CUNDALL

Munters # Oasis™ Indirect Evaporative Cooler

Product Engineering Review

Desktop Study

Job No: 1005138

Latest Revision: R8

Date: 19 December 2012

CUNDALL

Document Quality Validation & History

Job Title		Oasis™ Indirect Evaporative Cooler			Job Number
Document Title		Desktop Study			1005138
Version / Revision	Date	Purpose of issue / description of revision / version Draft Issue			
RO	28/11/11		Prepared by	Checked by	Verified by
		Name	BJ/WS	MW	MRH
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Draft Issue			
R1	29/11/11		Prepared by	Checked by	Verified by
		Name	BJ/WS	MW	MRH
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Draft Issue			
R2	15/12/11		Prepared by	Checked by	Verified by
		Name	BJ/WS	MW	MRH
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Final issue			
R3	23/12/11		Prepared by	Checked by	Verified by
		Name	BJ/WS	MW	M
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Final Issue			
R4	25/01/12		Prepared by	Checked by	Verified by
		Name	BJ/WS	PL	MW
		Signature			

Version / Revision	Date	Purpose of issue / description of revision / version Draft Issue			
R5	30/01/12		Prepared by	Checked by	Verified by
		Name	BJ/WS	PL	MW
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Draft Issue			
R6	20/02/12		Prepared by	Checked by	Verified by
		Name	BJ/WS	PL	MW
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Final issue			
R7	31/08/12		Prepared by	Checked by	Verified by
		Name	BJ	PL	MW
		Signature			
Version / Revision	Date	Purpose of issue / description of revision / version Final Issue			
R8	19/12/12		Prepared by	Checked by	Verified by
		Name	WS	PL	MW
		Signature			

Contents

Introduction

1.0 Introduction

1.1 Background

This document describes the technical theory behind Indirect Air Optimisation (IAO), with specific reference to the Munters Oasis™ Indirect Evaporative Cooler (IEC). This is an alternative to the traditional data centre cooling arrangement that consists of a chilled water system utilising chillers and CRAC units.

The preliminary function of this document is to provide an engineering review of the Oasis product and its modes of operation, with reference to operating energy consumption in comparison with traditional cooling approaches.

This document is an update of the first engineering review issued in February 2012. The first report was based on data collected from the Munters, their selection tool and historical data from sites in the US, which has subsequently been proved to be conservative, as the European Oasis IEC has been developed. Following completion of the European prototype and test programme, a revised selection tool is available with improved input data.

The European unit is a modular design which has now been fitted with more efficient fans, motors and compressors. The internal airflow configuration has been re-worked to reduce pressure drop. This has been proven via an independent 200 point pressure test, and is in addition to an independent heat exchanger efficiency test.

By selecting five 300kW units rather than the previous six 200kW units, Munters would like to demonstrate the improvement in operational costs with a small increase in capital costs. This selection represents a more realistic approach to a 1MW data hall with the new product range available.

In addition to the previous locations analysed, Istanbul has been added to assess the units suitability in this area. Imagery has been updated and a DCiE curve has been produced to highlight the units efficiency at part load.

Revision 8 of the report includes analysis for Frankfurt.

1.2 Brief Overview of Oasis™ Indirect Evaporative Cooler

An IAO (equally known as air-side economisation) is a strategy that utilises the cooling effect of air that is saturated with various percentages of water. "Economisers are cooling technologies that take advantage of favourable outdoor conditions to provide partial or full cooling without using the energy of a refrigeration cycle"[1]

The Oasis™ Indirect Evaporative Cooler has been designed in response to the growing demand from data centre owners, operators and designers for a highly efficient cooling strategy. A number of factors such as energy costs, sustainability policy and increasing IT densities has provoked this shift away from traditional

nergy
water
uses

- Low ambient - Air to air heat exchange, no supplemental cooling
- Medium ambient - Air to air heat exchange with evaporative cooling
- High ambient - Air to air heat exchange with evaporative and mechanical cooling

In recent years a number of IAO cooling units have come to market promising reduced PUE figures by reducing the energy losses consumed by mechanical plant. This method of cooling has emerged as a development from direct air optimised (DAO) cooling. Whilst DAO remains a credible method of cooling, IAO has the added advantage of circulating the data hall process air in a sealed environment, therefore reducing the risk of external contamination and humidity control issues. IAO systems also have less stringent filtration requirements that reduces both the static pressure loss of fans and maintenance requirements.

The Oasis™ Indirect Evaporative Cooler has been developed following the principles of IAO cooling. It incorporates a patented evaporative polymer heat exchanger system that uses evaporative cooling and keeps data hall and outside air separated.

The Oasis™ Indirect Evaporative Cooler overcomes the inherent inefficiencies of a chilled water system that arise from the gas to liquid to gas heat exchanges and the necessity to circulate an intermediate cooling medium. The unit has also been designed to deliver air at increased supply temperatures to maximise ambient cooling.

Both DAO and IAO systems can incorporate a back-up mechanical cooling system to be used when external ambient conditions rise above the temperature at which air can be delivered to the servers within permissible levels. DAO has been the first derivative of this technology to gain market acceptance. The primary reasons why attention has shifted to IAO are humidity control and the risk of external contaminants.

1.3 Site Considerations

This report will consider the operating characteristics of the Oasis™ Indirect Evaporative Cooler in a typical data centre application. This report covers the following regions:

- London Heathrow
- Madrid
- Abu Dhabi
- Beijing
- Shanghai
- Moscow
- Istanbul
- Frankfurt

The Oasis™ Indirect Evaporative Cooler system is designed to be applied throughout the world, but its operational efficiency will be dependent on local ambient conditions. The governing factor that determines the units mode of operation is the ambient wet bulb (wb) temperature. The wb temperature is the lowest temperature that can be reached by the evaporation of water, most commonly encountered on wet skin when you sweat or come out of the shower. In dry air there is a lower moisture content and therefore greater potential for evaporative cooling, a process that adds moisture to the air to increase its relative humidity and decreases the corresponding achievable dry bulb temperature.

In hot humid climates with a high relative humidity, the air becomes fully saturated reducing the effect of evaporative cooling. At this point mechanical cooling is activated to supplement the required cooling.

The plots below indicate the typical annual temperature frequency profile for all six locations

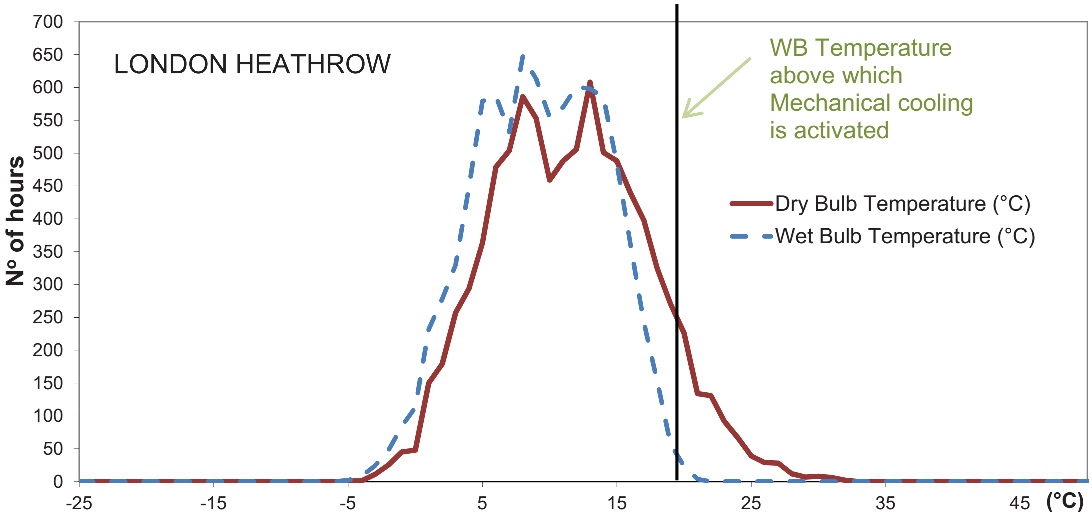


Figure 1.1: Typical Annual Temperature Frequency Profile for London Heathrow.

Evaporative cooling produces sufficient cooling capacity for the vast majority of the year, DX cooling likely to be required <50h per typical year.

Low dry and wet bulb temperatures during majority of the year permit the scavenger air fan to modulate down.

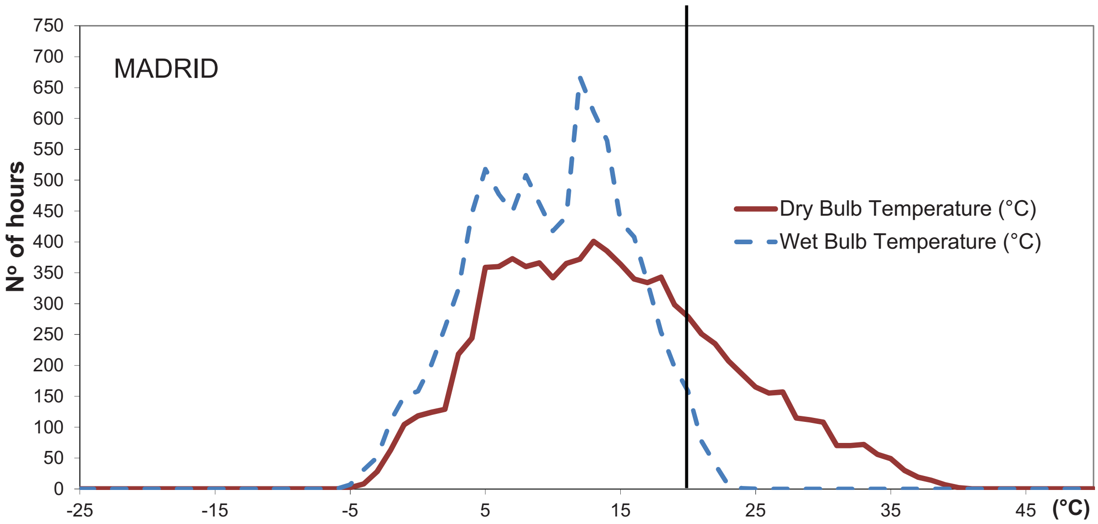


Figure 1.2: Typical Annual Temperature Frequency Profile for Madrid.

Although dry bulb temperature is much higher than for the London area, the range of wet bulb temperatures suggest similar operation of the system as for London. DX cooling likely to be required <300h per typical year.

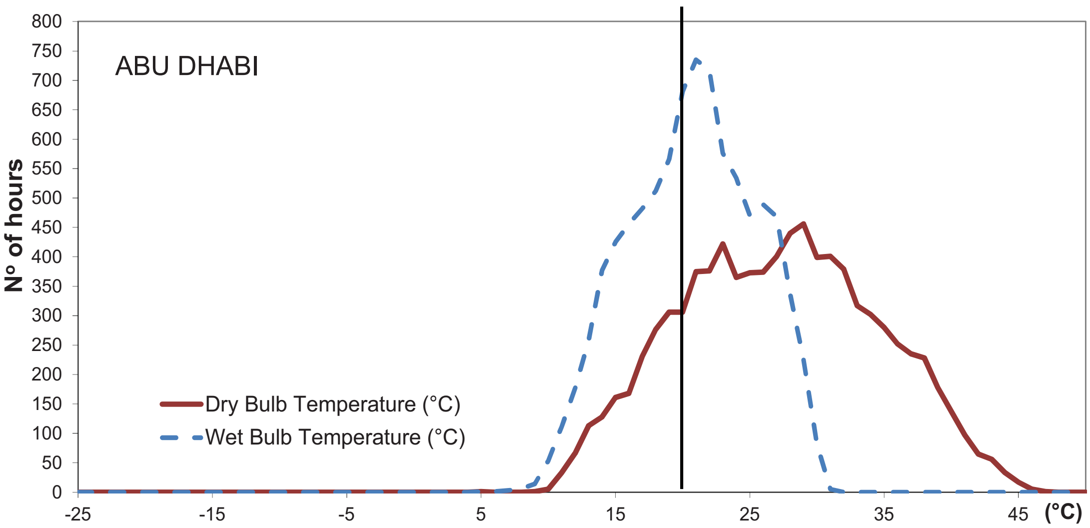


Figure 1.3: Typical Annual Temperature Frequency Profile for Abu Dhabi.

Evaporative cooling will provide sufficient cooling during ~40% of the year. For the remainder of the year DX cooling will need to cover additional cooling requirement.

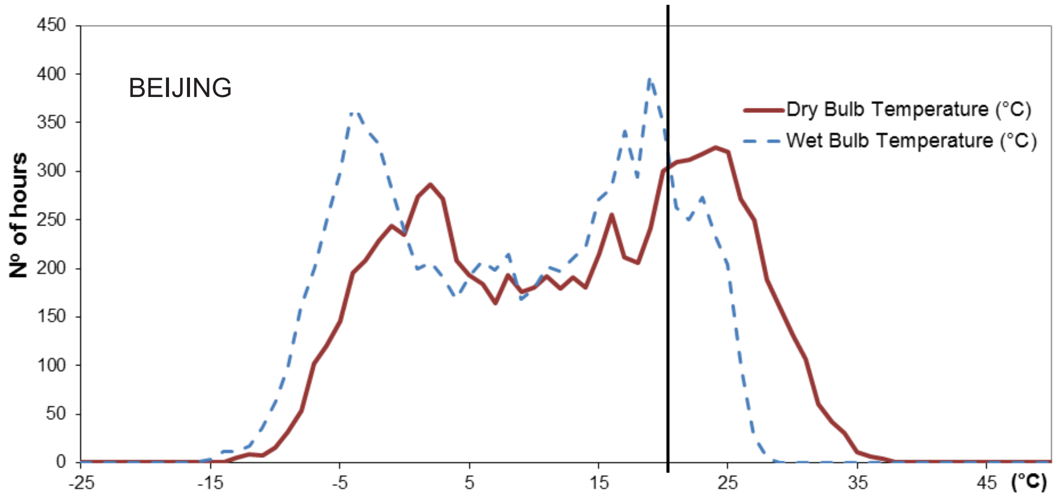


Figure 1.4: Typical Annual Temperature Frequency Profile for Beijing.

Wet bulb temperature is below the set point temperature for majority of the year, however, DX cooling will be active for ~1500h during a typical year.

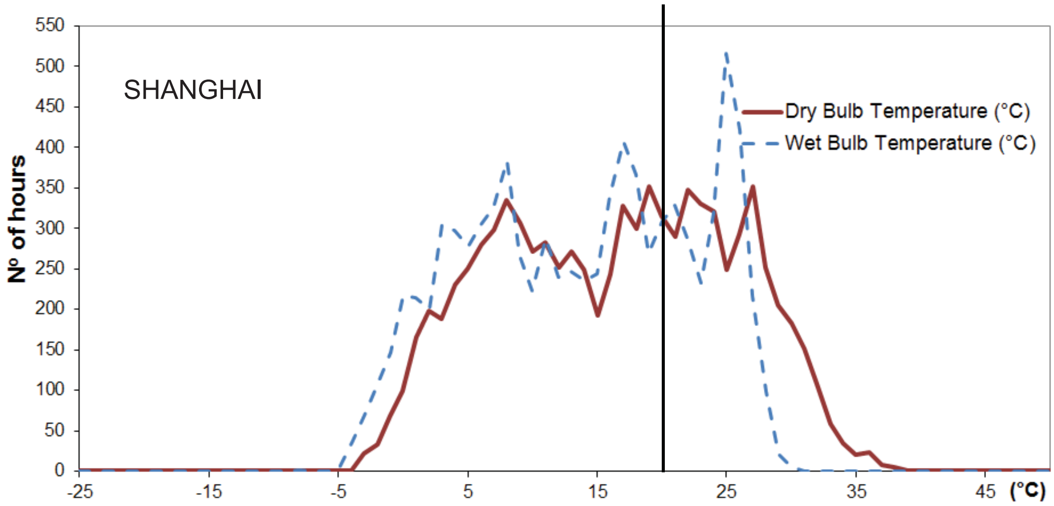


Figure 1.5: Typical Annual Temperature Frequency Profile for Shanghai.

Tight correlation of the dry and wet bulb temperature means a limited benefit from evaporative cooling. DX cooling will be required for ~2600h during a typical year.

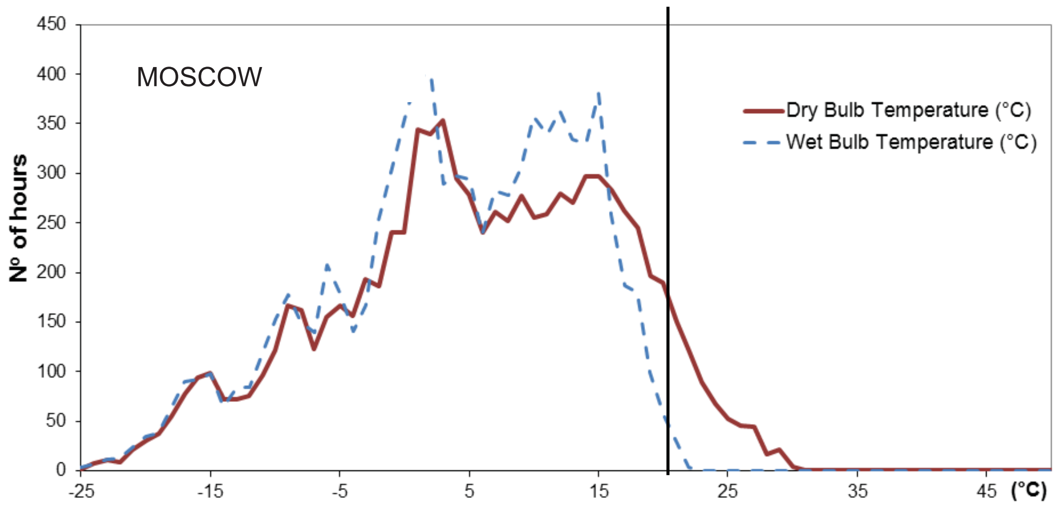


Figure 1.6: Typical Annual Temperature Frequency Profile for Moscow.

Low humidity during the summer period makes evaporative cooling very efficient, DX cooling will be required for <100h during a typical year.

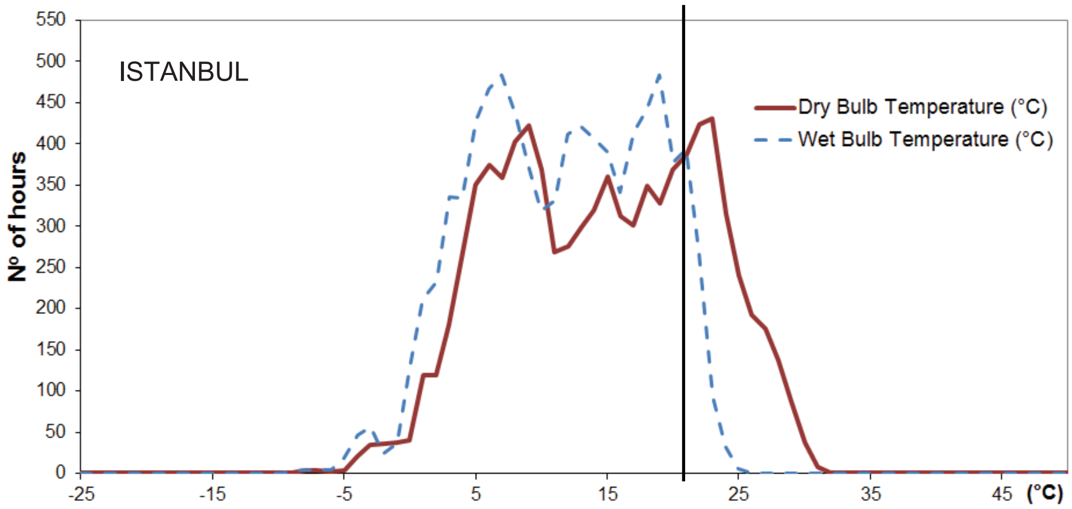


Figure 1.7: Typical Annual Temperature Frequency Profile for Istanbul.

The wet bulb temperature will be above the saturation point for >900h, above which DX cooling will be required.

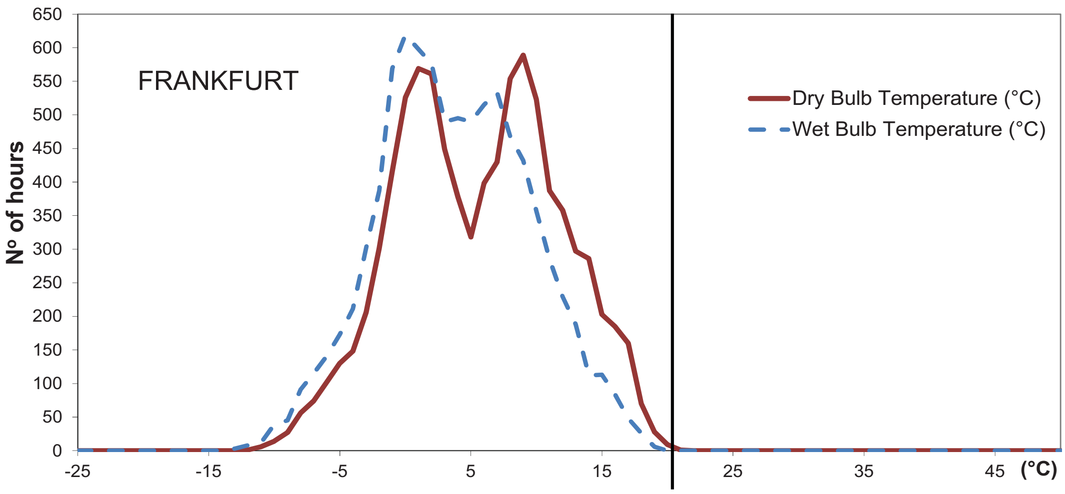


Figure 1.8: Typical Annual Temperature Frequency Profile for Frankfurt.

