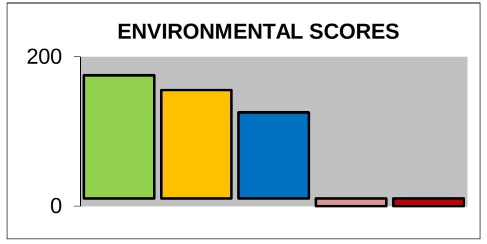
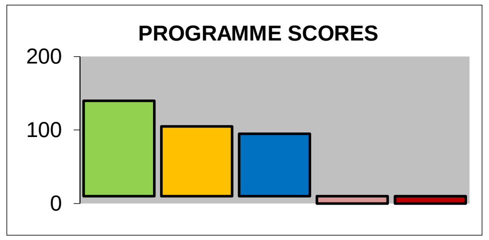
COMPARISON BASED ON PRESCRIBED CONTROL GROUP WEIGHTING SCORES

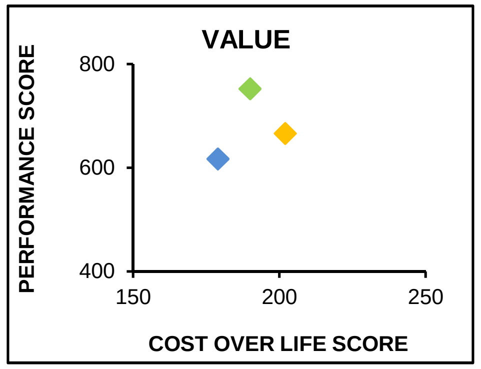
KEY CATEGORY	SUB-CATEGORY		OPTIONS					
		Client Weighting	Indirect Air Optimisation with Excool	Direct Air Optimisation	Chilled Water	OPTION X	OPTION X	
RESILIENCE	RELIABILITY	5	8	7	6	0	0	
	EASE OF MAINTENANCE	5	7	6	4	0	0	
	HISTORIC OPERATION	5	1	7	10	0	0	
	DESIGN LIFE	5	8	7	5	0	0	
	Sub-total	20	120	135	125	0	0	
TECHNICAL PERFORMANCE	LOAD HANDLING	5	9	8	6	0	0	
	TOLERANCES	5	8	6	8	0	0	
	FLEXIBILITY OF USE	5	5	5	7	0	0	
	SPATIAL TAKE	5	8	8	5	0	0	
	CONTAMINATION RISK	5	7	4	7	0	0	
	Sub-total	25	185	155	165	0	0	
COST OVER LIFE	CAPITAL COST	5	6	6	4	0	0	
	MAINTENANCE COST	5	7	6	8	0	0	
	ENERGY CONSUMPTION COST	5	10	7	5	0	0	
	WATER CONSUMPTION	5	3	7	10	0	0	
	RELATED BUILDING COST	5	6	8	5	0	0	
	Sub-total	25	160	170	160	0	0	
ENVIRONMENTAL	CARBON EMISSIONS	5	10	7	5	0	0	
	WATER USAGE	5	3	7	10	0	0	
	MANUFACTURE	5	8	7	4	0	0	
	NOISE EMISSIONS	5	7	5	3	0	0	
	DISPOSAL	5	7	5	3	0	0	
	Sub-total	25	175	155	125	0	0	
PROGRAMME	PROCUREMENT	5	5	4	7	0	0	
	DESIGN	5	8	5	5	0	0	
	SPEED OF INSTALLATION	5	7	5	3	0	0	
	COMMISSIONING	5	8	7	4	0	0	
	Sub-total	20	140	105	95	0	0	
	TOTAL SCORE	115	780	720	670	0	0	
	TOTAL SCORE EXCL. COST		620	550	510	0	0	

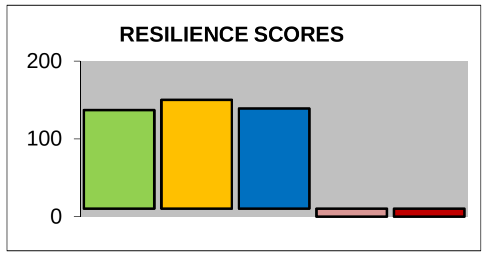
Excool

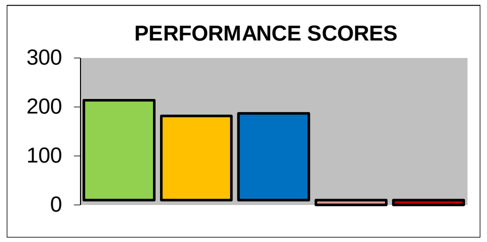
COMPARISON BASED ON WEIGHTINGS PRESCRIBED FOR A DATA CENTRE DEVELOPER TYPE CLIENT

