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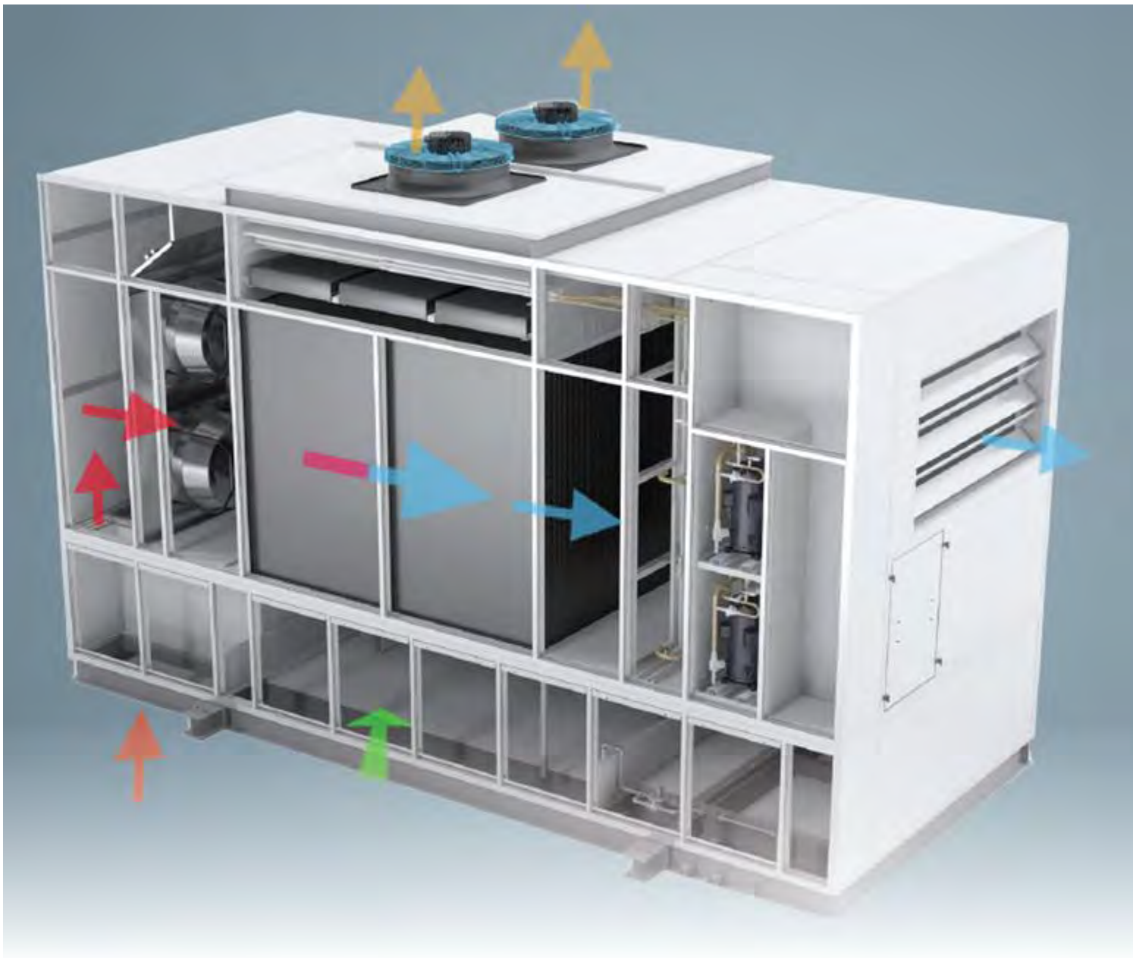