The wet bulb temperature will not exceed saturation point during typical year, minimising the use of DX cooling to few hours per year.

2.0 Data Centre Cooling Principles

2.1 Introduction

This section starts by outlining the traditional ideas of data centre cooling, and then presents the concept of IAO, before giving an outline of the main components of the cooling system, manufacturer options, and modes of operation. As part of this review the operation of the Oasis product and its efficiency is assessed in accordance with Test Reference Year (TRY) weather data.

2.2 Data Centre Cooling Methods

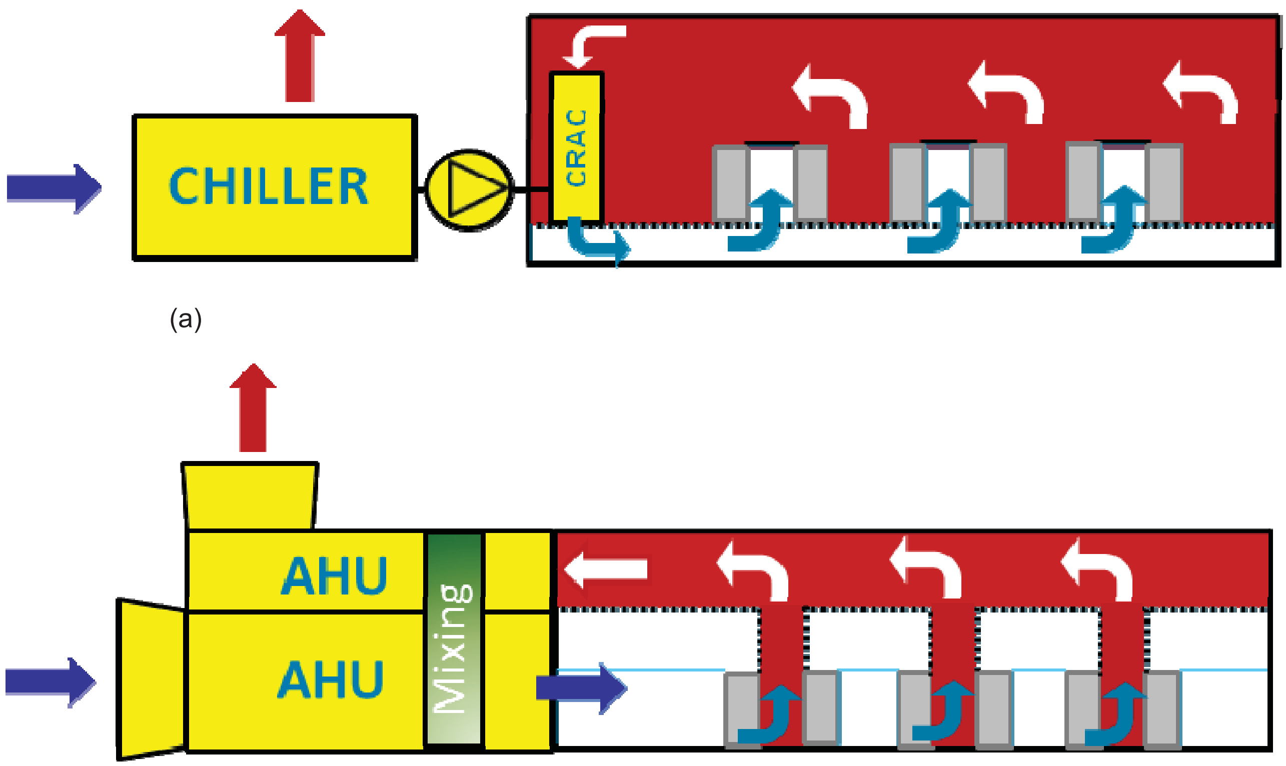
The increasing power consumption of data centres in today's market is well documented. In all cases the majority of data centre power is used to power the IT cabinets and data centre cooling plant. With high density blade servers being commonly implemented inside racks, it is not uncommon to find that the temperature rise across the inlet-outlet faces of a particular server approaches14°C (i.e. 20°C IN, 34°C OUT), although some manufacturers are quoting much higher allowable ΔT's. In more traditional data centres operating in full recirculation mode with CRACs, a considerable amount of energy is required to cool this hot exhaust air by 14°C. This traditional concept with CRACs, chillers and pumps is demonstrated in Figure 2.2(a). The inherent inefficiencies of a chilled water system come from the movement of three bodies of heat transfer medium (air, water and air), and the efficiency losses when transferring from one to the other. The introduction of a chiller refrigeration circuit exaggerates this effect further.

Fresh air cooling (i.e. no mechanical cooling) presents a viable option to reduce data centre power consumption, that moves on from the concept of closed circuit cooling (mechanical cooling), to utilising fresh air directly or indirectly to cool the space. DAO requires one medium of heat transfer and no heat exchanges (other than the heat exchange within the server). This type of system has been a precursor to IAO which requires two air mediums and one heat exchange.

Following the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) 2008 Technical Committee (TC 9.9) meeting, the extent of operating conditions for servers has been extended to allow for 18-27°C (DB), 5.5^{o}C dew point to 60% Relative Humidity (RH), at the server intake. It should be noted at this point that ASHRAE has issued an update to this standard [2011] whereby the window for allowable operating conditions has been extended to allow higher temperatures for limited periods of time. The move to widen the envelope from the 2008 standard has increased the interest in air-side economisation schemes, as the method can drastically reduce power consumption of cooling systems, and so the Power Usage Effectiveness (PUE) of data centres.

The concept behind a fresh air cooling strategy has been feasible but not widely accepted, due to the uneconomical number of hours temperatures would be above set points and possible variations in humidity, until ASHRAE extended the environmental window as noted above. Some of the early adaptors of this strategy deployed DAO approaches whereby the air was directly supplied to the data hall once it has been filtered and treated. This fresh air cooling strategy has been employed by some leading industry figures such as *Microsoft (Dublin facility), **Google and ***Yahoo (Lockport), thus demonstrating that this type of strategy is viable. The concept has suffered from fears over reliability, particularly the risk of an external contamination event, and an unwillingness to move away from proven methods. This has led to IAO being explored as a preferred cooling alternative.

* http://www.datacenterknowledge.com/inside-microsofts-dublin-mega-data-center/
** http://www.datacenterknowledge.com/archives/2009/07/15/googles-chiller-less-data-center/
*** http://www.datacenterknowledge.com/archives/2010/09/20/inside-the-yahoo-computing-coop/



(a)

(b)

Figure 2.2: Data Centre Cooling: (a) The traditional method with chillers and CRACs, (b) Direct fresh air optimised cooling DAO.

To date, the number of built direct or indirect air optimised data halls have been limited, although implemented by a number of industry leaders. A number of different solutions have been explored with DAO which are largely dependent of 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 2.2b). A third less frequent solution has also been implemented whereby air is delivered via a large floor void or plenum (****HP Wynyard Data Centre) which is then used to pressurise a system of enclosed cold aisles.

2.3 Indirect Air Optimisation

In the present case with IAO, a modular solution with the Munters patented Oasis™ Evaporative Polymer Exchanger (EPX), as shown in Figure 2.3, is explored where the data hall remains a sealed entity. In essence the heat from the data hall return air is rejected through to the external ambient via a evaporative polymer tube air to air heat exchanger, and cooled down to a suitable temperature for re-delivery into the data hall.

It has become common practice in the data centre industry to refer to this method of cooling as 'adiabatic cooling' but this is an incorrect statement. When a gas is compressed under adiabatic conditions, its pressure increases and its temperature rises without a gain or loss of any heat. Conversely, when a gas expands under adiabatic conditions, its pressure and temperature both decrease without the gain or loss of heat. This is not the case with IAO cooling.

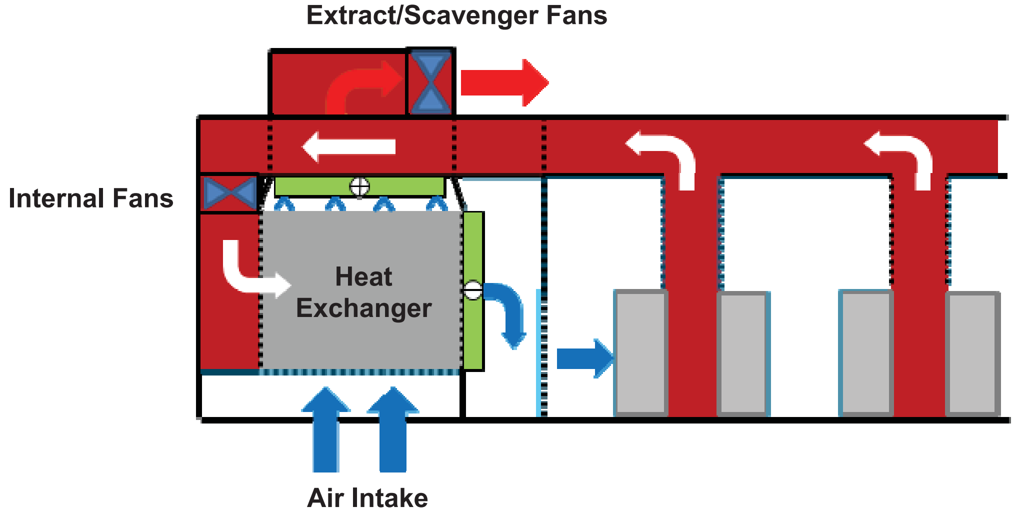


Figure 2.3: The application of Indirect Air Optimisation with Hot Aisle Containment (IAO).

2.4 Recognised Demand for Air-side Economisation Cooling Methods

It has been recognised that the power consumption of data centres is climbing at an exponential rate, with a conservative estimate putting UK maximum data centre power consumption at 6.44GW.[2] The cost of power is rising and is set to climb further as fossil fuels become depleted and carbon taxation climbs. Both of these factors are contributing to a drive to lower data centre power consumption and eliminate mechanical and electrical losses.

A range of technologies are now available to lower the losses associated with electrical distribution, UPS's, data hall configuration and heat dissipation systems. Economisers have been recognised as a key technology in this drive to lower PUE by eliminating the refrigeration cycle (for all but extreme design conditions). It is possible to build a data centre that can operate within ASHRAE 'Class 1' set points using IAO that does not require mechanical cooling in many regions of the world.[3]

A number of major air handling equipment and refrigeration manufacturers such as Munters have product offerings to meet this growing demand. The majority of these designs are based around the same principle of air to air heat exchange with evaporative cooling and mechanical cooling backup.

Considering the benefits of IAO, take-up has been relatively limited due to misunderstandings of how to correctly apply the technology, unfamiliarity and high initial costs[1]. IAO does offer a more scalable source of cooling that is better suited to modern demands for modular 'just in time' data centres.[4][5]

Early adopters such as large corporate self-build data centre users have recognised these advantages of improved PUE and scalability by completely reorganising their data centre portfolio. This can be an expensive investment, particularly at a time when credit is hard to come by.

As existing wholesale data centre stock becomes occupied, and developers look to expand their portfolio, it is the scalability of IAO, amongst many other reasons, that is making the technology more attractive than traditional chilled water. Once the building shell and basic infrastructure has been installed, cooling units can be procured and installed as the IT load increases. This is also true for chilled water but the initial investment is far higher.

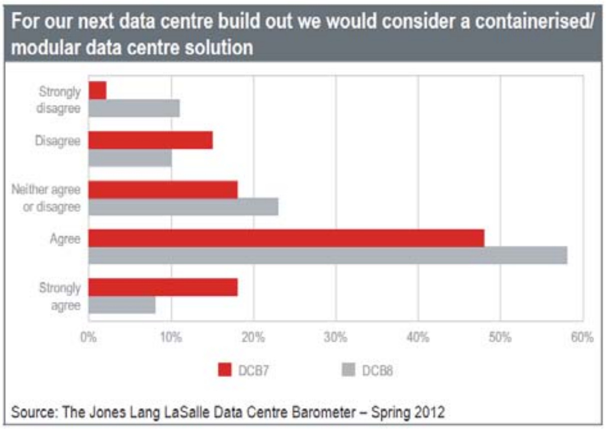


Figure 2.4: The Jones Laing LaSalle data centre barometer

The Jones Laing LaSalle survey shows that clients are increasingly considering modular scalable solutions[6]. Although this does not directly indorse IAO as a preferential technology, it does hint that technologies such as IAO which better lend themselves to modular design will become more attractive.

2.5 ASHRAE Compliance

Before discussing the Munters unit and its application to data centres in more detail, this section sheds more light on the ASHRAE recommended thermal conditions in Data Processing Environments.

Mission critical data centres necessitate stringent environmental control to meet the ‘Class 1’ ASHRAE guidelines. It is therefore widely accepted that the equipment air intake temperatures be maintained within the ASHRAE bands defined in Figure 2.5.1 (below).

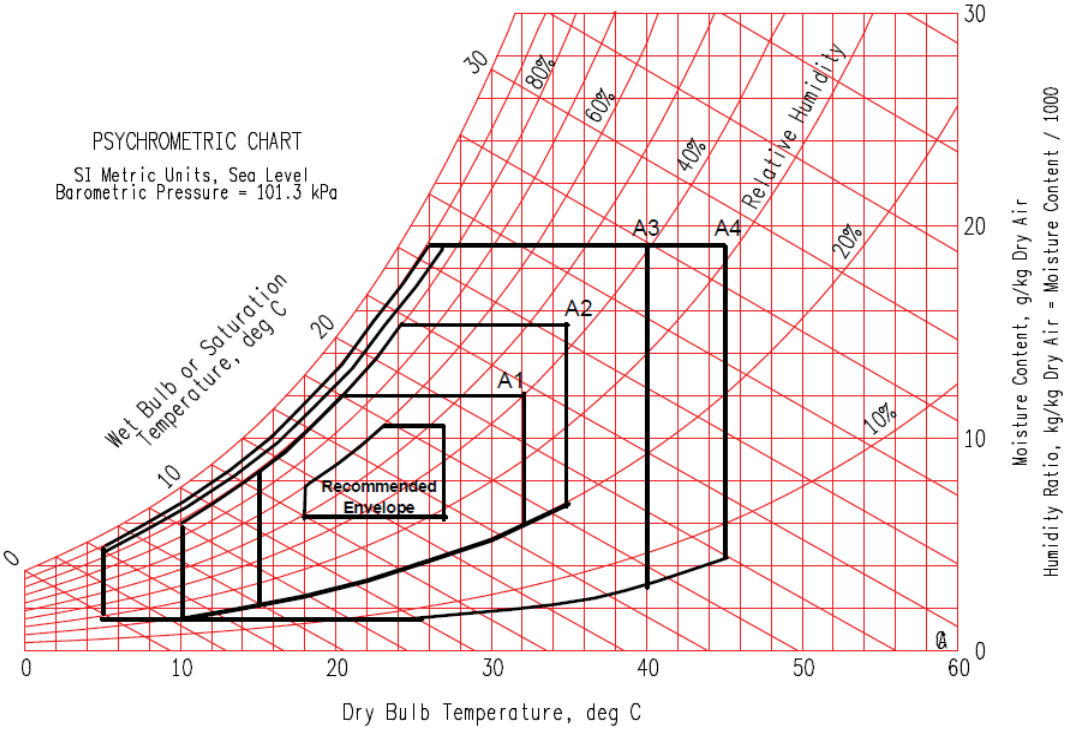


Figure 2.5.1: ASHRAE 2011 Environmental Classes for Data Centres

Taking a closer look at the guidelines for data processing environments, one can extract the ‘Reliability’ range of server air intake temperatures that is 18-27°C DB at 5.5°C dew point to 60% RH as shown in the ‘Class 1’ region in Figure 2.5.1. In the event of a cooling failure within the facility, ASHRAE defined the ‘Allowable’ range of server air intake temperatures, 15-32°C, that may be encountered by the IT equipment for short periods. It is required that the design satisfies the former band of temperatures during normal operation of the data centre, and maintains compliance with the maximum rate of change of 5°C and 5% RH per hour. These guidelines apply to IT equipment installed in all sizes of data centres as well as Comms rooms, regardless of the cooling strategies adopted.

The TRY weather profile for London Heathrow is displayed on the Psychrometric chart in Figure 2.5.2. Also plotted on the figure are the regions that define the operation of a typical DAO system. As can be seen, the Heathrow weather profile indicates an average cold/dry climate with temperatures peaking above 30°C for a few hours of the year. Note the figure indicates that the number of hours whereby the external ambient conditions satisfy ‘Class 1’ are limited, and that if DAO was to be implemented here, for a large number of hours during the year the ambient air would need to be put through a humidifier and subsequently mixed with data hall return air to achieve the ‘Class 1’ operating conditions. The data also indicates that for a number of hours during the year, a supplementary mechanical cooling and dehumidification system is required.

The data in Figure 2.5.2, may however favour the implementation of IAO. This is explored in more detail in Section 2.6, where the same psychometric analysis is illustrated for the application of the Munters product in this region.

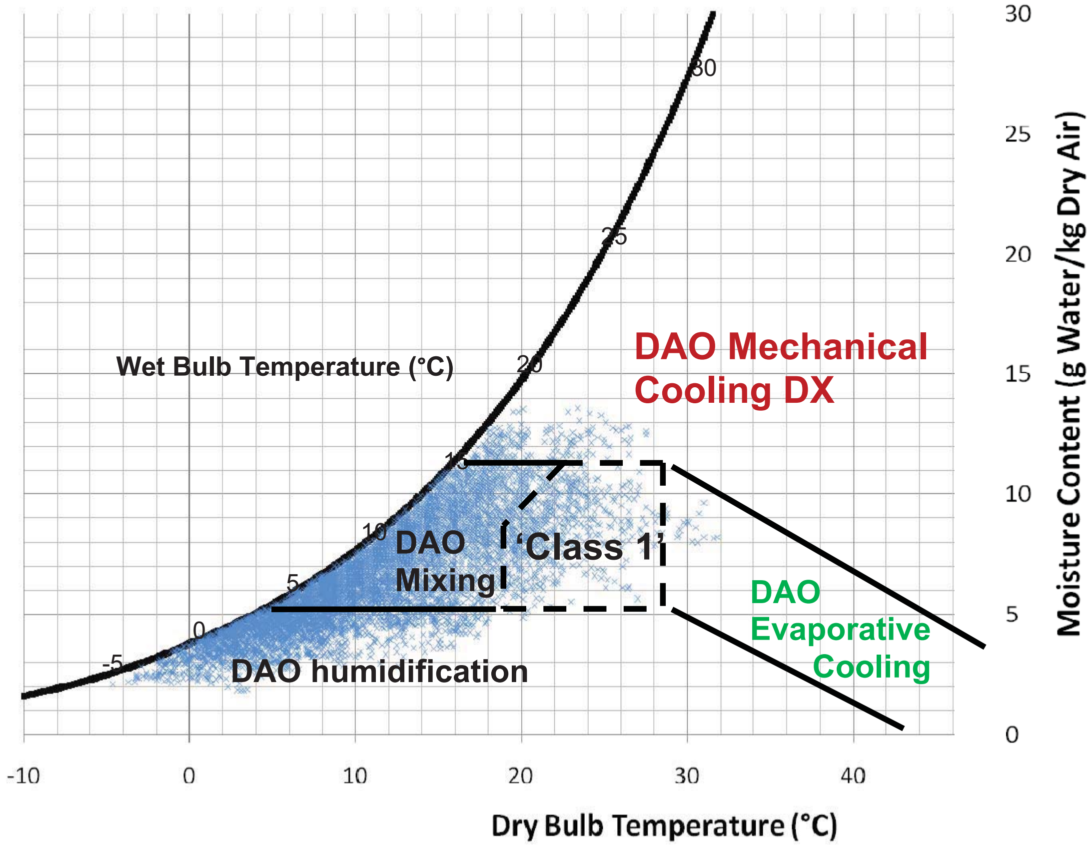


Figure 2.5.2: TRY Weather Data for London Heathrow and the implications of applying DAO in this region. The data is plotted on a Psychrometric chart that is overlaid with the ASHRAE ‘Class 1’ Zone.

2.6 IAO Using the OasisTM Indirect Evaporative Cooler

Based on information supplied by the manufacture, it can be seen from figure 2.6 that the majority of operating hours of the Oasis^{TM} Indirect Evaporative Cooler will require evaporative cooling or a combination of evaporative and mechanical cooling. Below approximately 5°C wb, the air is cold enough to cool the data centre through the polymer heat exchanger without supplementary cooling. The 19°C wb temperature at which mechanical cooling has to be engaged is limited to relatively few hours and will act as 'top-up' cooling to supplement the evaporative system.