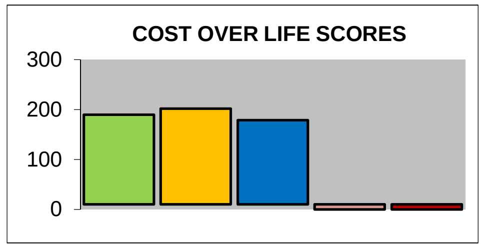
COMPARISON BASED ON WEIGHTINGS PRESCRIBED BY A DEVELOPER TYPE CLIENT

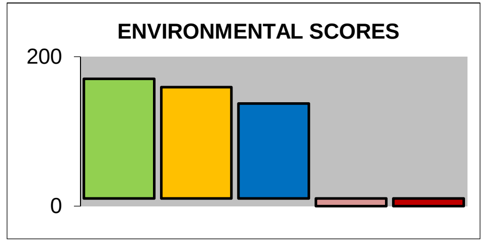
KEY CATEGORY	SUB-CATEGORY		OPTIONS				
		Client Weighting	Indirect Air Optimisation with Excool	Direct Air Optimisation	Chilled Water	OPTION X	OPTION X
RESILIENCE	RELIABILITY	8	8	7	6	0	0
	EASE OF MAINTENANCE	4	7	6	4	0	0
	HISTORIC OPERATION	5	1	7	10	0	0
	DESIGN LIFE	5	8	7	5	0	0
	Sub-total	22	137	150	139	0	0
TECHNICAL PERFORMANCE	LOAD HANDLING	6	9	8	6	0	0
	TOLERANCES	4	8	6	8	0	0
	FLEXIBILITY OF USE	6	5	5	7	0	0
	SPATIAL TAKE	7	8	8	5	0	0
	CONTAMINATION RISK	6	7	4	7	0	0
	Sub-total	29	214	182	187	0	0
COST OVER LIFE	CAPITAL COST	9	6	6	4	0	0
	MAINTENANCE COST	6	7	6	8	0	0
	ENERGY COST	4	10	7	5	0	0
	WATER CONSUMPTION	4	3	7	10	0	0
	RELATED BUILDING COST	7	6	8	5	0	0
	Sub-total	30	190	202	179	0	0
ENVIRONMENTAL	CARBON EMISSIONS	2	10	7	5	0	0
	WATER USAGE	7	3	7	10	0	0
	MANUFACTURE	3	8	7	4	0	0
	NOISE EMISSIONS	8	7	5	3	0	0
	DISPOSAL	7	7	5	3	0	0
	Sub-total	27	170	159	137	0	0
PROGRAMME	PROCUREMENT	8	5	4	7	0	0
	DESIGN	7	8	5	5	0	0
	SPEED OF INSTALLATION	9	7	5	3	0	0
	COMMISSIONING	9	8	7	4	0	0
	Sub-total	33	231	175	154	0	0
	TOTAL SCORE	141	942	868	796	0	0
	TOTAL SCORE EXCL. COST		752	666	617	0	0