Munters

Oasis™ DCiE – Indirect Evaporative Cooler

Product Engineering Review – Desktop Energy and Water Study

Job No: 1012111

Latest Revision: C

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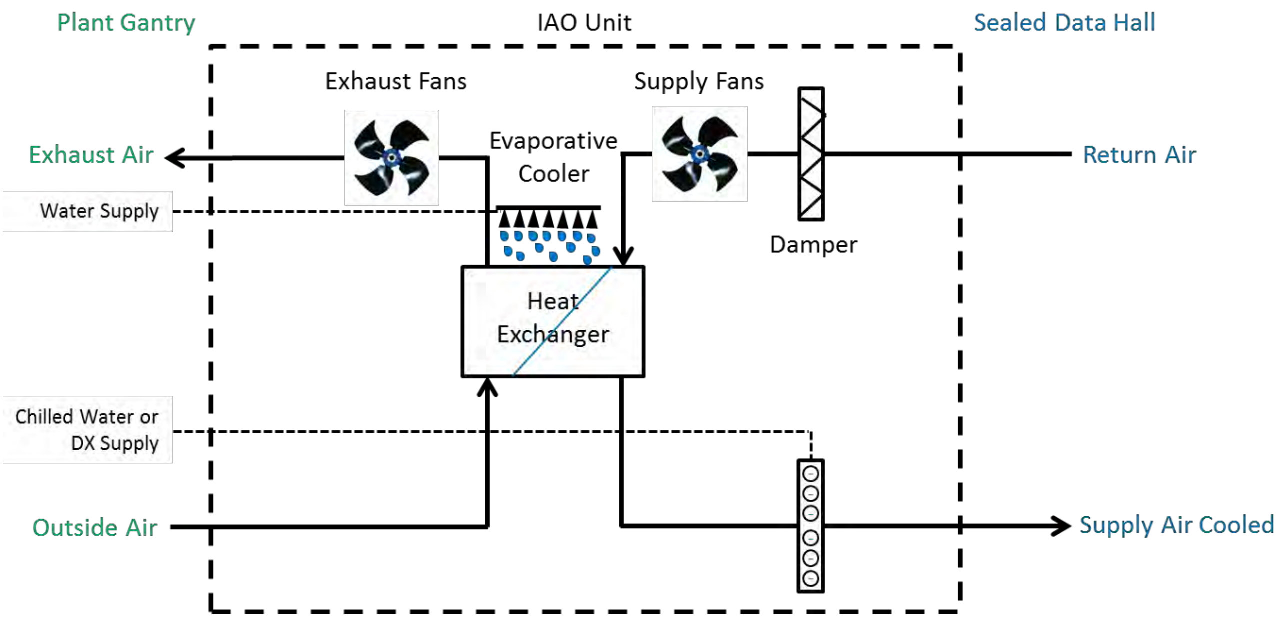
Executive Summary

Cundall has been engaged by Munters to provide a Product Engineering Review of the Oasis™ Indirect Evaporative Cooler in comparison to other suitable technologies in East Asia, South East Asia and Australia. This report will focus on the operational energy and water cost impacts of the systems whilst also discussing the products operation, capital cost requirements and design considerations. The Munters Oasis™ Indirect Evaporative Cooler has been assessed against a standard chiller with CRAHs, free cooling air cooled chiller, water cooled chiller and Direct Air Optimisation.

The Oasis™ Indirect Evaporative Cooler system has been designed specifically for data centres with energy efficiency as the central driver. The unit takes advantage of the cooling effect created by evaporation of water (liquid) to vapour, and the updated permissible supply air conditions published by ASHRAE. The system uses an air to air heat exchanger that is combined with the following functions, with the set points based on the rooms supply and return air conditions:

- Low ambient (Dry) - Air to air heat exchange
- Low ambient (Wet) - Air to air heat exchange with evaporative cooling
- Medium ambient - Air to air heat exchange with evaporative and mechanical cooling
- High ambient – Recirculation mode with mechanical cooling

The Oasis™ Indirect Evaporative Cooler has been developed following the principles of Indirect Air Optimisation (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.