It is important to note at this point that the mechanical cooling top-up is very different from the DAO system opposite whereby the mechanical cooling needs to be sized to accommodate the full cooling load due to recirculation mode.

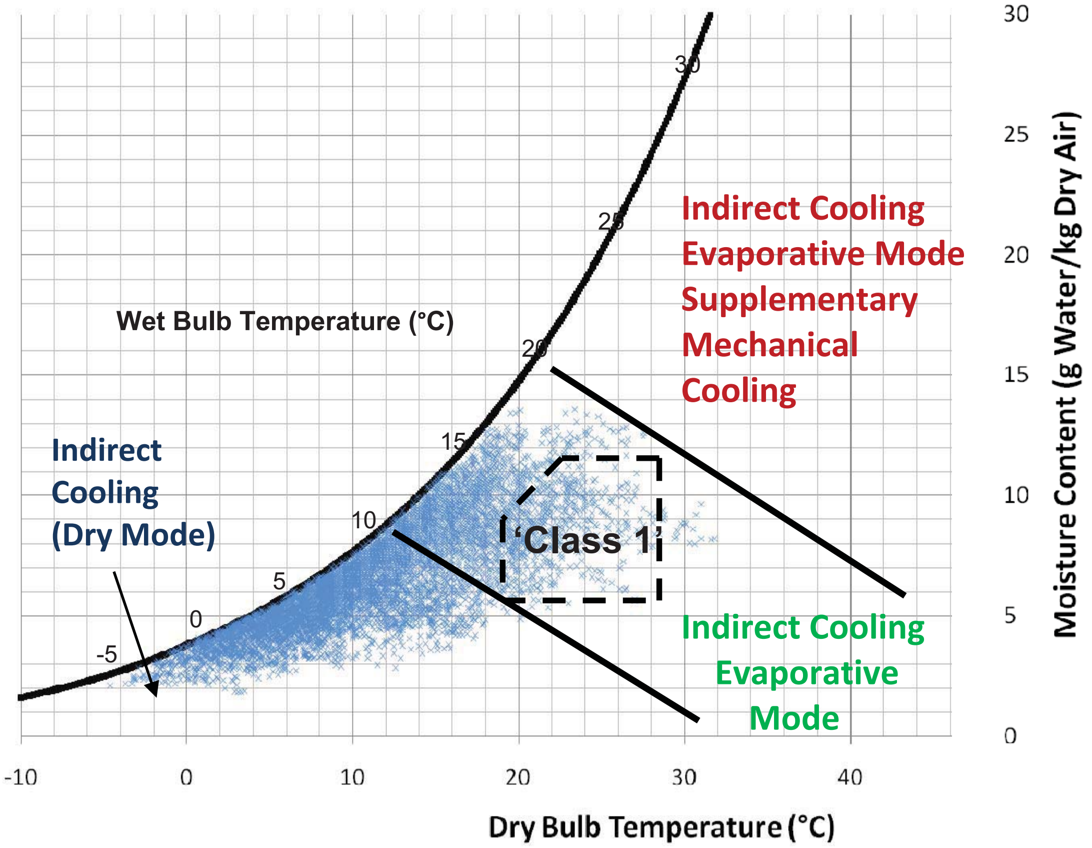


Figure 2.6: TRY Weather Data for London and the Implications of Applying Evaporative Cooling with Oasis in this Region.

IAO using the Oasis^{TM} Indirect Evaporative Cooler will eliminate the problems associated with external humidity entering the system. By segregating the air path into two separate circuits through a polymer tube heat exchanger, internal conditions can be closely controlled and external air humidity can be manipulated. A large percentage of the power used by DAO and IAO systems is attributed to fan power. DAO fans are used to draw external air through extensive filter banks, coils and dampers into the data hall with an additional fan used for extract. IAO fans are employed to move air through the heat exchanger, into the data hall and back to the IAO unit. External air is forced through the other side of the polymer tube heat exchanger and exhausted without treatment. An energy balance between the two air movement systems (DAO forcing air through extensive filters, IAO forcing air through both sides of a heat exchanger) can be a point of debate, with IAO having the additional benefits of humidity and pollutant segregation.

Any energy calculation comparing DAO and IAO also needs to take into account the excess energy consumed by either humidifying or dehumidifying the air. Subsequently, any cost analysis needs to consider the evaporated water costs and associated storage infrastructure.

CUNDALL

3.0 Cooling Unit Selection & Application

3.1 Oasis^{TM} Indirect Evaporative Cooler Configurations

In order to assess the Oasis^{TM} Indirect Evaporative Cooler performance, a typical unit selection is presented in Figures 3.1.1(a-c); details of which are tabulated in section 4.0 and appendix 8.1. The selection is based on a hypothetical scenario for a data hall IT load of 1000kW, which is to be supported by five Oasis^{TM} Indirect Evaporative Coolers at (N+1). This arrangement is shown in the proceeding sections in Figures 3.2(a-b).

Three unit sizes are available rated at 100kW, 200kW and 300kW. These units can be configured for top, bottom or front supply.

The selection presents a typical unit for the most efficient deployment in this test case, with efficient air flow management systems such as aisle containment to be employed in the data hall. The maximum air volume duty of the external scavenger fans for this selection is 68,000 m³/h (per unit) and the internal recirculation fans 56,785 m³/h (per unit), however, it must be emphasised that these are design maximum capacities and that during normal operation the scavenger air volume flow rates will reduce, as they are a function of the external ambient conditions.

The unit is designed to supply a constant volume of air into the data hall if IT load remains constant at a constant temperature. The supply fans are controlled by a pressure differential between the supply aisle and return plenum. The control strategy used to ensure constant supply temperature is by means of a combination of variable scavenger fan volume and variable mechanical cooling duty. Evaporative cooling is a fixed variable (on/off), that is self-scaling as evaporation rate is a function of ambient conditions. If ambient temperatures climb above the achievable evaporative cooling duty of the unit, then mechanical cooling can be scaled to 'top-up' the required duty.

Figure 3.1.1(a-c): 3D representation of a floor mounted Oasis^{TM} Indirect Evaporative Coolers 100kW to 300kW.

Figure 3.1.1(b):

Figure 3.1.1(c):

When making a selection for a particular location and application, the cost of electricity and water can be factored in to minimise the final operational costs. By raising or reducing the point at which evaporative cooling is activated, the amount of water and the amount of electricity consumed can be manipulated.

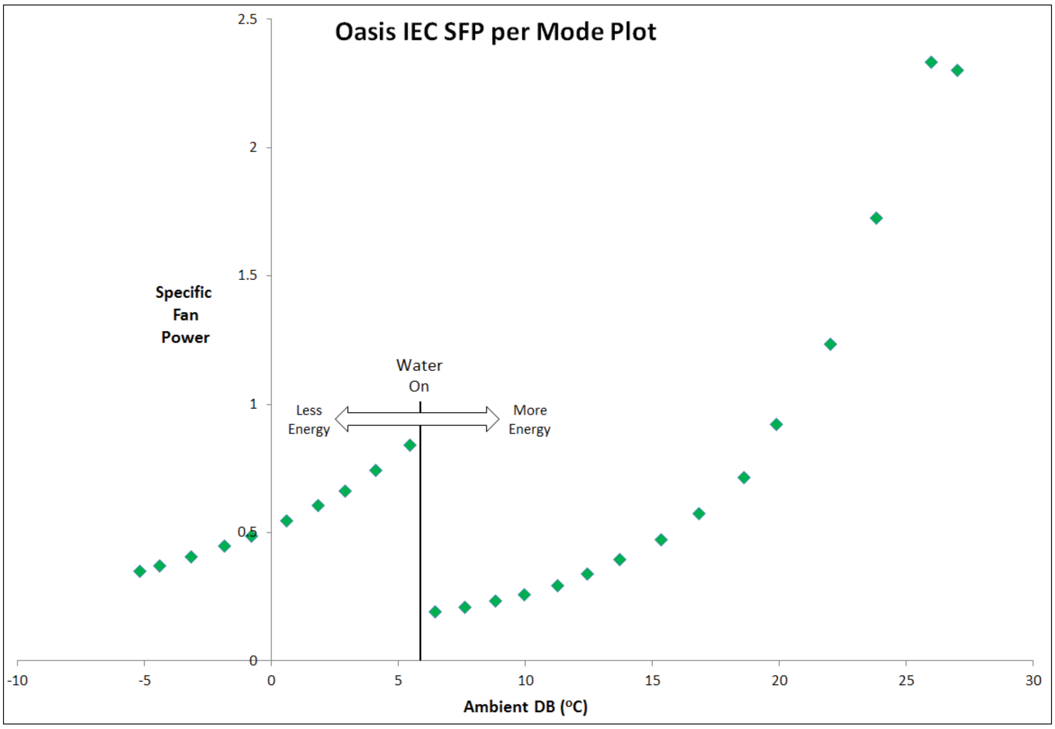


Figure 3.1.2: SFP vs ambient db plot through Oasis IEC

The unit can be configured to be roof or floor mounted. The process air enters the top of the unit and is drawn down by the fans and through the polymer tube heat exchanger. The process air then passes through an evaporator coil (if fitted), and out of the front or bottom of the unit into the data hall. Scavenger air is drawn into the base of the unit and up through the polymer tube heat exchanger by high level fans. Air leaving the heat exchanger passes through a mist eliminator and condenser before being exhausted.

The roof mounted unit (figure 3.1.1(c)) has its supply and return to the data hall at the base of the unit with scavenger air being pulled in from the side and exhausted out of the top. The unit is inherently flexible to the individual needs of a project.

Applicable to 100kW, 200kW and 300kW units

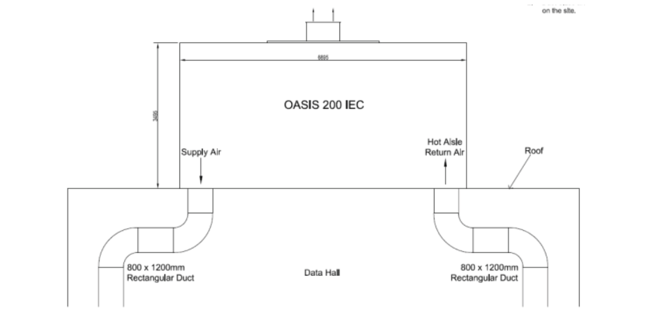
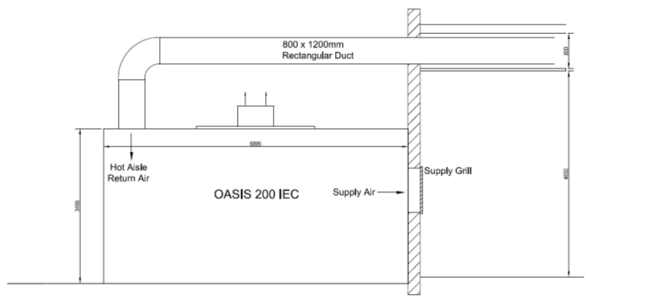
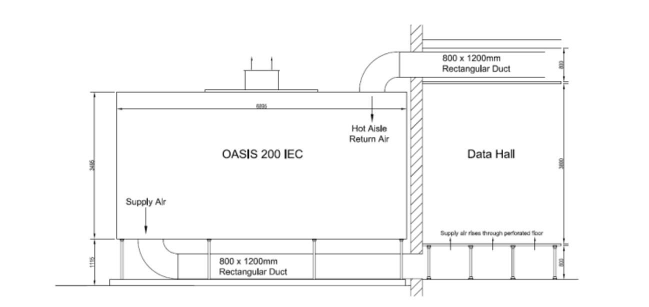
<table>
<tr><td>Roof Mounted</td><td>
</td></tr>
<tr><td>Side Mounted (Wall Supply)</td><td>
</td></tr>
<tr><td>Side Mounted (Duct Supply)</td><td>
</td></tr>
</table>

Figure 3.1.3: Example Oasis IEC arrangements

The Oasis™ Indirect Evaporative Cooler uses a patented evaporative polymer tube heat exchanger module (figure 3.1.4(a-b)) that is the heart of the Oasis cooling philosophy. The number of modules within a unit will vary depending on its rating. Multiple polymer ribbed tubes mounted in an aluminium frame create a large surface area for heat transfer to take place. The tube profile causes a large degree of turbulence in the air stream that improves heat transfer but increases static pressure loss. It should be noted that the pressure loss, and the required fan power, across this type of heat exchanger is significantly less than a tightly fitted plate design. The polymer tubes and the aluminium housing that contains them provides excellent corrosion resistance in the harshest of environments. The water spray and welded stainless steel sump is a robust and reliable cooling method. Deposits that accumulate on the tubes during evaporation are dislodged by a pressure difference across the tubes causing them to vibrate.

The patented polymer tube heat exchanger is an innovative design that has already been manufactured and deployed. An increasing number of Munters clients requested additional performance verification from an external authority. Munters commissioned Intertek to verify the performance of a notional heat exchanger. This test confirmed the performance of the heat exchange system against figures quoted by Munters.

Intertek/ETL Certified Test Data

For

Munters EPX® Indirect Evaporative Heat Exchanger

Compiled From

Intertek Report No. 100484062CRT-001
October 31, 2011

Efficiency figures for the polymer tube heat exchanger from the manufacturer state that when running dry, the heat exchanger is up to 56.6% efficient. This figure then climbs to a maximum 83.5% when wetted and with increased scavenger air flow.

Mains, grey or harvested water that has been suitably treated can be used for evaporative cooling as opposed to other units with misting that require a mains supply. The chemical make-up of the water changes as the evaporation process progresses. Dirty air that passes through the heat exchanger will also contain contaminants such as pollen and dust that are deposited and washed into the sump. Automatic controls constantly measure the water content and are designed to dump the sump water when calcium content climbs above a set point.

As with any evaporative cooler, the reuse of water used for evaporative cooling needs to be monitored and managed to ensure no outbreaks of legionella occur. Legionella typically enters the system via potable make-up water for the evaporation process. The legionella bacteria then requires certain conditions for concentrations to increase. The Oasis™ Indirect Evaporative Cooler maintains the water in a dark environment, light being an essential component for legionella growth. Water within the unit is continuously moving, eliminating any stagnant water needed for legionella to grow. Sump water temperature is also monitored and dumped if it climbs too high or is left standing for too long. Regular cleaning and drying out of the unit kills any bacteria that might be present and removes any accumulated nutrients.

Munters have commissioned an independent report ' Legionella Risk Analysis, Installation of Oasis IEC' compiled by Vincotte Environmental, with a copy available on request.

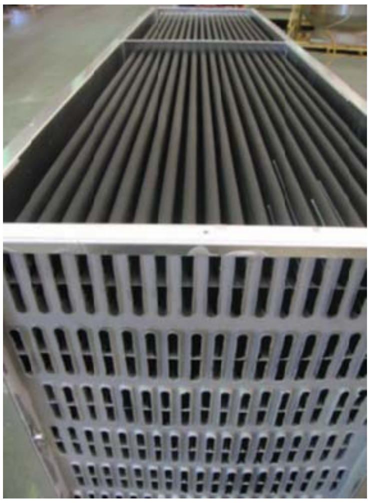


Figure 3.1.4(a-b): Polymer tube heat exchanger detailed view

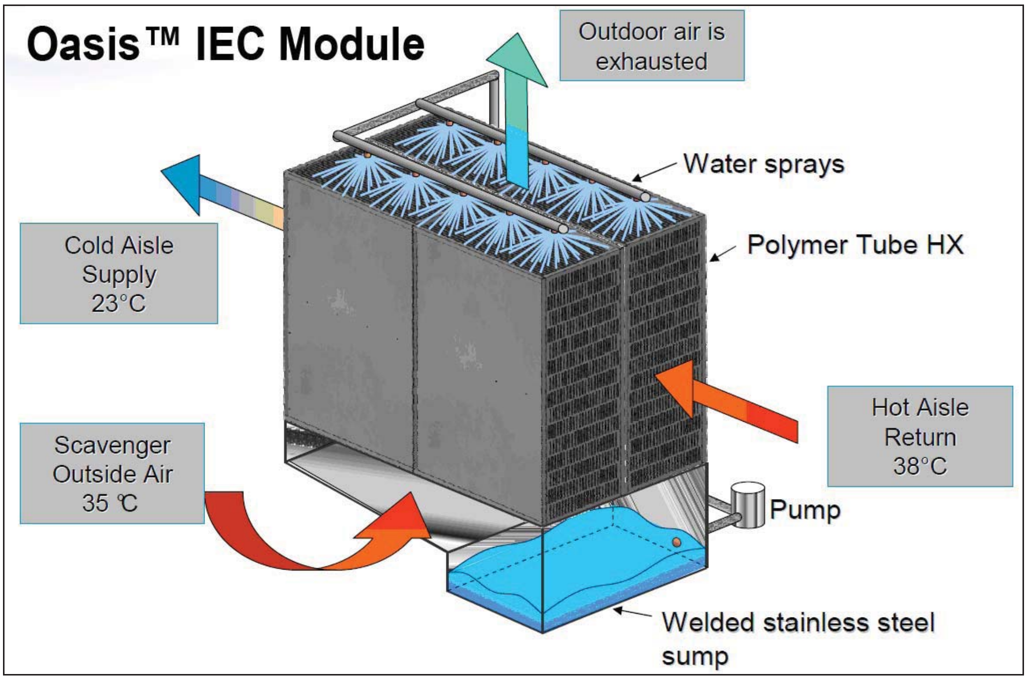


Figure 3.1.5: Oasis™ Indirect Evaporative Cooler polymer heat exchanger function diagram

The unit and its various functions can be viewed in operation at www.munters.com/oasisvideo

Some images showing the internal cooling mechanism of the unit are given in Figure 3.1.6(a-b)

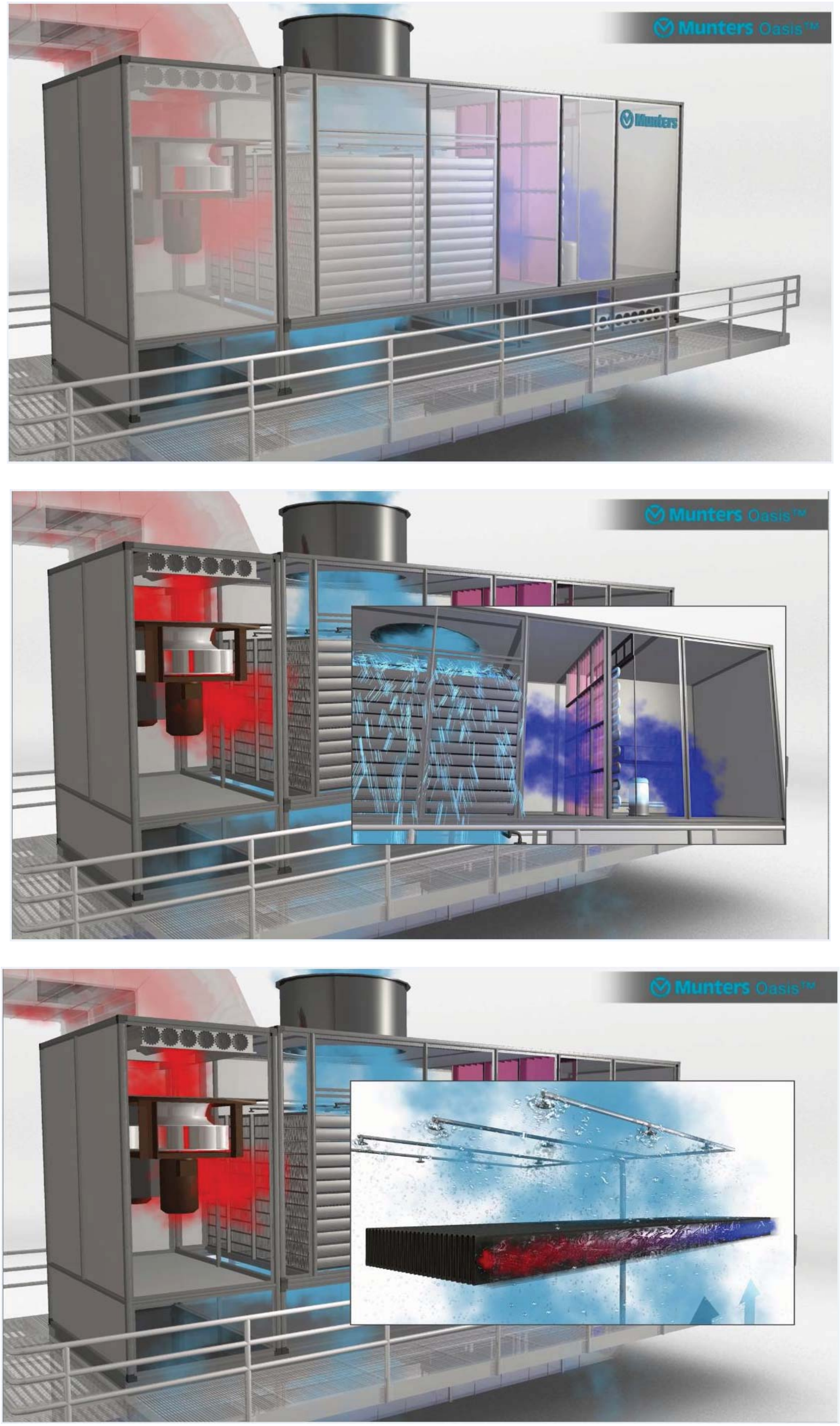


Figure 3.1.6(a-b)

3.2 Oasis™ Indirect Evaporative Cooler Test Case Layouts

To assess the spatial take of the two deployment strategies considered (floor and roof), a hypothetical layout of the main cooling plant is shown in Figure 3.2(a-b). Two Oasis™ Indirect Evaporative Cooler configurations have been illustrated to highlight the inherent flexibility of the roof or ground mounted system. As shown in Figure 3.2(a) and 3.2(b) both IAO solutions require dedicated water storage. However, the spatial coverage of the cooling plant for the roof mounted option is significantly reduced. This option will obviously increase the height of the building and the structural requirements of the building.