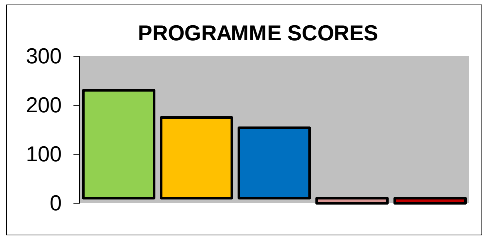












Excool

COMPARISON BASED ON WEIGHTINGS PRESCRIBED FOR A DATA CENTRE END USER TYPE CLIENT

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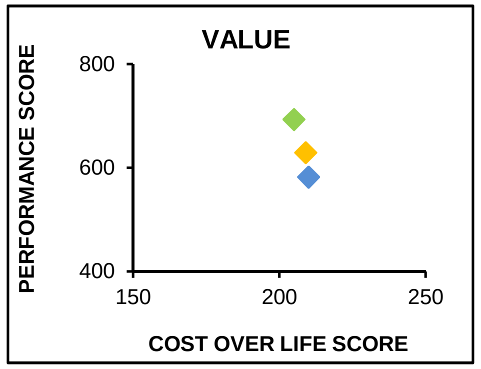
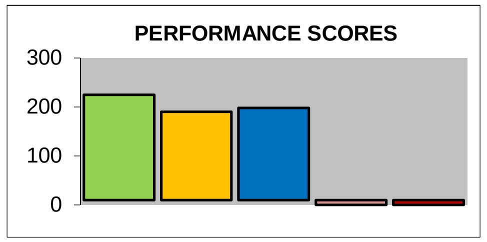
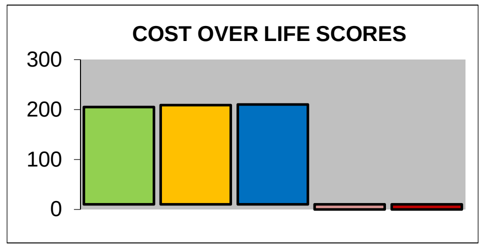
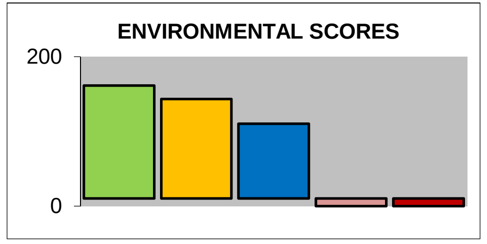
COMPARISON BASED ON WEIGHTINGS PRESCRIBED BY AN END USER TYPE CLIENT

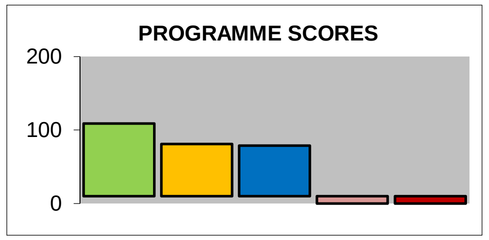
KEY CATEGORY	SUB-CATEGORY	Client Weighting	OPTIONS				
			Indirect Air Optimisation with Excool	Direct Air Optimisation	Chilled Water	OPTION X	OPTION X
RESILIENCE	RELIABILITY	9	8	7	6	0	0
	EASE OF MAINTENANCE	9	7	6	4	0	0
	HISTORIC OPERATION	7	1	7	10	0	0
	DESIGN LIFE	7	8	7	5	0	0
	Sub-total	32	198	215	195	0	0
TECHNICAL PERFORMANCE	LOAD HANDLING	8	9	8	6	0	0
	TOLERANCES	6	8	6	8	0	0
	FLEXIBILITY OF USE	6	5	5	7	0	0
	SPATIAL TAKE	5	8	8	5	0	0
	CONTAMINATION RISK	5	7	4	7	0	0
	Sub-total	30	225	190	198	0	0
COST OVER LIFE	CAPITAL COST	4	6	6	4	0	0
	MAINTENANCE COST	8	7	6	8	0	0
	ENERGY COST	8	10	7	5	0	0
	WATER CONSUMPTION	7	3	7	10	0	0
	RELATED BUILDING COST	4	6	8	5	0	0
	Sub-total	31	205	209	210	0	0
ENVIRONMENTAL	CARBON EMISSIONS	3	10	7	5	0	0
	WATER USAGE	4	3	7	10	0	0
	MANUFACTURE	7	8	7	4	0	0
	NOISE EMISSIONS	5	7	5	3	0	0
	DISPOSAL	4	7	5	3	0	0
	Sub-total	23	161	143	110	0	0
PROGRAMME	PROCUREMENT	5	5	4	7	0	0
	DESIGN	4	8	5	5	0	0
	SPEED OF INSTALLATION	4	7	5	3	0	0
	COMMISSIONING	3	8	7	4	0	0
	Sub-total	16	109	81	79	0	0
	TOTAL SCORE	132	898	838	792	0	0
	TOTAL SCORE EXCL. COST		693	629	582	0	0











Excool