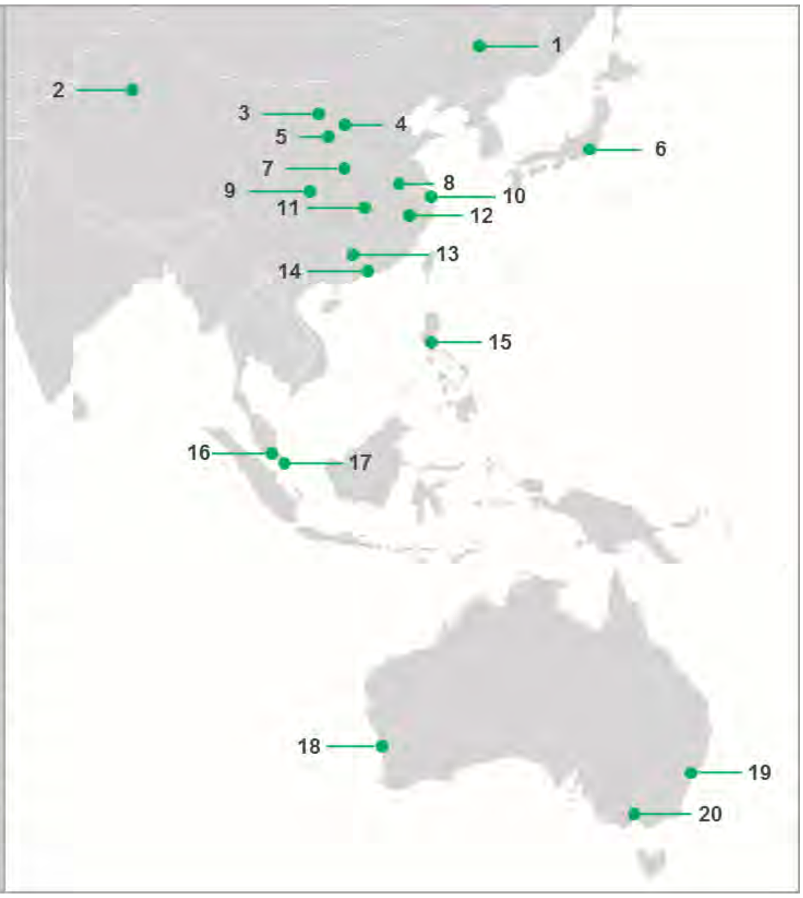
The system can incorporate a back-up mechanical cooling system to be used when external ambient conditions rise above the temperature at which air can be delivered to the servers within permissible levels. DAO has been the first derivative of this technology to gain market acceptance. The primary reasons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

The key benefits of the Munters Oasis™ Indirect Evaporative Cooler are as follows:

- Operational energy savings, leading to annual operational cost savings.
- Peak electrical demand savings, leading to annual operational cost savings and capital cost savings in electrical support systems.
- Operational water savings when compared to water cooled chillers, leading to annual operational cost savings.
- Low PUE allowing effective marketing to energy conscious clients
- Reduced contamination potential when compared to a Direct Air Optimisation system.
- Effective in the implementation of a modular stage by stage design allowing deferred commitment of capital costs.
- Low maintenance requirements as compared to Direct Air Optimisation.

A summary of the locations assessed and the operational costs savings compared is shown below. This analysis is based on a nominal data hall with 720kW capacity with the savings showing the utility, electricity and water, cost reductions compared to water cooled chillers with CHARs.

01.	Harbin (HeiLongJiang), China	69%
02.	Urumqi (Xinjiang), China	69%
03.	Hohhot, Inner Mongolia	70%
04.	Beijing, China	63%
05.	Shijiazhuang (HeBei), China	63%
06.	Tokyo, Japan	67%
07.	Zhengzhou (Henan), China	63%
08.	Nanjing (Jiangsu), China	61%
09.	Chongqing, China	60%
10.	Shanghai, China	61%
11.	Wuhan (Hubei), China	58%
12.	Hangzhou (ZheJiang), China	61%
13.	Guangzhou (Guangdong), China	54%
14.	Hong Kong, Hong Kong	54%
15.	Manila, Philippines	42%
16.	Kuala Lumpur, Malaysia	42%
17.	Singapore, Singapore	37%
18.	Perth, Australia	69%
19.	Sydney, Australia	71%
20.	Melbourne, Australia	72%



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Contents

1. 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 primary function of this document is to provide a comparative engineering review of the Oasis product and its modes of operation, with reference to operating energy and water consumption.

This report will cover the following items:

1. Introduction to the Munters Oasis™ unit.
2. Discussion on data centre cooling options and the background information to it effectiveness.
3. Capital Cost analysis for Singapore.
4. Operational energy and cost analysis for 20 locations.

The report then summarises the conclusions and provides supporting information in the appendices.

1.2 Product Overview

Indirect Air Optimisation, IAO (equally known as air-side economisation) is a strategy that utilises the cooling effect of air that is saturated to various levels. “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”[i]

The Oasis™ Indirect Evaporative Cooler has been designed in response to the demand from data centre owners and operators for a highly efficient cooling strategy. A number of factors including energy costs, environmental policy and increasing IT densities has triggered a shift from traditional chilled water systems.