The purpose of this study is to compare the Oasis product in a typical data centre application against a typical free-cooling chilled water system. DAO has been referred to thus far due to its relevance as an alternative to IAO and its place as a precursor to IAO is worth noting. The remainder of this report will focus on the Oasis™ Indirect Evaporative Cooler unit verses free-cooling chilled water.

Smaller Munters Units

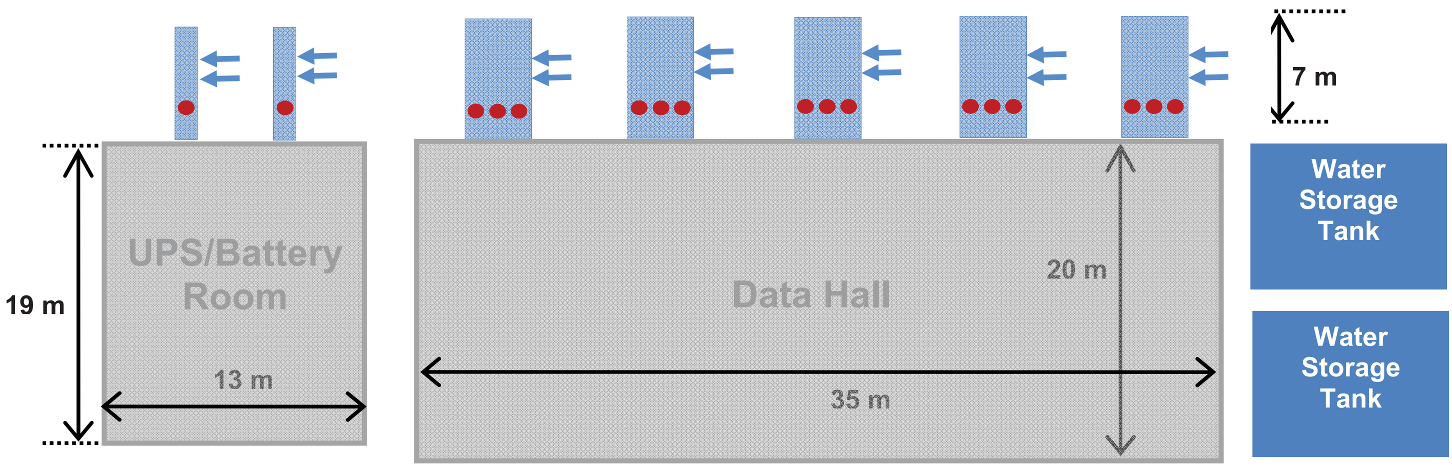


Figure 3.2(a)

Smaller Munters Units

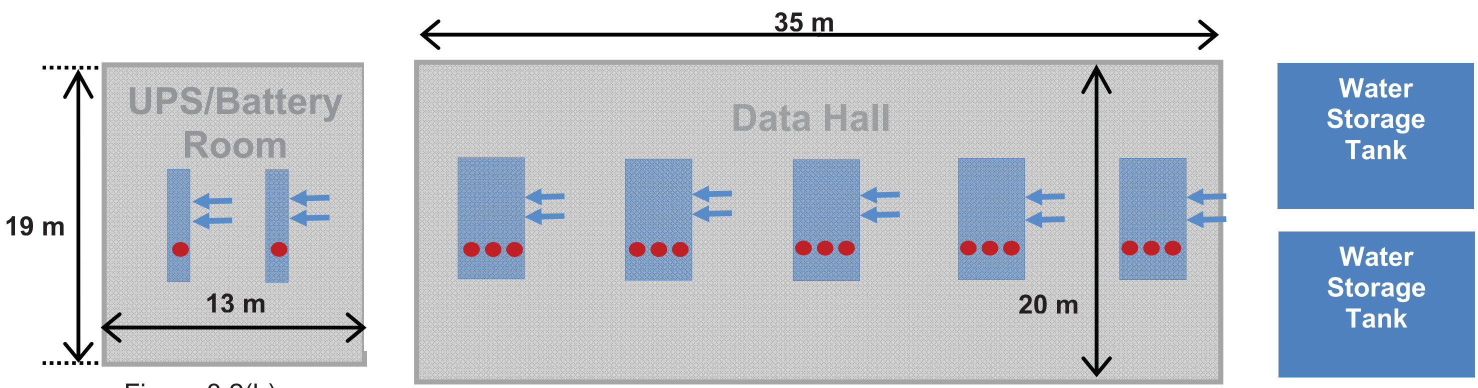


Figure 3.2(b)

Figure 3.2: Typical Cooling Plant Arrangement to Deliver 1MW of Cooling Across a 700m² Data Hall for: (a) IAO cooling using Oasis™ Indirect Evaporative Cooler (floor mounted), (b) IAO using Oasis™ Indirect Evaporative Cooler (roof mounted)

3.3 Free-Cooling Chilled Water Test Case Layout

The free-cooling 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. Chillers and pumping equipment can be placed on the room to reduce the building footprint, but space for CRAC units will always need to be allowed for.

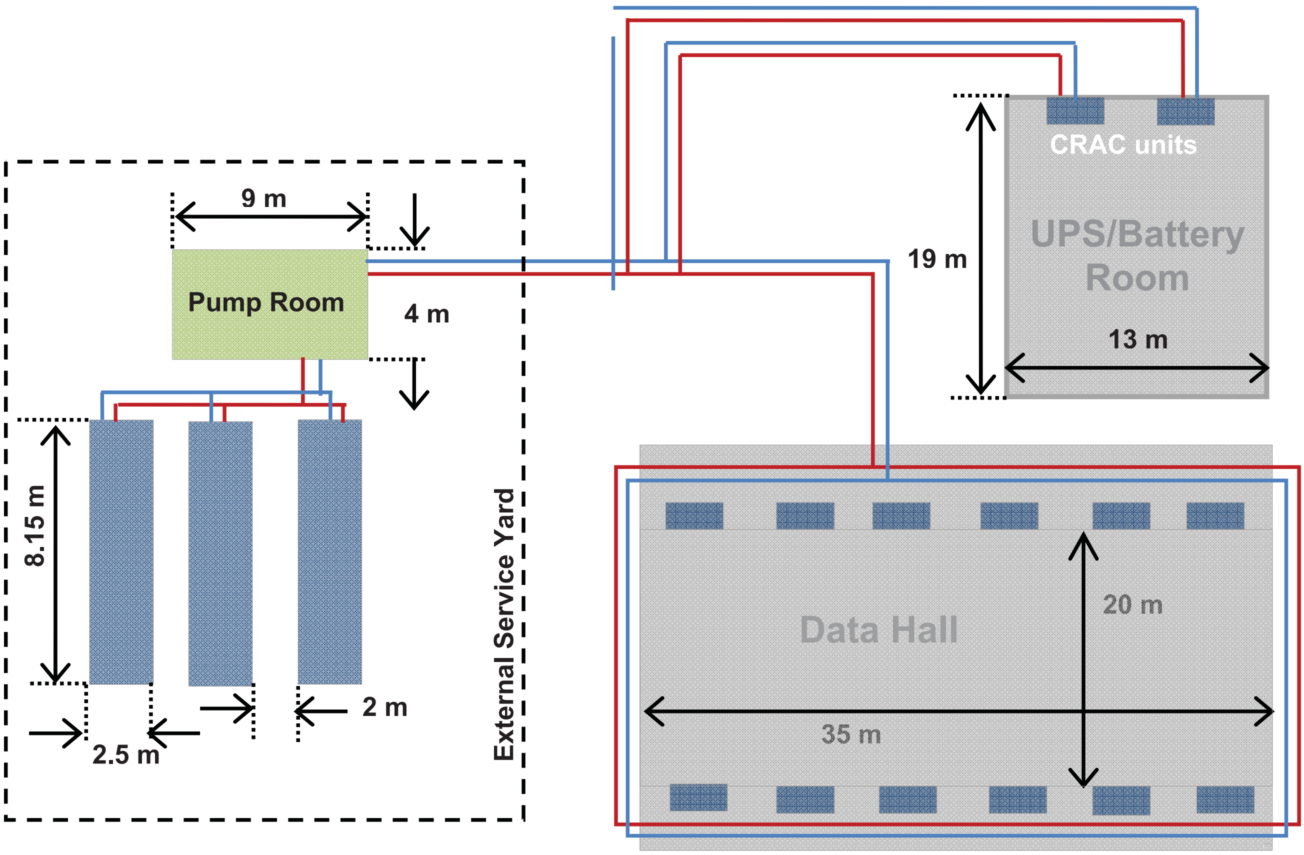


Figure 3.3: Typical cooling plant arrangement to deliver 1MW of cooling across a 700m² data hall for a chilled water system

3.4 Electrical Infrastructure Requirements

A chilled water data centre has a higher PUE than an IAO solution for reasons mentioned earlier in this report. With IT demand being a fixed load, higher PUE data centres will require additional power to support cooling systems such as chillers, pumps, CRAC units and ancillary equipment, as opposed to an IAO data centre that will require fans, a small amount of pump power, and potentially some DX cooling top up depending on location. This has several knock on cost saving effects.

An IAO site will need a smaller power supply than a chilled water equivalent, reducing utility costs of getting power to site and making more sites viable[7]. Transformer and generator ratings can be reduced along with switchgear and cable sizes. This will have obvious cost benefits as well as easing the construction process.

Alternatively, reducing the required power (per m^2)means that more IT space can be allocated for a given supply of power to site.

CUNDALL

Costs

4.0 Capital Costs

These costs are for guidance only and relate to the hypothetical test case.

For Indirect Air Optimisation using Oasis™ Indirect Evaporative Coolers, the costs relate to 5no. units for data hall cooling, 2 no. smaller Oasis™ Indirect Evaporative Coolers for UPS room cooling, and 4 water storage tanks in a 2N arrangement. 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.

System Descriptic	Main Cooling Plant	Capital Cost per unit (£)	Total Cost (£)
Oasis™ Indirect Evaporative Cooler (floor mounted)	Oasis unit (×5) Smaller Oasis units (×2) AHU (x1) Ductwork Water storage for 2no. tanks Total	£150k £87k £25k £50k £ for water tank £ for pumps £ for water treatment £4k for pipework = £24k	£750k £174k £25k £50k £48k **£1,047k**
Water-side Economisation Chilled Water	Free-Cooling Chillers(×3) CRAC units (×14) Pumps + Pipework + Ancillaries AHU (x1)	£132 £18k £350k £25K	£396k £253k £350k £40k **£1,039k**

Figure 4.0: Chilled water vs oasis IEC costs

Although the cost figures for the mechanical elements of the different options are similar, the increased power requirements for 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.

The distribution system used for a chilled water system is inherently more intensive than an air optimised solution. Installing pipework, pumps, pressurisation equipment, valves, connecting and commissioning equipment is more costly in terms of programme, labour and materials.

IAO systems require ducted air distribution from the external cooling unit to the floor void or room, and a return from the hot isles back to the cooling unit but this type of infrastructure is less extensive. This system is quicker, cheaper and simpler to install and requires minimal commissioning. With fewer constituent parts, single points of failure are reduced and on-going maintenance is simplified to a few moving parts. Commissioning of an IAO system, like a chilled water system, requires flushing and pressure testing. Air as the heat transfer medium reduces the risk and waste of this process. With fewer interfaces between heat transfer mediums, fewer systems need to be verified and the ASHRAE sequence of commissioning levels is reduced.

The Oasis unit is delivered pre-commissioned and tested. Final connection of the electrical power distribution system completes cooling system install, ready for calibration.

5.0 Energy Costs

The results below have been made for a number of locations including :

- London Heathrow
- Madrid,
- Abu Dhabi
- Beijing
- Shanghai
- Moscow
- Istanbul
- Frankfurt

The calculation is based on the 1MW data hall (1500W/m²). The supply/return temperature is assumed to be 25/39°C for Munters Oasis Option and for chilled water options (CHW flow/return is 15/20°C). The options with chilled water systems assume N+1(N=2) arrangement, with 2 chillers operating at their design load. The Munters Oasis option assumes N+1(N=4) arrangement, with 2 units equipped with additional filtration to clean the re-circulated air (25% of the total volume).

It is assumed for the purposes of this calculation that the data halls are fully loaded with the IT equipment and represents a static constant condition. It is assumed that load is uniformly distributed throughout the data hall.

Three chillers have been selected on the basis that although two can satisfy the cooling and resilience demand at N+1, the +1 unit would be greater in capacity than reverting to two smaller units to satisfy N with a smaller +1 unit.

The energy data given in the following sections are based on a theoretical model produced by Cundall to independently review energy consumption. The data can be seen as conservative when compared to Munters selection tool, see section 8.3.

5.1 London Heathrow

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 appendix 10 The data has been gathered using TRY weather data for London Heathrow.

Figure 5.1.1 below presents the comparison of the annual energy consumption for the two cooling strategies considered earlier but with the additional comparison of a standard air-cooled chiller.

The flat characteristic of the standard chillers is a result of the relatively constant chiller efficiency regardless of the ambient conditions, whilst the major benefit from free-cooling chillers is expected during the winter months. At the same time, free-cooling chiller efficiency is slightly lower than for standard chillers during design summer conditions and therefore their peak power consumption is higher. For the Oasis™ Indirect Evaporative Cooler option, process air fans are the main energy consumer and as they run at constant speed all year round, the overall energy consumption related to the Oasis™ Indirect Evaporative Cooler option is relatively constant.

The results indicate that the application of the Oasis™ Indirect Evaporative Cooler can bring significant energy savings over chillers thanks to reduced mechanical operating hours and increased set point temperatures. On the other hand, the pressure drop on the process air fans is significant which results in relatively high specific fan power (SFP) energy consumption figures for the recirculation fans.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.2**	**11.9**	**344**
	Total Cooling*	**3.3**	**5.5**	**29.7**
PUE (partial)**		**1.33**	**1.20**	**1.03**
Chiller Operating hours [h]		8760h	8760h	DX - 84h, Evaporative - 4235h
Energy Consumption [kWh]	Chiller + evaporative	1,774,103	776,906	26,884
	Fans (cooling only)	581,865	581,865	284,349
	Pumps	658,078	470,056	-
	Total	**3,014,046**	**1,828,828**	**311,233**
Annual Costs [£]***	Energy	180,843	109,730	18,674
	Water	0	0	2,687
	Total Costs	**180,843**	**109,730**	**21,361**
	Cost Savings [%]	0%	39%	88%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

Figure 5.1.2 opposite shows the comparison of the total annual costs of energy and water used. The costs of energy for the London area can be expected to be reduced by around 88% when compared to the standard chillers. It should also be noted that water consumption constitutes approximately 15% of the running costs of the Munters Oasis system, however, it may become a significant component of the annual bill, especially in arid climates.

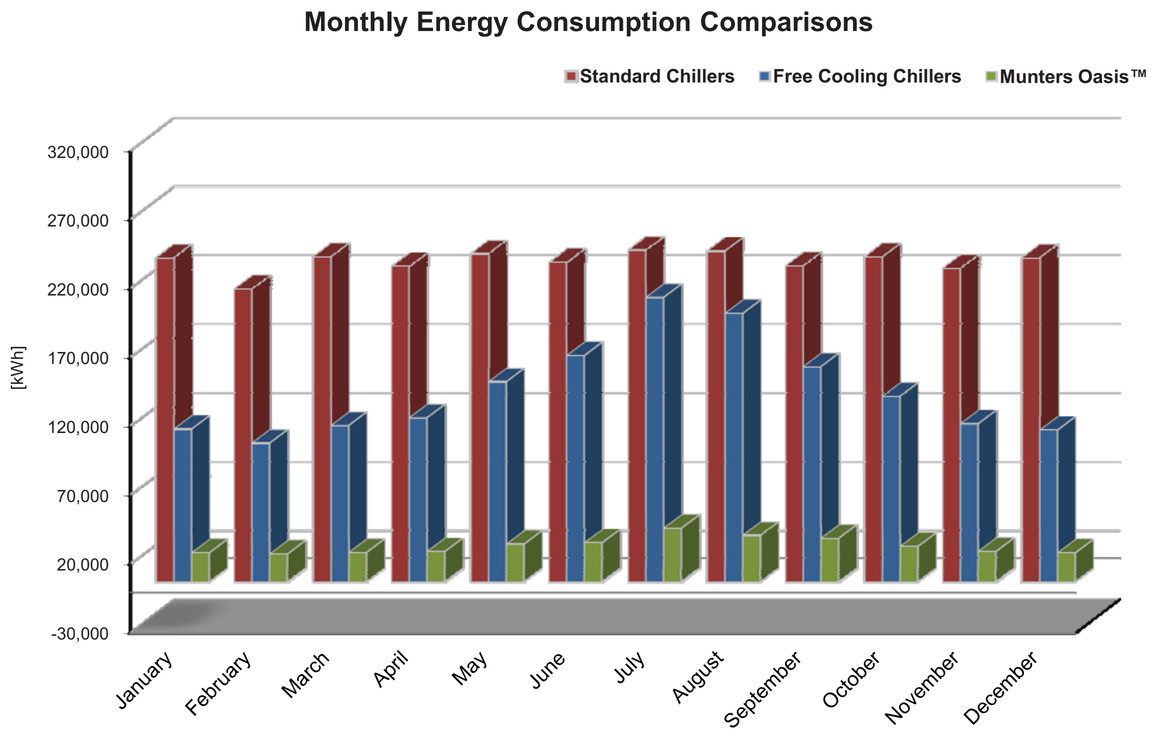


Figure 5.1.1: Annual Variation of Energy Consumption for all three cooling options considered for the London region.

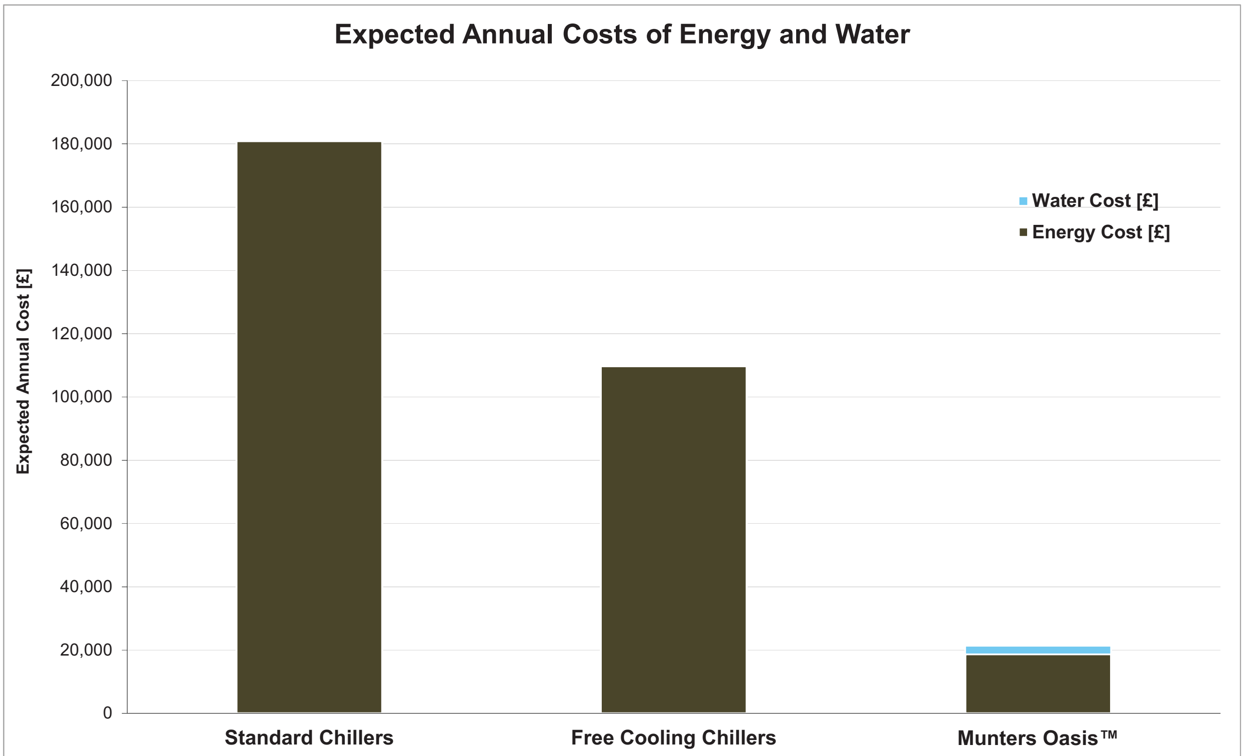


Figure 5.1.2. Total annual costs of energy and water consumed by the data hall.