The Oasis™ Indirect Evaporative Cooler system has been designed specifically for data centres with energy efficiency as the central driver. The unit takes advantage of the cooling effect created by evaporation of water (liquid) to vapour, and the updated permissible supply air conditions published by ASHRAE in TC9.9. The system uses an air to air heat exchanger that is combined with the following functions, with the set points based on the rooms supply and return air conditions:

- Low ambient (Dry) - Air to air heat exchange
- Low ambient (Wet) - Air to air heat exchange with evaporative cooling
- Medium ambient - Air to air heat exchange with evaporative and mechanical cooling
- High ambient – Recirculation mode with mechanical cooling

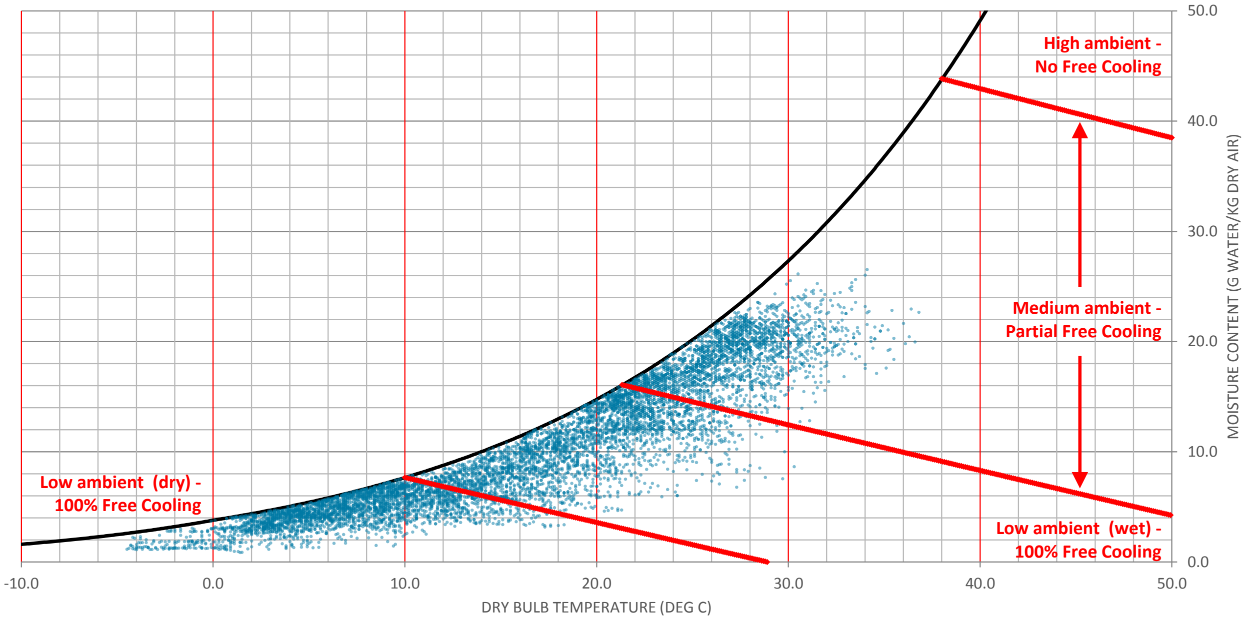

Figure 1: Psychometric weather data for Shanghai, China, showing the different cooling methods.

In recent years a number of IAO cooling units have come to market promising reduced Power Usage Effectiveness (PUE) figures by reducing the energy losses consumed by mechanical plant. PUE is a metric used to determine the energy efficiency of a data centre. PUE is determined by dividing the amount of power entering a data centre by the power used to run the computer infrastructure within it.

This method of cooling has emerged as a development from direct air optimised (DAO) cooling. In many locations with favourable climate DAO remains a credible method of cooling, however, 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.

Where ambient conditions dictate a need for supplementary cooling, the Oasis™ Indirect Evaporative Cooler will be fitted with inbound cooling coils from either centralised chilled water or unitised direct expansion. The coil could be sized to meet the ASHRAE extreme peak conditions for ambient wet and dry bulb temperatures as opposed to the peak conditions for added resiliency.