5.2 Madrid

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 appendix 10. The data has been gathered using TRY weather data for Madrid.

<table>
<tr><th colspan="2"></th><th>Standard Chillers</th><th>Free Cooling Chillers</th><th>Munters Oasis™</th></tr>
<tr><td rowspan="2">Seasonal Cooling COP</td><td>Chiller + evaporative</td><td>5.1</td><td>8.9</td><td>301</td></tr>
<tr><td>Total Cooling*</td><td>3.3</td><td>4.8</td><td>26.4</td></tr>
<tr><td colspan="2">PUE (partial)**</td><td>1.33</td><td>1.22</td><td>1.04</td></tr>
<tr><td colspan="2">Chiller Operating hours [h]</td><td>8760h</td><td>8760h</td><td>DX - 478h,
Evaporative - 4608h</td></tr>
<tr><td rowspan="4">Energy Consumption [kWh]</td><td>Chiller + evaporative</td><td>1,842,477</td><td>1,052,001</td><td>31,207</td></tr>
<tr><td>Fans (cooling only)</td><td>585,221</td><td>585,221</td><td>324,884</td></tr>
<tr><td>Pumps</td><td>661,874</td><td>472,767</td><td>-</td></tr>
<tr><td>Total</td><td>3,089,571</td><td>2,109,989</td><td>356,091</td></tr>
<tr><td rowspan="4">Annual Costs [£]***</td><td>Energy</td><td>262,614</td><td>179,349</td><td>30,268</td></tr>
<tr><td>Water</td><td>0</td><td>0</td><td>8,246</td></tr>
<tr><td>Total Costs</td><td>262,614</td><td>179,349</td><td>38,513</td></tr>
<tr><td>Cost Savings [%]</td><td>0%</td><td>32%</td><td>85%</td></tr>
</table>

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

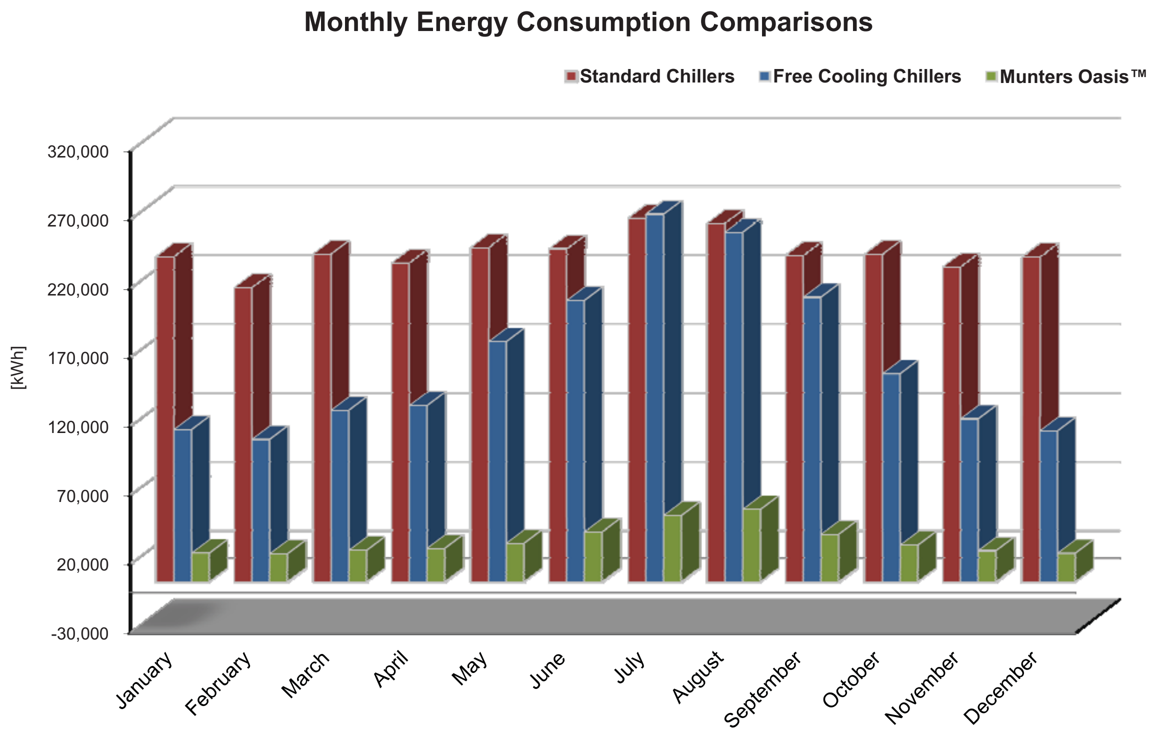


Figure 5.2.1: Annual Variation of Energy Consumption for all three cooling options considered for the Madrid region.

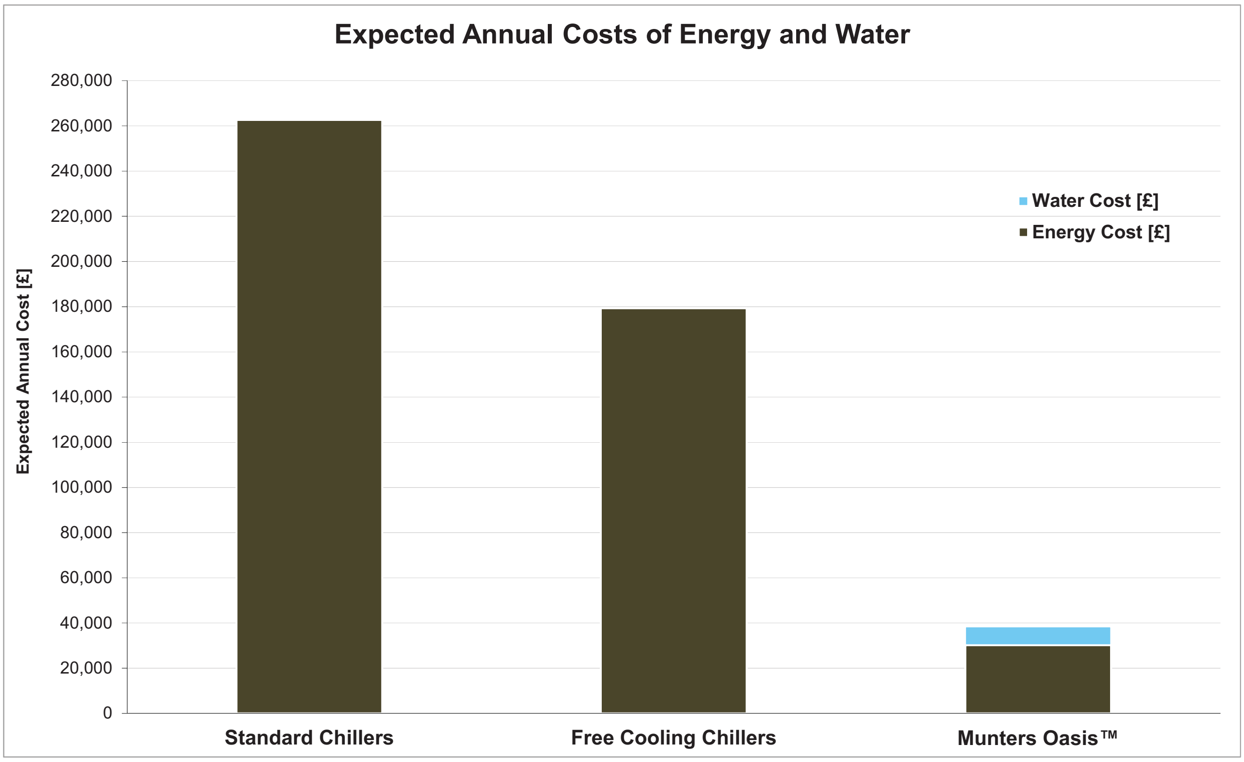


Figure 5.2.2: Total annual costs of energy and water consumed by the data hall.

5.3 Abu Dhabi

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 appendix 10 The data has been gathered using TRY weather data for Abu Dhabi.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**4.3**	**3.9**	**65**
	Total Cooling*	**3.0**	**2.9**	**10.7**
PUE (partial)**		**1.36**	**1.37**	**1.09**
Chiller Operating hours [h]		8760h	8760h	DX - 5886h, Evaporative - 8735h
Energy Consumption [kWh]	Chiller + evaporative	2,192,911	2,428,159	146,621
	Fans (cooling only)	588,612	588,612	746,005
	Pumps	665,709	475,507	-
	Total	**3,447,232**	**3,492,278**	**892,625**
Annual Costs [£]***	Energy	89,628	90,799	23,208
	Water	0	0	13,754
	Total Costs	**89,628**	**90,799**	**36,962**
	Cost Savings [%]	0%	-1%	59%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

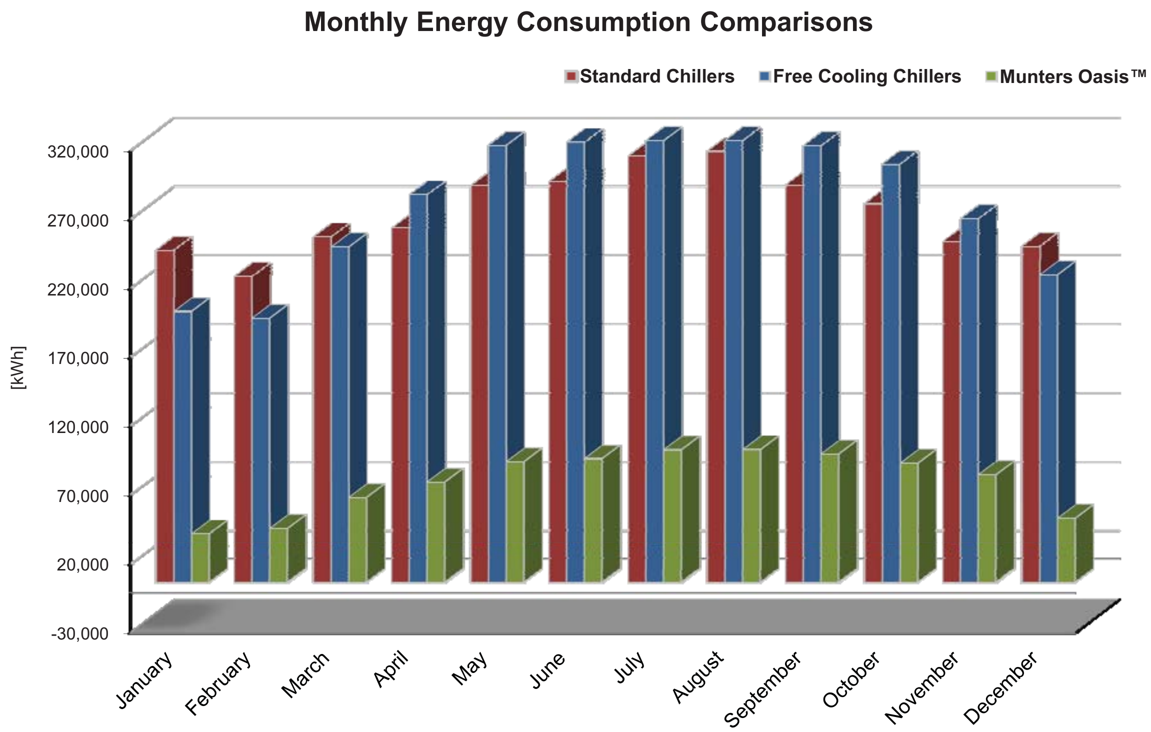


Figure 5.3.1: Annual Variation of Energy Consumption for all three cooling options considered for the Abu Dhabi region.

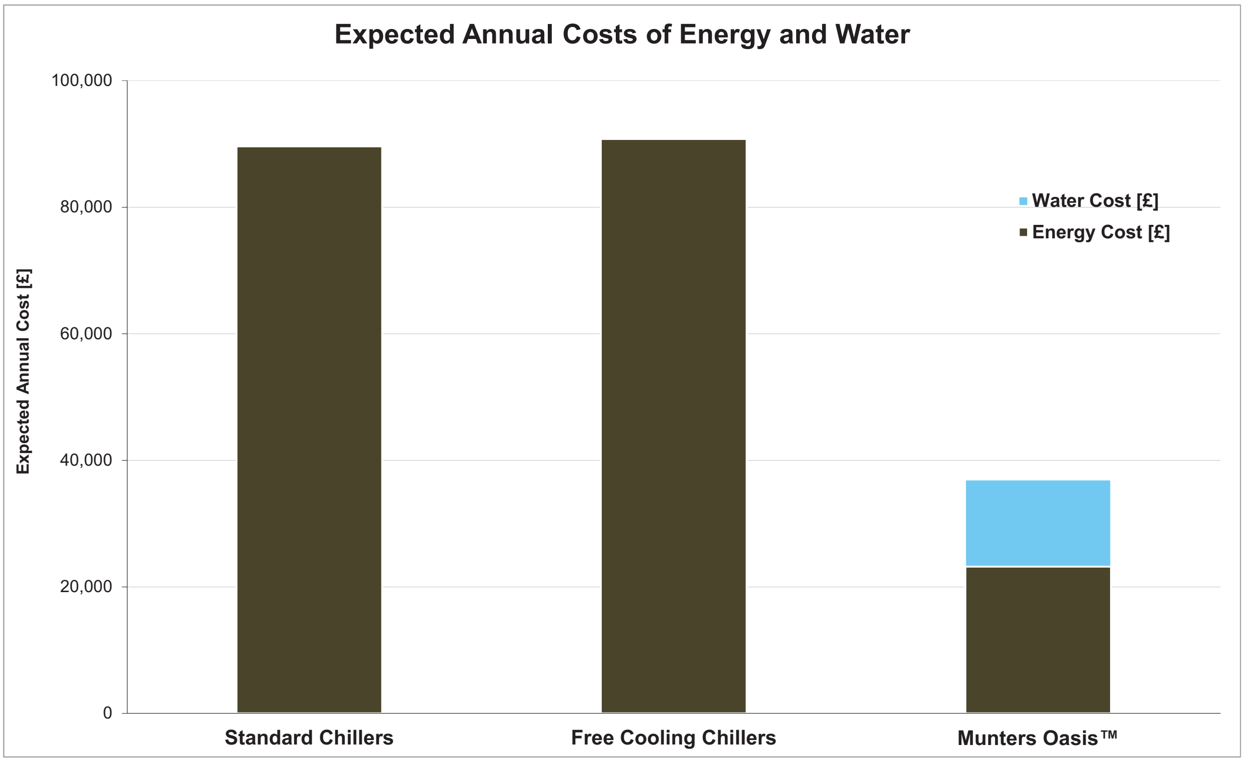


Figure 5.3.2. Total annual costs of energy and water consumed by the data hall.

CUNDALL

5.4 Beijing

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 appendix 10 The data has been gathered using TRY weather data for Beijing.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.1**	**7.9**	**188**
	Total Cooling*	**3.3**	**4.5**	**17.4**
PUE (partial)**		**1.33**	**1.24**	**1.06**
Chiller Operating hours [h]		8760h	8760h	DX - 2102h, Evaporative - 4303h
Energy Consumption [kWh]	Chiller + evaporative	1,851,527	1,194,718	50,024
	Fans (cooling only)	584,134	584,134	489,506
	Pumps	660,644	471,889	-
	Total	**3,096,305**	**2,250,740**	**539,530**
Annual Costs [£]***	Energy	244,608	177,808	42,623
	Water	0	0	4,842
	Total Costs	**244,608**	**177,808**	**47,465**
	Cost Savings [%]	0%	27%	81%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

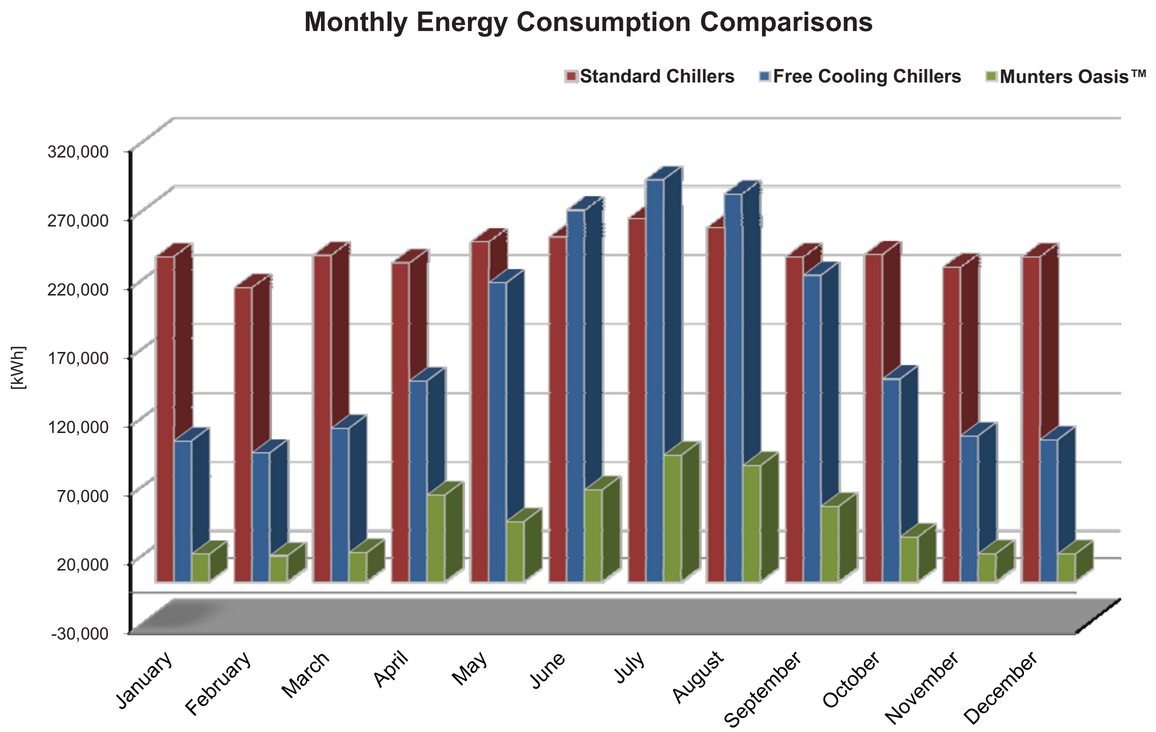


Figure 5.4.1: Annual Variation of Energy Consumption for all three cooling options considered for the Beijing region.

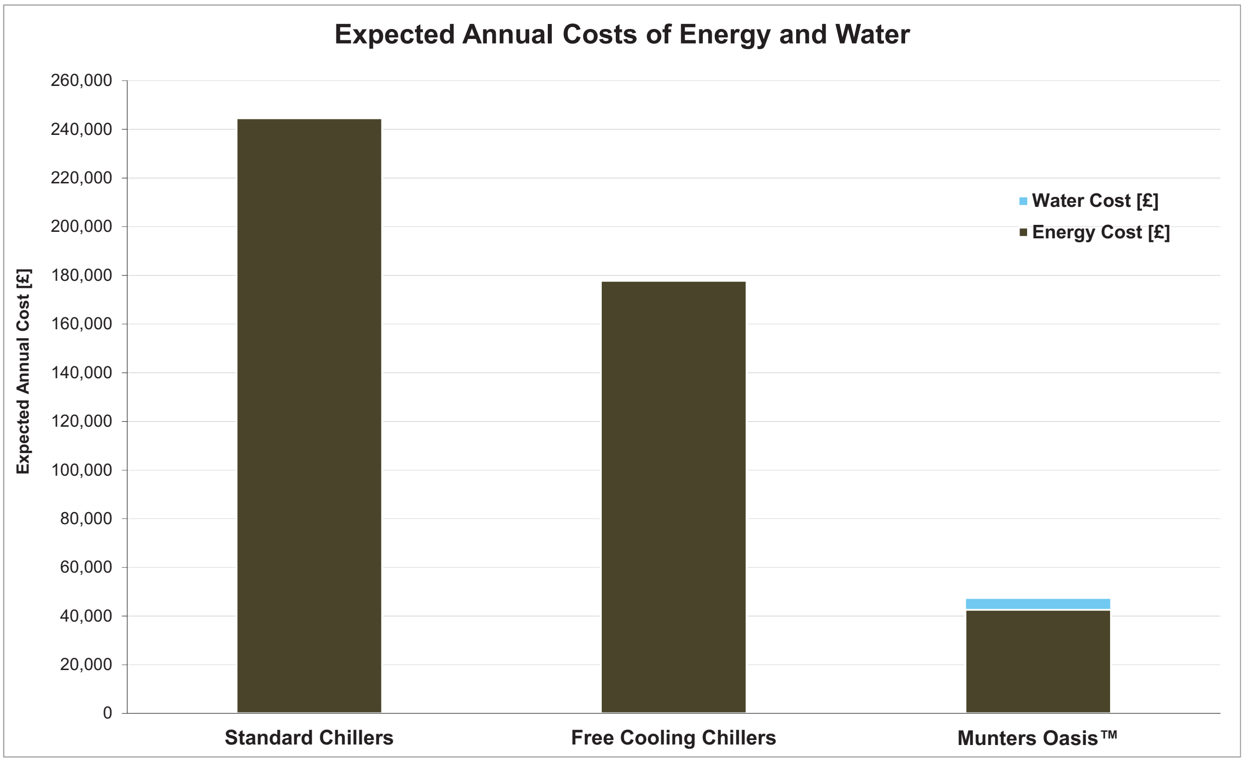


Figure 5.4.2: Total annual costs of energy and water consumed by the data hall.

5.5 Shanghai

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 appendix 10. The data has been gathered using TRY weather data for Shanghai.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.0**	**6.9**	**114**
	Total Cooling*	**3.3**	**4.2**	**15.8**
PUE (partial)**		**1.33**	**1.26**	**1.06**
Chiller Operating hours [h]		8760h	8760h	DX - 3024h, Evaporative - 5612h
Energy Consumption [kWh]	Chiller + evaporative	1,872,650	1,378,163	83,083
	Fans (cooling only)	583,639	583,639	515,731
	Pumps	660,085	471,490	-
	Total	**3,116,375**	**2,433,292**	**598,814**
Annual Costs [£]***	Energy	271,125	211,696	52,097
	Water	0	0	2,555
	Total Costs	**271,125**	**211,696**	**54,651**
	Cost Savings [%]	0%	22%	80%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

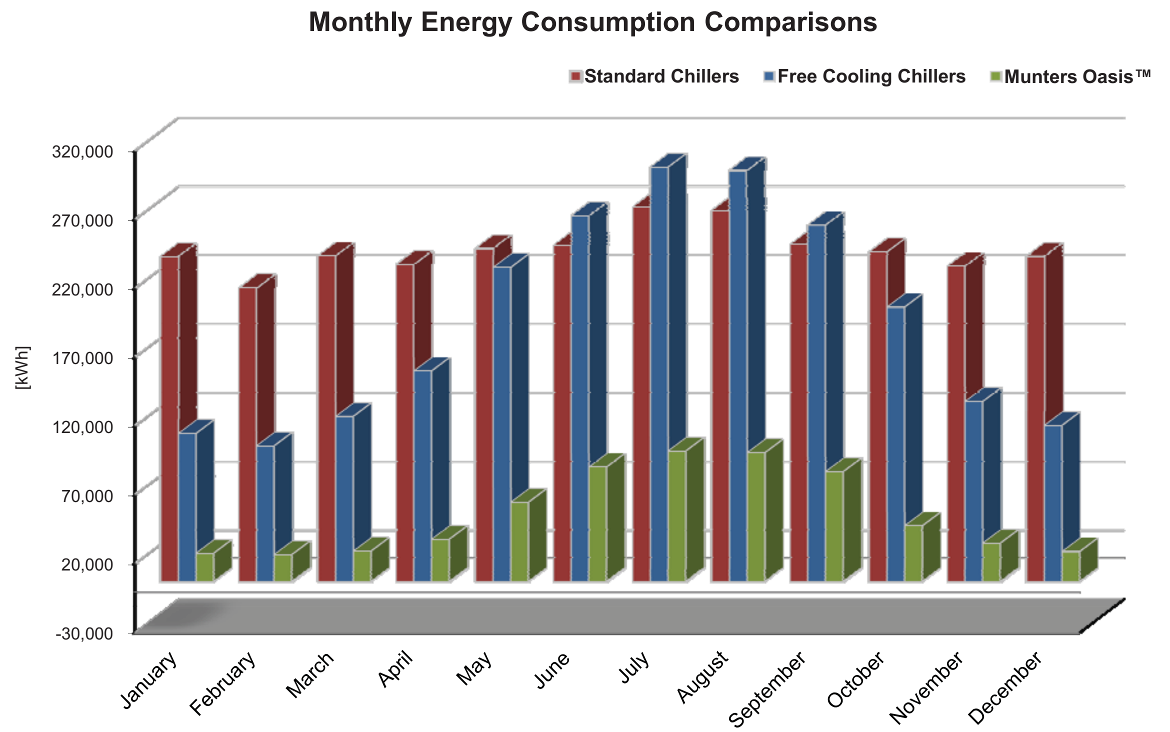


Figure 5.5.1: Annual Variation of Energy Consumption for all three cooling options considered for the Shanghai region.

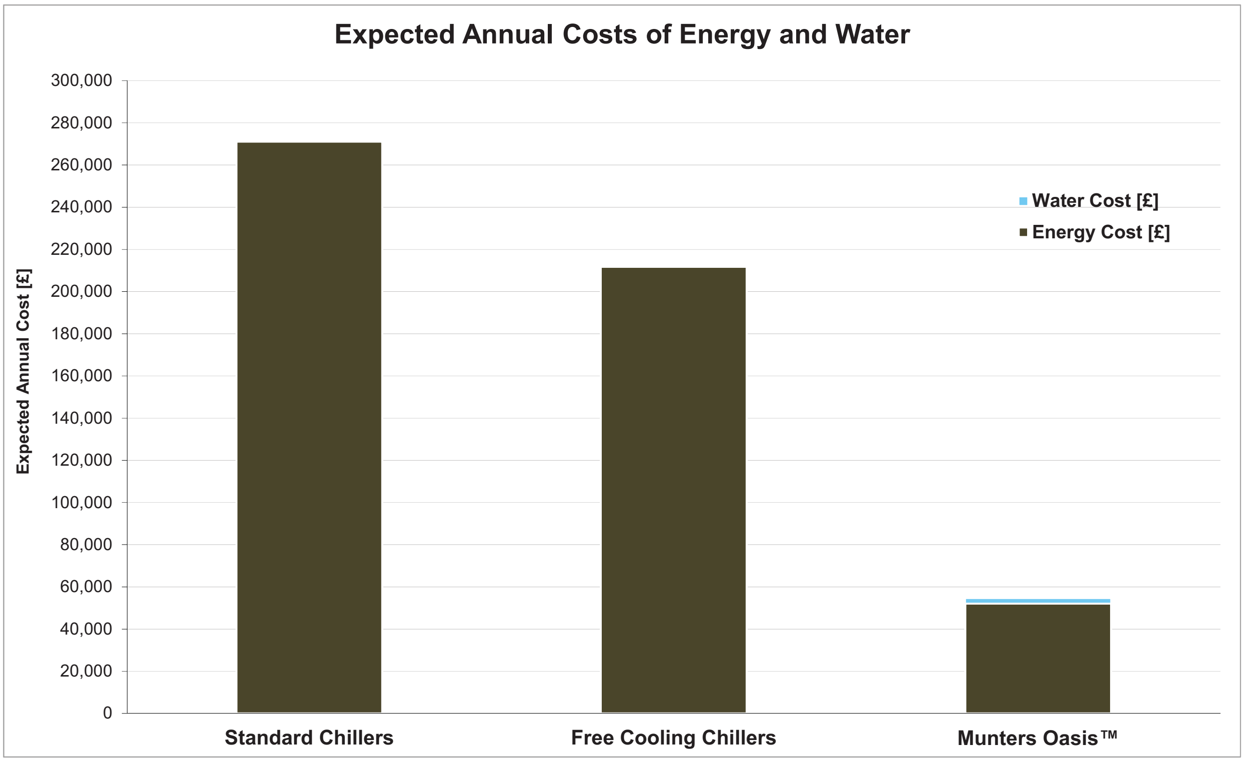


Figure 5.5.2. Total annual costs of energy and water consumed by the data hall.

5.6 Moscow

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 10 The data has been gathered using TRY weather data for Moscow.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.2**	**14.6**	**484**
	Total Cooling*	**3.3**	**6.1**	**30.6**
PUE (partial)**		**1.33**	**1.18**	**1.03**
Chiller Operating hours [h]		8760h	8760h	DX - 189h, Evaporative - 2919h
Energy Consumption [kWh]	Chiller + evaporative	1,775,576	631,916	19,044
	Fans (cooling only)	581,856	581,856	282,308
	Pumps	658,068	470,049	-
	Total	**3,015,500**	**1,683,821**	**301,352**
Annual Costs [£]***	Energy	211,085	117,867	21,095
	Water	0	0	574
	Total Costs	**211,085**	**117,867**	**21,668**
	Cost Savings [%]	0%	44%	90%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

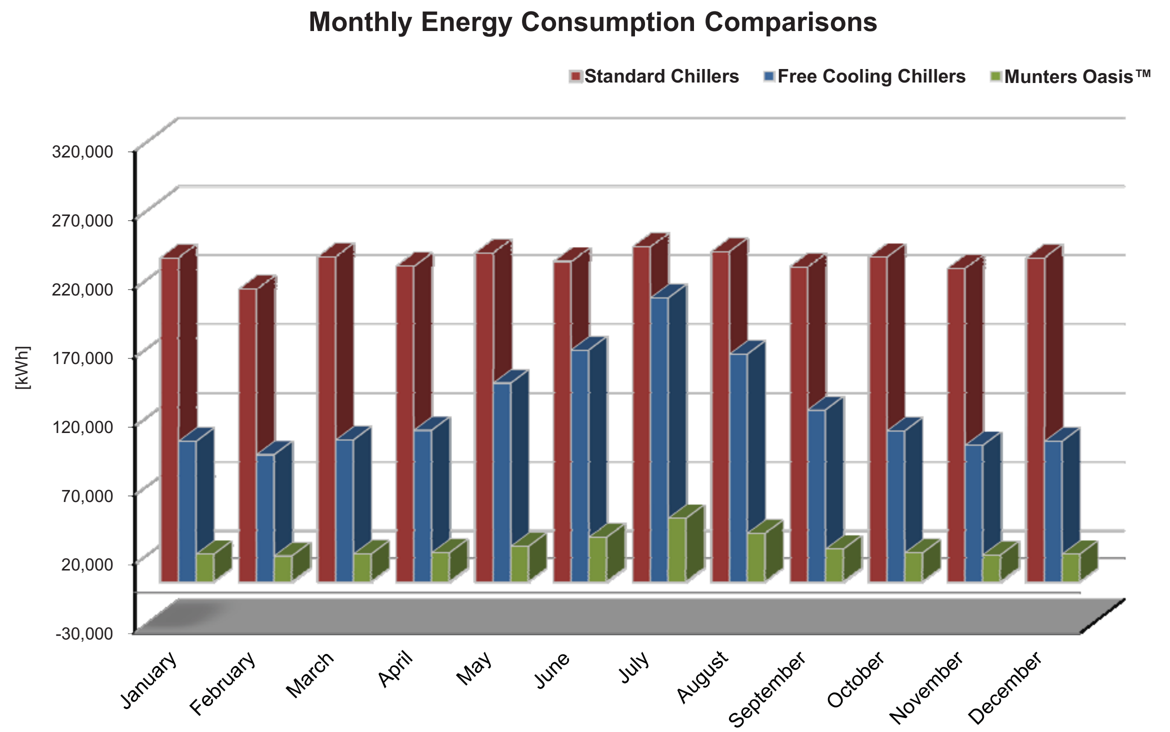


Figure 5.6.1: Annual Variation of Energy Consumption for all three cooling options considered for the Moscow region.

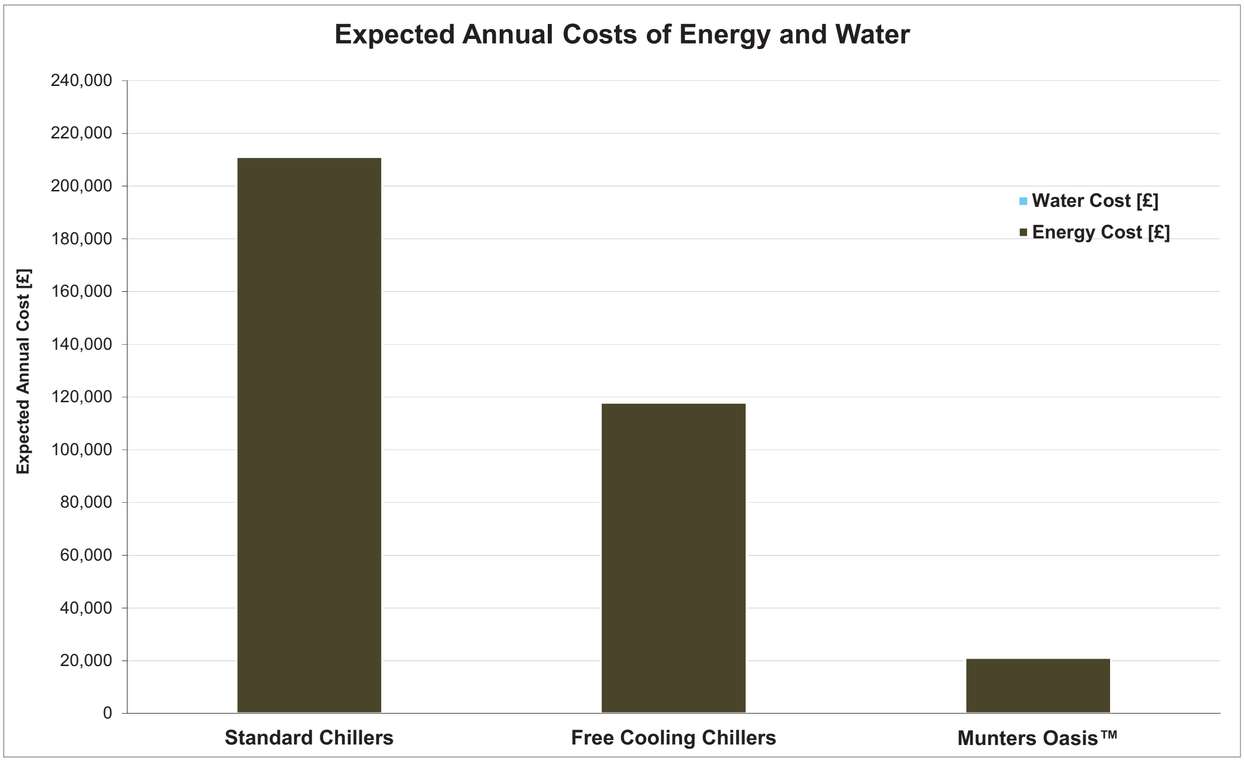


Figure 5.6.2. Total annual costs of energy and water consumed by the data hall.

5.7 Istanbul

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 10 The data has been gathered using TRY weather data for Istanbul.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.1**	**7.8**	**218**
	Total Cooling*	**3.3**	**4.5**	**20.2**
PUE (partial)**		**1.33**	**1.24**	**1.05**
Chiller Operating hours [h]		8760h	8760h	DX - 1653h, Evaporative - 5130h
Energy Consumption [kWh]	Chiller + evaporative	1,820,879	1,197,553	42,945
	Fans (cooling only)	584,342	584,342	419,419
	Pumps	660,879	472,057	-
	Total	**3,066,100**	**2,253,952**	**462,364**
Annual Costs [£]***	Energy	153,305	112,698	23,118
	Water	0	0	26,994
	Total Costs	**153,305**	**112,698**	**50,112**
	Cost Savings [%]	0%	26%	67%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

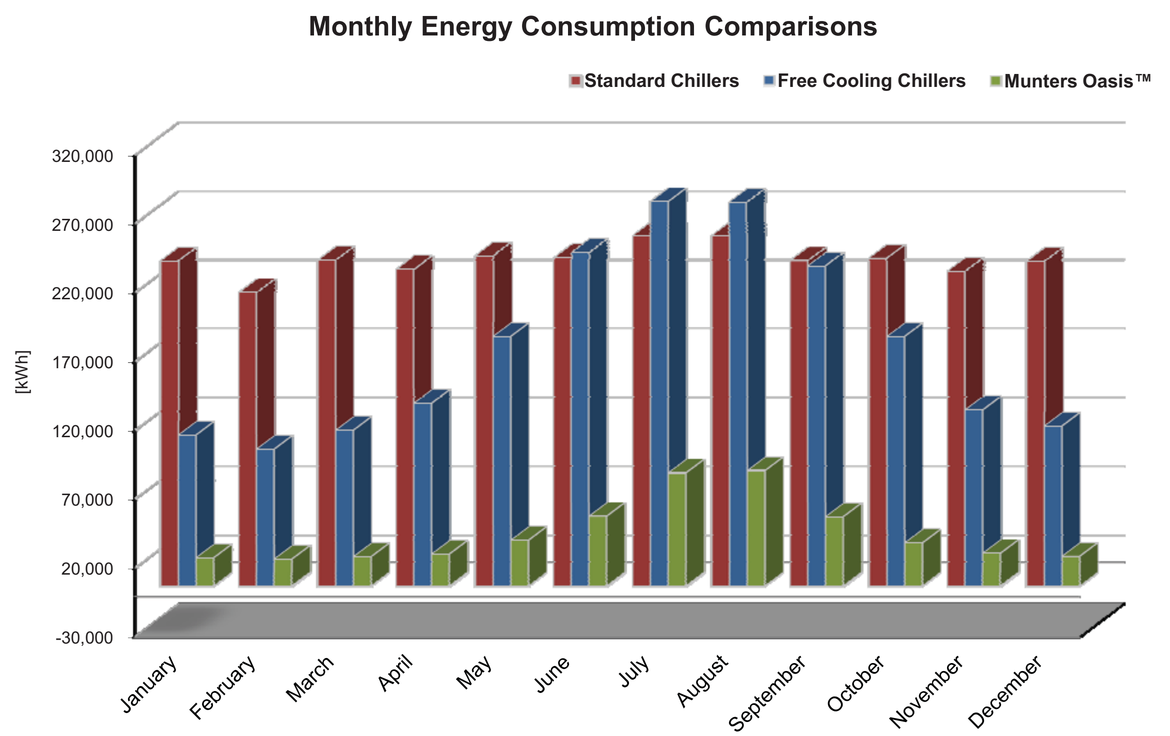


Figure 5.7.1: Annual Variation of Energy Consumption for all three cooling options considered for the Istanbul region.

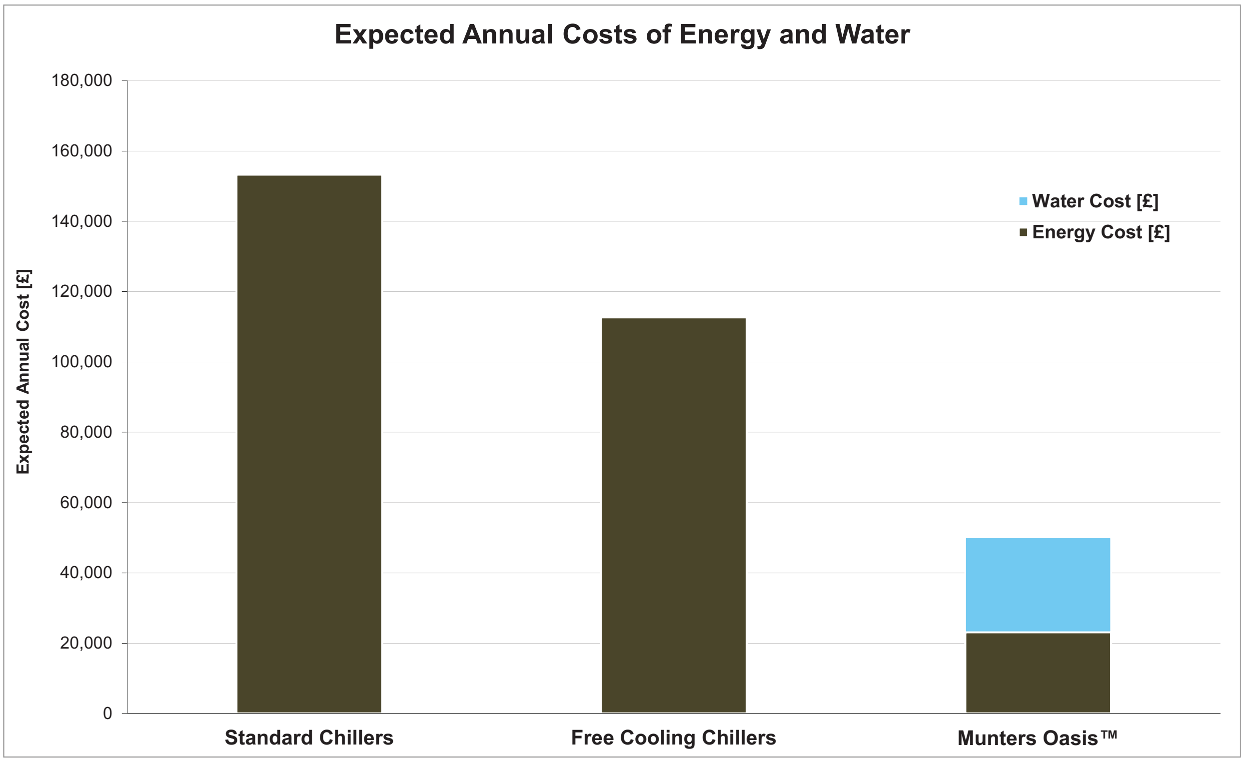


Figure 5.7.2: Total annual costs of energy and water consumed by the data hall.