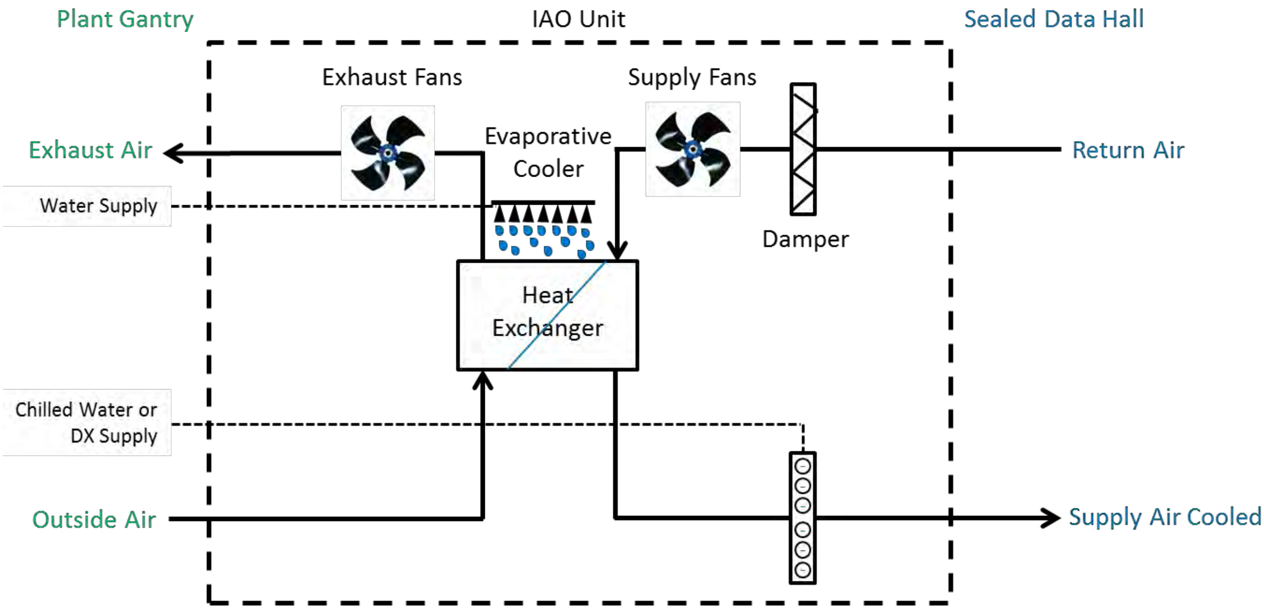

Figure 2: Schematic of the key IAC components.