CUNDALL

5.8 Frankfurt

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 10 The data has been gathered using TRY weather data for Frankfurt.

		Standard Chillers	Free Cooling Chillers	Munters Oasis™
Seasonal Cooling COP	Chiller + evaporative	**5.2**	**19.7**	**1015**
	Total Cooling*	**3.3**	**6.8**	**35.8**
PUE (partial)**		**1.32**	**1.16**	**1.03**
Chiller Operating hours [h]		8760h	8760h	DX - 6h, Evaporative - 1448h
Energy Consumption [kWh]	Chiller + evaporative	1 766 135	469 238	9 129
	Fans (cooling only)	581 885	581 885	249 591
	Pumps	658 101	470 072	-
	Total	**3 006 121**	**1 521 195**	**258 720**
Annual Costs [£]***	Energy	150 306	76 060	12 936
	Water	0	0	1 530
	Total Costs	**150 306**	**76 060**	**14 466**
	Cost Savings [%]	0%	49%	90%

* - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)

**- PUE(partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc.

***- The cost of electricity and water is given in section 10.2.1

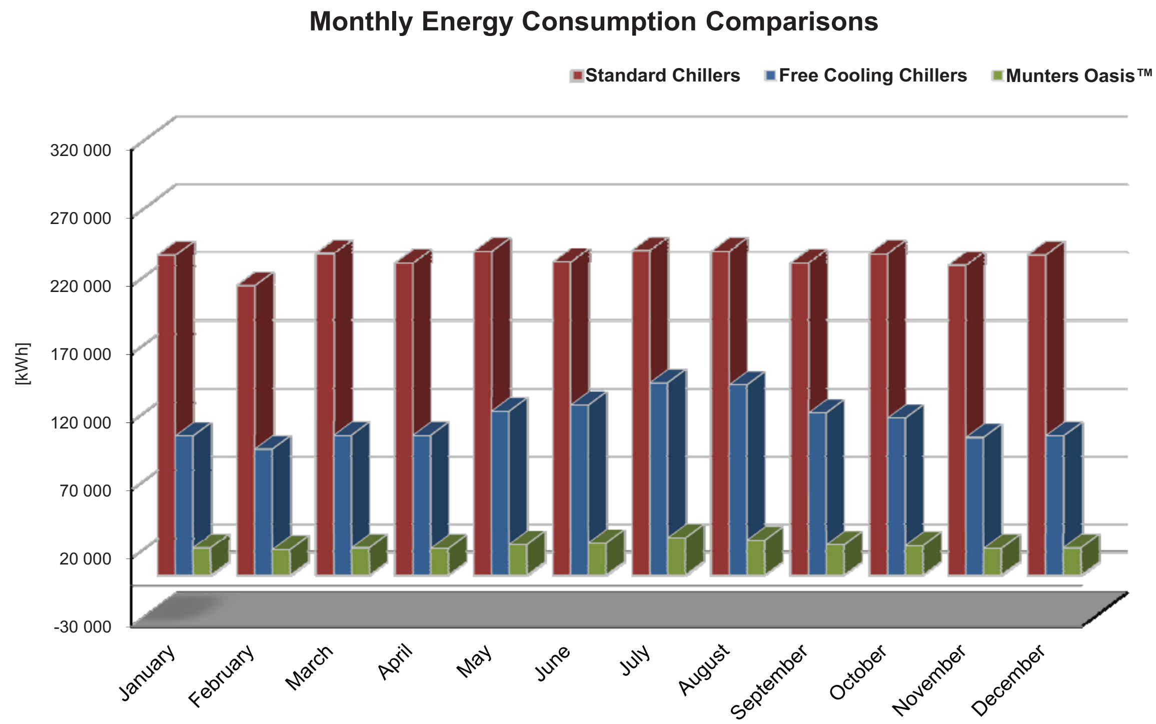


Figure 5.7.1: Annual Variation of Energy Consumption for all three cooling options considered for the Frankfurt region.

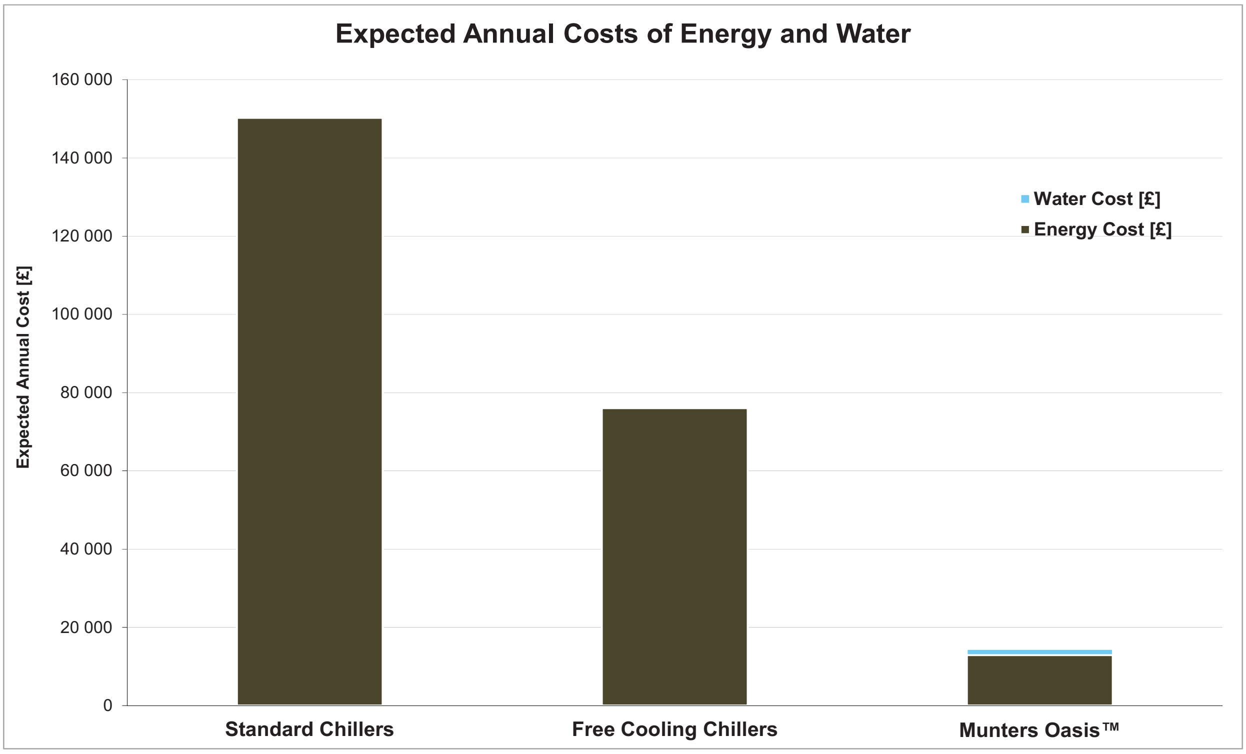


Figure 5.7.2: Total annual costs of energy and water consumed by the data hall.

6.0 Whole Life Costs

A comparison between the total cost of ownership values for two cooling technologies such as IAO and chilled water, gives a more realistic and holistic picture of the true costs that should be considered rather than upfront capital costs. BSRIA offer a recognised method for whole life cost analysis that recognises capital costs, utility costs, recurring maintenance and net present values.

BSRIA

PROJECT TITLE	Oasis IEC vs Free Cooling Chillers				
PROJECT NUMBER	LHR				
DATE OF ANALYSIS	30-Aug-12				
DISCOUNT RATE USED FOR ANALYSIS	3.5		STUDY PERIOD	15	It is usual to enter the discount rate in % per annum and the study period in years, but other units can be chosen provided both are consistent

	BASE CASE	ALTERNATIVE
NPV LUMP SUMS	£1,039,000.00	£1,047,000.00
ENERGY + WATER COSTS	£1,153,359.06	£248,492.06
NPV OF TOTAL WHOLE LIFE COST	£2,192,359.06	£1,295,492.06
EQUIVALENT ANNUAL COST (NPV)	£190,351.73	£112,481.19
NET SAVING		896,867.00
SAVINGS-TO-INVESTMENT RATIO (SIR)		113.11
DISCOUNTED PAY BACK PERIOD		-0.1 years

Alternative has lowest Whole Life Cost

IAO using the Oasis unit is shown to be significantly cheaper over a 15 year period than a chilled water equivalent.

7.0 Part Loading

A large proportion of a data halls life is spent at part load. This can be for many reasons such as initial phased deployment, maintenance/equipment changeover, or the installed server demand rising and falling. IAO systems are extremely efficient at part load. The air and fan based system is able to take advantage of the fan laws which dictate that consumed power will be to the power of three higher as fan duty increases.

Chilled water systems have a number of fixed loads that apply regardless of IT load. Chilled water systems generally have to be designed to satisfy a tighter dead band of load with the inherent limitations this brings.

Clients in the present market are looking for designs that offer low initial capital outlay that can be phased as demand increases, combined with low running costs. Although a chilled water system can be phased, the initial capital outlay and running costs will be higher than an IAO system that simply requires an additional cooling unit and a means to connect it to the data hall.

The Oasis IEC lends itself particularly well to part loading for the reasons given above. A DCiE plot illustrates this point.

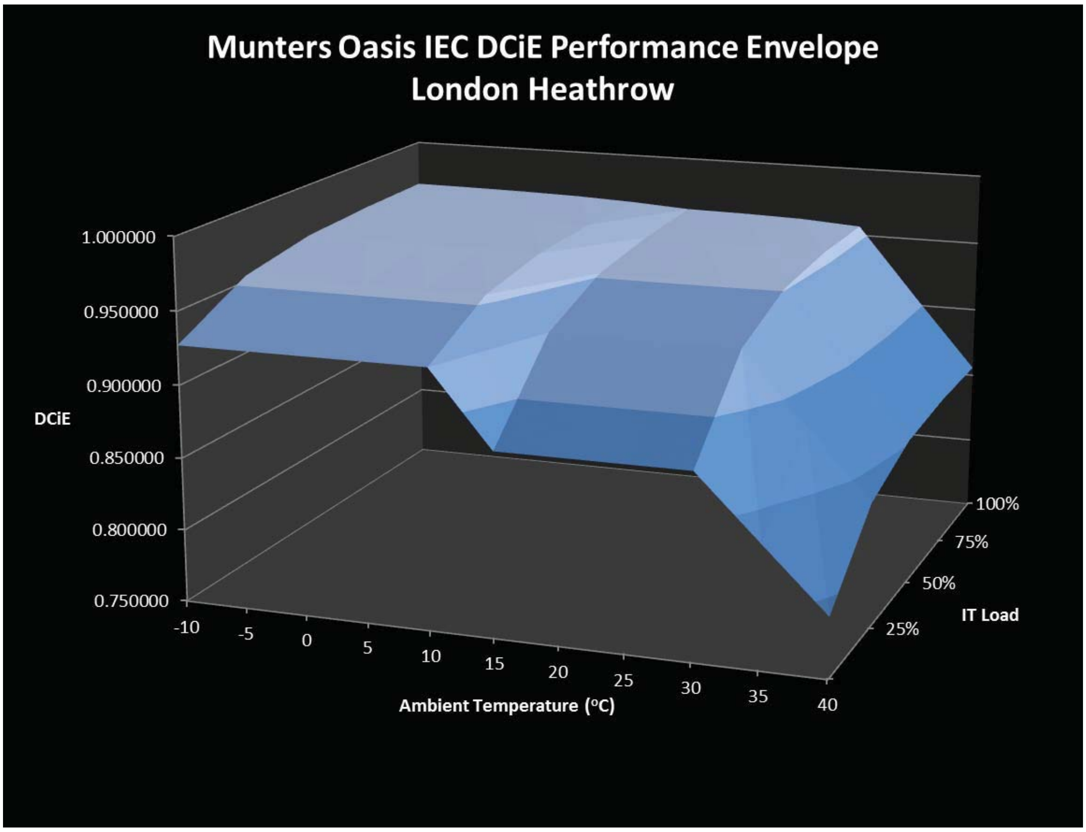


Figure 7.0: Munters Oasis IEC performance plot

CUNDALL

8.0 Conclusion

This report has compared the operational efficiency of the Oasis^{TM} Indirect Evaporative Cooler compared to a free-cooling chilled water cooling system of comparable size. The report has aimed to be a subjective analysis of the product itself and its suitability as a credible data centre cooling strategy. The report has also evaluated the various attributes of the technology, the overall attributes of an IAO system compared to chilled water, and the energy / water costs of each system.

The headline benefit that has clearly been demonstrated is that annual energy consumption is reduced as a result of using the Oasis^{TM} Indirect Evaporative Cooler. A number of reasons can be cited to explain why this finding has come to be the case:

- To remove energy from a data hall, heat goes through a number of exchanges from air to water to air (not including server to air heat exchanges and internal chiller exchanges). Each exchange has a temperature approach and an efficiency loss associated with it. These combined losses reduce overall system efficiency.
- Chilled water systems involve the movement of three mediums of heat transfer (air, water, air). Each medium requires fans or pumps for circulation, the latter being a major energy loss.
- IAO systems can maximise the potential cooling contained in ambient air due to reduced approach temperature losses allowing supply air temperature to closely match the highest ambient temperature.
- Evaporative cooling can be used on a free cooling chiller to increase its efficiency, but the advantage gained in comparison to evaporative cooled IAO is reduced due to lower chilled water temperature set points at the chiller.
- IAO will only require mechanical cooling when ambient wet bulb temperature exceeds the required internal supply set point (with losses). This set point for a chilled water free cooling chiller will be far lower.

The Oasis^{TM} Indirect Evaporative Cooler as a packaged cooling solution has a number of attributes that enhance its performance. The heat exchanger from information provided is an innovative cost effective design that requires minimal maintenance and will have a longer lifespan than conventional plate heat exchanger arrangements. This comes at a cost with efficiency being slightly lower than alternative plate heat exchangers on the market.

The heat exchanger tubes have to be positioned horizontally for cooling water to pass through them. As a result, data hall air has to make more directional changes to get through the heat exchanger than other IAO options. Total Static Pressure (TSP) in the unit is relatively high in the unit because of this and the heat exchanger; this in turn has increased the specific fan power. The air path will be improved with the roof mounted unit. It is worth noting that the internal static pressure loss of this type of heat exchanger will be less than equivalent plate type arrangements.

Supply fans are positioned in the return air stream before air enters the heat exchanger. This is an advantage over other systems that place fans in the supply air stream with fan gains increasing supply temperature. This can make a heat exchanger by-pass arrangement more difficult to implement if fan power is to be reduced in very cold climates.

Chilled water systems have minimal water needs compared to the Oasis^{TM} Indirect Evaporative Cooler other than to refill during maintenance. At London Heathrow the annual water consumption of the Oasis unit is 4,221m3. This is an additional cost but more importantly requires additional infrastructure. In hotter dryer countries this figure will increase along with water costs.

When the DX system is activated, the COP is lower than that of a dedicated chiller system. This fact is emphasised following preliminary analysis of hotter climates such as Abu Dhabi. This emphasises the greater effectiveness of this product in the correct environment and application.

Headline cost figures provided by Munters indicate that the capital cost of Oasis^{TM} Indirect Evaporative Cooler compared to a free-cooling chilled water system will be slightly higher. These figures are by no means definitive and further detailed cost analysis is needed to support these findings and will form part of the next stage of this study.

Further analysis of installation and maintenance costs is required to highlight the benefits of the Oasis™ Indirect Evaporative Cooler due to reduced system complexity and fewer moving parts compared to chilled water. A maintenance contract from Munters would require little additional maintenance services for the remainder of the mechanical systems.

Region	Oasis IEC pPUE	Free-Cooling Chiller pPUE
London Heathrow	**1.03**	**1.18**
Madrid	**1.04**	**1.21**
Abu Dhabi	**1.09**	**1.35**
Beijing	**1.06**	**1.22**
Shanghai	**1.06**	**1.24**
Moscow	**1.03**	**1.17**
Istanbul	**1.05**	**1.22**
Frankfurt	**1.03**	**1.16**

The improvements seen in this revision of the report compared to the previous revisions are significant in terms of the Oasis unit performance, but have a relatively small impact in the pPUE. As energy for cooling reduces, any improvements made are minimal compared to the IT load.

9.0 References

[1] Kaiser et.al. White Paper #41, 2011, The Green Grid

[2] Quantifying Data Centre Space in the UK. Data Centre Dynamics Focus, November 2011, page 16

[3] Newcombe.L, 2011. Manchester to Madrid – Chillers not needed, Version 1.0

[4] Bitterlin.I, 2011. Maximising the Grid Capacity of Data Centres

[5] The Jones Lang LaSalle Data Centre Barometer. Jones Lang LaSalle, Autumn 2011 – Issue 7

[6] The Jones Lang LaSalle Data Centre Barometer. Jones Lang LaSalle, Spring 2012 – Issue 8

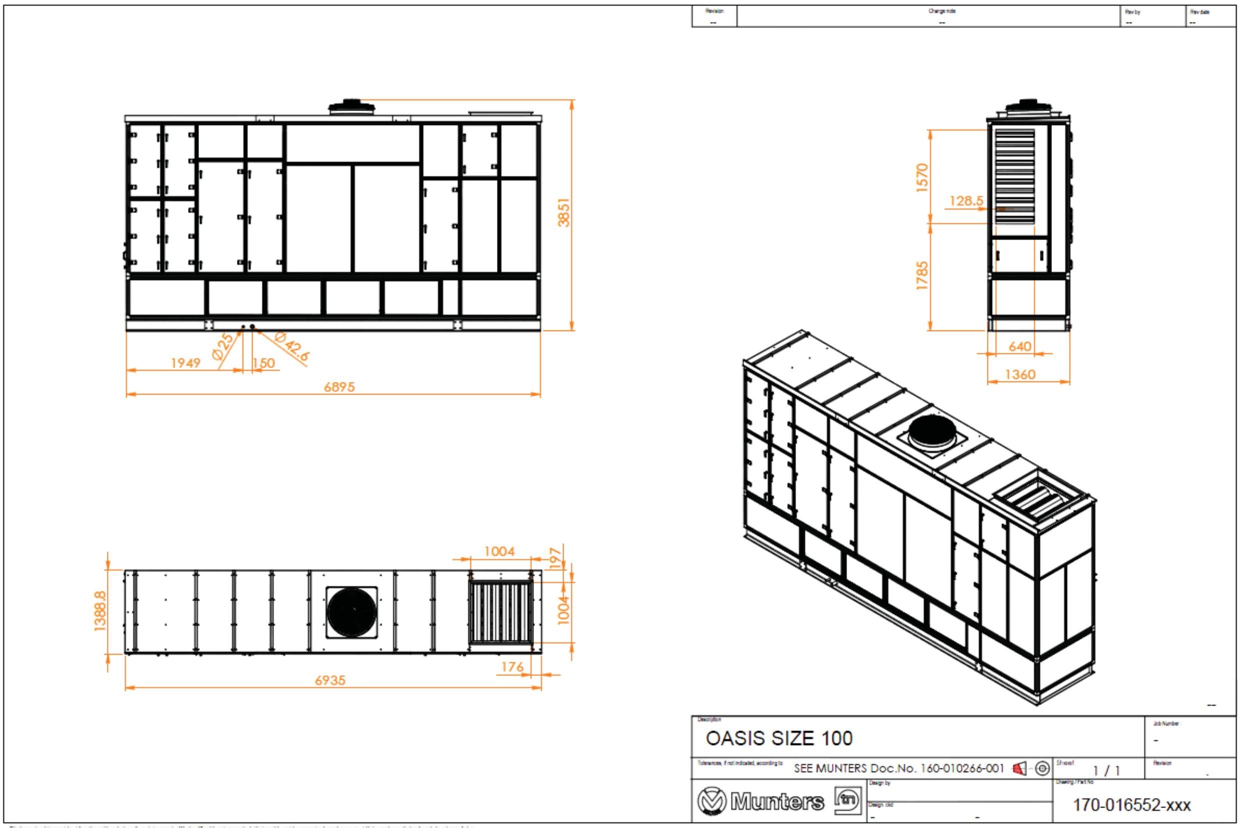
[7] Tozer.R et.al. 2012. Minimising Data Centre Total Cost of Ownership Through Energy Efficient Analysis. CIBSE ASHRAE Technical Symposium.