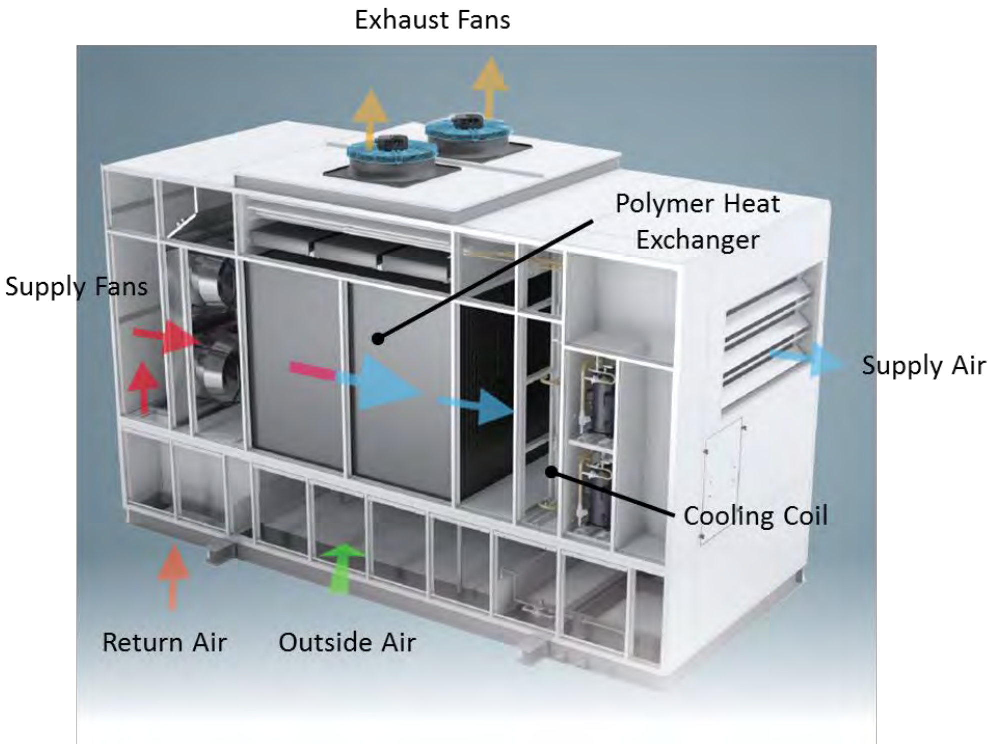

Figure 3: 3D representation of an Oasis™ unit, with key features labelled.

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 chilled water cooling medium. The unit has also been designed to deliver air at increased supply temperatures to maximise ambient cooling, particularly where elevated data hall temperatures can be achieved.

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 tolerances. 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 major cities throughout East Asia, South East Asia and Australia:

1. Harbin (HeiLongJiang), China
2. Urumqi (Xinjiang), China
3. Hohhot, Inner Mongolia
4. Beijing, China
5. Shijiazhuang (HeBei), China
6. Tokyo, Japan
7. Zhengzhou (Henan), China
8. Nanjing (Jiangsu), China
9. Chongqing, China
10. Shanghai, China
11. Wuhan (Hubei), China
12. Hangzhou (ZheJiang), China
13. Guangzhou (Guangdong), China
14. Hong Kong, Hong Kong
15. Manila, Philippines
16. Kuala Lumpur, Malaysia
17. Singapore, Singapore
18. Perth, Australia
19. Sydney, Australia
20. Melbourne, Australia

The Oasis™ Indirect Evaporative Cooler system is designed to be applied throughout the world. The 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 wet bulb temperature is the lowest temperature that can be reached by the evaporation of water, most commonly encountered on wet skin when you sweat.

When water evaporates, or changes state from a liquid to a gas, the discharge of the gas also takes an amount of heat with it. The result is a decreased amount of heat and thus decreased temperature in the surface. 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.

Weather data used for analysis has been taken from hourly records downloaded from the US Department of Energy in EnergyPlus weather format. This weather data utilises 10 years of actual weather data to provide average conditions which also represents minimum and maximum conditions accurately.

Location	Typical Temperature Profile
1. Harbin (HeiLongJiang), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -28°C and 30°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature follows a similar temperature profile with maximum of 27°C WB. Free Cooling Potential: 95% Partial Free Cooling Potential: 5%
2. Urumqi (Xinjiang), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -20°C and 31°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature remains much lower with dry air coinciding with high temperatures, the maximum wet bulb temperature is 20°C. Free Cooling Potential: 100% Partial Free Cooling Potential: 0%
3. Hohhot, Inner Mongolia	Temperature Conditions: Ambient dry bulb temperatures are commonly between -18°C and 31°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature follows a similar temperature profile with maximum of 25°C WB. Free Cooling Potential: 99% Partial Free Cooling Potential: 1%