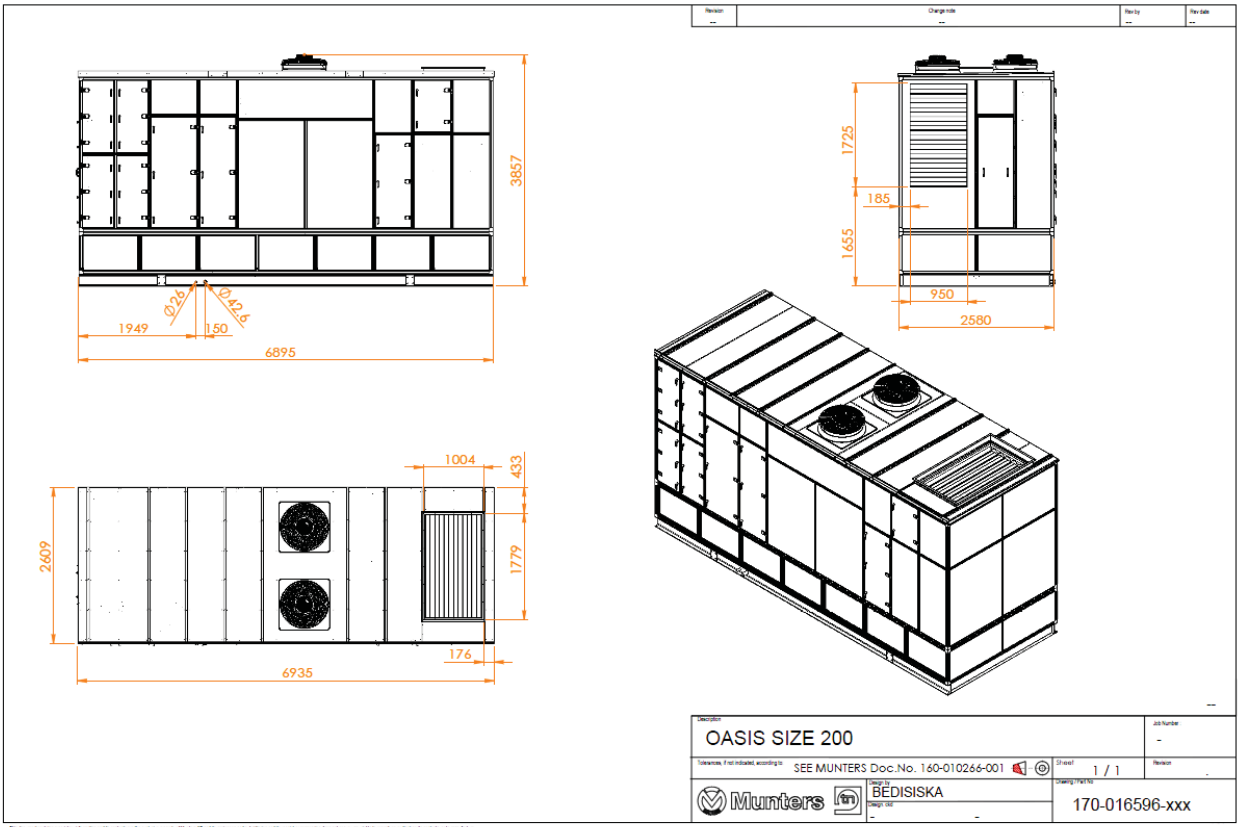
10.0 Appendices

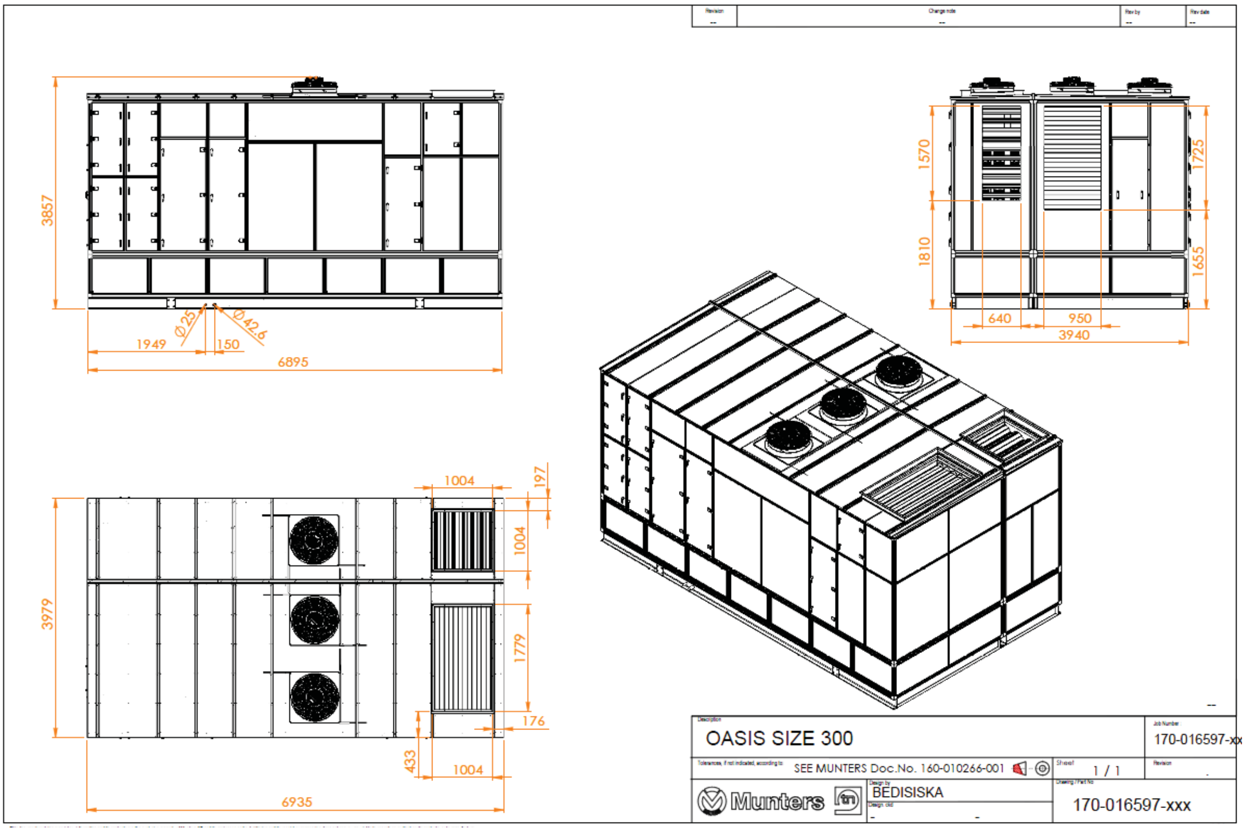
10.1 Technical Schedule

The following table details the typical design criteria which may be considered when selecting a unit. Typical selection figures have been given for the design case data hall and ambient conditions at London Heathrow provided by Munters.

Design Parameter	Design Criteria	Comments
Design Cooling Load	225kW per unit	The unit uses an evaporative polymer tube heat exchanger system with a scavenger fan that can be sized to suit the required cooling duty. N+1 units are supplied for resilience.
Data Hall Supply	24-27°C db	Air needs to be supplied to the servers within the boundaries of the ASHRAE 'Class 1' conditions although this can be exceeded for short periods. 25°C db supply will be targeted for the purposes of this study.
Data Hall Return	36-39°C db	A typical target ΔT for this type of application would be 12°C. Increasing the ΔT across the servers reduces supply fan duty but increases the heat dissipation duty of the heat exchanger per unit of air.
Typical Internal Air Flow	12.6 m3/s per unit	Airflow is based on a typical 200kW unit but will vary according to unit duty.
Typical External Air Flow	0 – 12.5 m^3/s	Dependent on unit configuration and duty.
Supply TSP	200 Pa	TSP is dependent on unit duty and filtration requirements (external)
Scavenger TSP	210 Pa	Scavenger TSP will increase and decrease with evaporative cooling demand (external)
Design Fan Power	Variable	
Unit Water Usage Evaporated	5440.2 m^3 per annum (manufacturer data)	This figure does not include water that will be drained from the sump.
Maximum Pump Power	6.3 kW per unit (x5)	During normal operation this figure will be reduced
Unit Size (WxLxH) mm	3940x6895x4149	The design of the unit is adaptable to specific requirements and dimensions will vary accordingly
Unit Weight		The design of the unit is adaptable to specific requirements and unit weight will vary accordingly
Typical Electrical Supply	3 phase 400V	
Maximum Unit Input Power at Design Load	69.5 kW	


3851
1949
Ø25
Ø42.6
150
6895
1570
128.5
1785
640
1360
1004
197
1388.8
1004
176
6935
OASIS SIZE 100
SEE MUNTERS Doc.No. 160-010266-001
1 / 1
Munters
170-016552-xxx


3857
1949
Ø26
Ø42.6
150
6895
1725
185
1655
950
2580
1004
433
2609
1779
176
6935
OASIS SIZE 200
SEE MUNTERS Doc.No. 160-010266-001
1 / 1
Munters
BEDISISKA
170-016596-xxx


3857
1949
Ø25
Ø42.6
150
6895
1570
1810
1725
1655
640
950
3940
1004
197
1004
3979
1779
176
433
1004
6935
OASIS SIZE 300
170-016597-xx
SEE MUNTERS Doc.No. 160-010266-001
1 / 1
Munters
BEDISISKA
170-016597-xxx

CUNDALL

10.2 Basis of Calculation

10.2.1 Munters OasisTM Indirect Evaporative Cooler (IEC).

It is assumed for the purposes of this report that the data halls are fully loaded with the IT equipment and represents a static constant condition. It is assumed that load is uniformly distributed throughout the data hall.

The design IT load will be 1500 W/m^2 for 700m^2 data hall, therefore the total IT load for the data hall will be 1MW. The total annual IT electrical energy consumption will be as follows;

For the 1MW data hall, the electrical consumption of the IT equipment is **8,760,000 kWh / annum**

A calculator has been set up, specific to IAO and chilled water systems, for the purpose of calculating the energy consumption of the cooling system given the external ambient conditions as recorded in the TRY weather data.

The first input to the calculator are the ambient conditions for the region considered, i.e. External Dry Bulb Temperature, External Wet Bulb Temperature, Moisture Content, Dew Point, Enthalpy and Density. These parameters are entered for every hour of the year. In addition to this, the maximum supply air temperature to the facility as well as the ΔT across the cooling system is also defined.

The calculation process is split into a number of different control modes for the cooling units such as the use of dry or wet heat exchanger, modulating scavenger fan power and use of DX cooling. Each of the control modes has been assessed in terms of associated efficiencies for the heat exchanger, power consumption for fans and pumps and required energy input from DX cooling.

Energy associated with the supply fans has been taken as a constant figure based on the data given in the Munters spread sheet. Scavenger volume has been calculated based on the required heat exchanger efficiency to maintain a 25^{o}C supply. A heat exchanger efficiency graph has then be used to give the required volume. Scavenger fan data has been provided by the manufacturer. Fan Laws have then be used to calculate scavenger fan power.

The DX Condensers Energy Efficiency Ratio (EER), as defined in table opposite, which was based on the manufacturer’s data sheet, was used to convert the required total mechanical cooling energy into an electrical input power for the refrigeration system.

$$Energy\ Efficiency\ Ratio = \frac{Net\ Cooling\ Delivered}{Electrical\ Power\ Input}$$

Only the above elements directly involved in cooling are considered in the calculation, the fresh air ventilation system and lighting of the data hall is neglected.

It is worth noting that a given temperature from Munters has been used at which the sprays are activated. This temperature will be determined more precisely on a case by case basis, meaning that the maximum efficiency for a given location in the report might not be the most accurate.

In addition, the water consumption in the process of evaporative cooling has been calculated based on achieving the saturation point by the outside air, the rate of water consumption is the absolute humidity increase in the process of the evaporative cooling. In addition, an estimation of water excess has been made based on the periodic draining of the unit and due to the water droplets being carried out by the scavenger air.

The tables opposite summarise a number of assumptions used in calculation of the energy and water consumption of the Munters cooling Unit as well as the costs of water and electricity associated with various locations.

Assumptions used in the calculations

Parameter	Value
Supply set point Temperature to the Data Hall [°C]	25
Return set point Temperature from the Data Hall [°C]	39
Maximum scavenger air volume to supply air volume	1.1
Process Air Fan power at 63m^3/s (kW)	26.7
Process Air Fan Heat Gain [K]	1
Scavenger Air Fan SFP [W/l/s]	Variable
Proportion of circulation air filtrated	25%
Heat recovery efficiency (DRY)	Variable
Heat recovery efficiency (WET)	Variable
DX Cooling Efficiency (SEER)	4.1
DX cooling active only when off-coil Temperature of the process air is equal or higher than supply set point temperature	
Evaporative Cooling Total Pump Power [kW]	6.3
Water Use excess (loss, due to the not optimum water spraying, water droplets being carried away, etc.)	25%
Relative humidity achieved in the Evaporative cooling	100%
Minimum Outside Temperature for evaporative Cooling [°C]	Variable

	Tariff	Electricity (kWh)	Water (m^3)
London	-	-	-
	£	0.06	1.6
Madrid	€	0.1	1
	£	0.085	0.85
Abu Dhabi	AED	0.15	2.2
	£	0.026	0.39
Beijing	RMB ￥	0.781	6.21
	£	0.079	0.630
Shanghai	RMB ￥	0.86	3.71
	£	0.087	0.377
Moscow	Rub	3.38	11.8
	£	0.07	0.24
Istanbul	TRY	0.14	11.38
	£	0.05	4.01
Frankfurt	€	0.1	1
	£	0.085	0.85

Location	WB Spray Activation Temperature** (°C)
London	10.5
Beijing	7.5
Shanghai	9.5
Abu Dhabi	9.5
Madrid	9.5
Moscow	9.5
Istanbul	9.5
Frankfurt	9.5

**Provided by manufacturer

10.2.2 Chilled Water Units

The same global assumptions regarding the data hall arrangement were used in the analysis of the various systems, therefore the total IT load, set point temperatures, weather files and tariffs are the same for the chilled water system as for the Munters cooling system.

Chilled water system is composed of the major elements such as:

- Chilled water cooling system with the chillers and pumps,
- CRAC units of which the main elements are fans.

Only the above elements directly involved in cooling are considered in the calculation, the fresh air ventilation system and lighting of the data hall is neglected.

Energy spent on chillers depends on the Chillers energy efficiency ratio. The data from the manufacturers provide efficiencies for a range of outside temperatures. Based on this, the overall energy consumption of the chillers was calculated (for both, standard and free cooling chillers)

Pumps were modelled based on the assumed pressure head of the primary and secondary pumps, temperature difference between flow and return and efficiency of the motors.

Finally, fans within CRAC units were assumed to run at constant speed (due to the constant maximum cooling load) with volume calculated based on the cooling capacity and air temperature difference (return – supply).

The input parameters assumed in the energy calculations are summarised in the tables below and opposite (Note: EER figures include the energy requirements of the circulating pumps and chiller).

Parameter	Value
Supply set point Temperature to the Data Hall [°C]	25
Return set point Temperature from the Data Hall [°C]	39
CRAC unit Fan SFP [W/l/s]	1.03
CRAC unit Fan Heat Gain [K]	1
Chilled Water DT (Flow – Return) [K]	7
Pumps Efficiency [%]	80%
Pressure Head of the Primary Pumps [m]	10
Pressure Head of the Secondary Pumps [m]	15

CUNDALL

Toutside	EER (standard Chiller)	EER (Free-Cooling Chiller)	Toutside	EER (standard Chiller)	EER (Free-Cooling Chiller)	Toutside	EER (standard Chiller)	EER (Free-Cooling Chiller)
-25	6.24	28.15	0	6.24	28.15	25.00	5.51	3.60
-24.5	6.24	28.15	0.5	6.24	28.15	25.50	5.51	3.60
-24	6.24	28.15	1	6.24	28.15	26.00	5.38	3.51
-23.5	6.24	28.15	1.5	6.24	28.15	26.50	5.38	3.51
-23	6.24	28.15	2	6.24	28.15	27.00	5.25	3.43
-22.5	6.24	28.15	2.5	6.24	28.15	27.50	5.25	3.43
-22	6.24	28.15	3	6.24	28.15	28.00	5.11	3.34
-21.5	6.24	28.15	3.5	6.24	28.15	28.50	5.11	3.34
-21	6.24	28.15	4	6.24	28.15	29.00	5.02	3.30
-20.5	6.24	28.15	4.5	6.24	28.15	29.50	4.95	3.26
-20	6.24	28.15	5	6.24	26.01	30.00	4.88	3.22
-19.5	6.24	28.15	5.5	6.24	26.01	30.50	4.81	3.19
-19	6.24	28.15	6	6.24	18.28	31.00	4.75	3.15
-18.5	6.24	28.15	6.5	6.24	18.28	31.50	4.68	3.12
-18	6.24	28.15	7	6.24	17.00	32.00	4.61	3.08
-17.5	6.24	28.15	7.5	6.24	17.00	32.50	4.54	3.04
-17	6.24	28.15	8	6.24	17.00	33.00	4.47	3.01
-16.5	6.24	28.15	8.5	6.24	17.00	33.50	4.40	2.97
-16	6.24	28.15	9	6.24	17.00	34.00	4.33	2.94
-15.5	6.24	28.15	9.5	6.24	16.00	34.50	4.26	2.90
-15	6.24	28.15	10	6.24	16.00	35.00	4.20	2.86
-14.5	6.24	28.15	10.5	6.24	16.00	35.50	4.13	2.83
-14	6.24	28.15	11	6.24	14.10	36.00	4.06	2.79
-13.5	6.24	28.15	11.5	6.24	14.10	36.50	3.99	2.76
-13	6.24	28.15	12	6.24	11.49	37.00	3.92	2.72
-12.5	6.24	28.15	12.5	6.24	11.49	37.50	3.85	2.68
-12	6.24	28.15	13	6.24	9.70	38.00	3.78	2.65
-11.5	6.24	28.15	13.5	6.24	9.70	38.50	3.71	2.61
-11	6.24	28.15	14	6.24	8.40	39.00	3.65	2.58
-10.5	6.24	28.15	14.5	6.24	8.40	39.50	3.58	2.54
-10	6.24	28.15	15	6.24	7.40	40.00	3.51	2.50
-9.5	6.24	28.15	15.5	6.24	7.40	40.50	3.44	2.47
-9	6.24	28.15	16	6.24	6.62	41.00	3.37	2.43
-8.5	6.24	28.15	16.5	6.24	6.62	41.50	3.30	2.40
-8	6.24	28.15	17	6.24	6.00	42.00	3.23	2.36
-7.5	6.24	28.15	17.5	6.24	6.00	42.50	3.16	2.32
-7	6.24	28.15	18	6.24	5.48	43.00	3.10	2.29
-6.5	6.24	28.15	18.5	6.24	5.48	43.50	3.03	2.25
-6	6.24	28.15	19	6.24	5.04	44.00	2.96	2.22
-5.5	6.24	28.15	19.5	6.24	5.04	44.50	2.89	2.18
-5	6.24	28.15	20	6.24	4.07	45.00	2.82	2.14
-4.5	6.24	28.15	20.5	6.24	4.07			
-4	6.24	28.15	21	6.08	3.97			
-3.5	6.24	28.15	21.5	6.08	3.97			
-3	6.24	28.15	22	5.93	3.88			
-2.5	6.24	28.15	22.5	5.93	3.88			
-2	6.24	28.15	23	5.79	3.78			
-1.5	6.24	28.15	23.5	5.79	3.78			
-1	6.24	28.15	24	5.65	3.69			
-0.5	6.24	28.15	24.5	5.65	3.69			
0	6.24	28.15	25	5.51	3.60			

10.3 Validation of the results

The table below summarises the energy and water consumption results calculated for the area of London in this report and compares them against the figures obtained from the Munters selection tool.

There are differences between the results, which could be for the following reasons:

- Both calculation tools have a different calculation methodology.
  - Munters selection tool seems to incorporate the performance data for 25 typical weather conditions (dry bulb temperature) and calculates the annual performance by splitting outdoor conditions into those 25 groups.
  - Cundall calculation procedure used in this report assesses the performance of the cooling unit separately for each hour of the year taking into account the specific weather conditions for each particular hour (dry bulb and wet bulb temperature).
- Set up of the calculation procedure. A number of assumptions have been made in the calculation procedure which may have an impact on the final results. All of the items below have been assumed based on the Munter's selection tool outputs or information provided by Munters, however, their validity needs to be carefully reviewed in order to confirm the results:
  - Performance Coefficients, e.g. pump power, SFP, DX COP figures.
  - Control strategy, e.g. set point temperatures, modulating fan powers, etc
  - Calculation methodology, including the formulas selected to describe all the phenomena occurring in the cooling units, assumption of the ideal processes (e.g. ideal humidification), etc.

A large variation in water consumption has been observed. This could simply be put down to the cautious figures provided by the manufacturer, or alternatively it could be attributed to the heat exchange process when wet. The Cundall model saturates all the scavenger air prior to entering the heat exchanger. This is not a true representation of the process in the Munters unit wherein, in fact, a constant evaporation process is taking place as air passes up through the heat exchanger, maintaining saturation. This will result in better efficiency and more water evaporated.

The number of hours Dx cooling is on has a large variation for the London data. For the majority of hours that Dx is on, the temperature is only marginally over the activation set point, hence the possibility for a large variation in hours and a small variation in kWh.

A likely cause for error is the heat exchanger efficiency curve used by Cundall and provided by the manufacturer. This graph is for a particular ambient temperature and will give erroneous results at higher ambient temperatures, causing scavenger energy consumption to increase. This explains the larger variations between the calculation methods in hotter countries.

All the above factors may have a bearing on the final results.

	Data Received from Munters	Calculated Outputs	Percentage Change
Annual Energy Consumption [kWh]	300,063	311,233	3.5%
Annual Water Consumption [l]	5,441	2,687	-49%
Predicted hours with Dx cooling ON	16	84	525%

** London Heathrow