Location	Typical Temperature Profile
4. Beijing, China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -10°C and 35°C, with maximum dry bulb temperatures of 37°C. The wet bulb temperature follows a similar temperature profile shifted by 5°C with maximum of 31°C WB. Free Cooling Potential: 85% Partial Free Cooling Potential: 15%
5. Shijiazhuang (HeBei), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -7°C and 34°C, with maximum dry bulb temperatures of 38°C. The wet bulb temperature follows a similar temperature profile with maximum of 29°C WB. Free Cooling Potential: 85% Partial Free Cooling Potential: 15%
6. Tokyo, Japan	Temperature Conditions: Ambient dry bulb temperatures are commonly between -5°C and 25°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature follows a similar temperature profile with maximum of 30°C WB. Free Cooling Potential: 86% Partial Free Cooling Potential: 14%
7. Zhengzhou (Henan), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -5°C and 34°C, with maximum dry bulb temperatures of 37°C. The wet bulb temperature follows a similar temperature profile with maximum of 30°C WB. Free Cooling Potential: 81% Partial Free Cooling Potential: 19%
8. Nanjing (Jiangsu), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -2°C and 34°C, with maximum dry bulb temperatures of 37°C. The wet bulb temperature follows a similar temperature profile with maximum of 27°C WB. Free Cooling Potential: 76% Partial Free Cooling Potential: 24%
9. Chongqing, China	Temperature Conditions: Ambient dry bulb temperatures are commonly between 5°C and 35°C, with maximum dry bulb temperatures of 37°C. The wet bulb temperature follows a similar temperature profile with maximum of 27°C WB. Free Cooling Potential: 70% Partial Free Cooling Potential: 30%
10. Shanghai, China	Temperature Conditions: Ambient dry bulb temperatures are commonly between 1°C and 33°C, with maximum dry bulb temperatures of 36°C. The wet bulb temperature follows a similar temperature profile with maximum of 30°C WB. Free Cooling Potential: 73% Partial Free Cooling Potential: 27%
11. Wuhan (Hubei), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between -1°C and 35°C, with maximum dry bulb temperatures of 38°C. The wet bulb temperature follows a similar temperature profile with maximum of 31°C WB. Free Cooling Potential: 70% Partial Free Cooling Potential: 30%
12. Hangzhou (ZheJiang), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between 0°C and 35°C, with maximum dry bulb temperatures of 39°C. The wet bulb temperature follows a similar temperature profile with maximum of 30°C WB. Free Cooling Potential: 70% Partial Free Cooling Potential: 30%
13. Guangzhou (Guangdong), China	Temperature Conditions: Ambient dry bulb temperatures are commonly between 8°C and 25°C, with maximum dry bulb temperatures of 34°C. The wet bulb temperature follows a similar temperature profile with maximum of 31°C WB. Free Cooling Potential: 50% Partial Free Cooling Potential: 50%

Location	Typical Temperature Profile
14. Hong Kong, Hong Kong	Temperature Conditions: Ambient dry bulb temperatures are commonly between 11°C and 34°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature follows a similar temperature profile shifted lower by 2-3°C, with maximum of 28°C WB. Free Cooling Potential: 47% Partial Free Cooling Potential: 53%
15. Manila, Philippines	Temperature Conditions: Ambient dry bulb temperatures are commonly between 23°C and 34°C, with maximum dry bulb temperatures of 36°C. The wet bulb temperature is typically between 21°C and 29°C. Free Cooling Potential: 3% Partial Free Cooling Potential: 97%
16. Kuala Lumpur, Malaysia	Temperature Conditions: Ambient dry bulb temperatures are commonly between 23°C and 33°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature is typically between 23°C and 28°C. Free Cooling Potential: 0% Partial Free Cooling Potential: 100%
17. Singapore, Singapore	Temperature Conditions: Ambient dry bulb temperatures are commonly between 23°C and 33°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature is typically between 23°C and 28°C. Free Cooling Potential: 0% Partial Free Cooling Potential: 100%
18. Perth, Australia	Temperature Conditions: Ambient dry bulb temperatures are commonly between 6°C and 31°C, with maximum dry bulb temperatures of 39°C. The wet bulb temperature follows a similar temperature profile shifter lower by 5°C, a maximum wet bulb temperature is much lower than the dry bulb at 25°C. Free Cooling Potential: 99% Partial Free Cooling Potential: 1%
19. Sydney, Australia	Temperature Conditions: Ambient dry bulb temperatures are commonly between 8°C and 28°C, with maximum dry bulb temperatures of 35°C. The wet bulb temperature follows a similar temperature profile shifter lower by 2-3°C, a maximum wet bulb temperature of 25°C is recorded. Free Cooling Potential: 96% Partial Free Cooling Potential: 4%
20. Melbourne, Australia	Temperature Conditions: Ambient dry bulb temperatures are commonly between 6°C and 30°C, with maximum dry bulb temperatures of 39°C. The wet bulb temperature follows a similar temperature profile shifted lower by 2-3°C, a maximum wet bulb temperature is much lower than the dry bulb at 24°C. Free Cooling Potential: 100% Partial Free Cooling Potential: 0%

A complete set of weather data is shown in Appendix C: - Weather Profiles.

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2. Data Centre Cooling Strategies

This section starts by outlining the background which makes IAO achievable before discussing the traditional ideas of data centre cooling, followed by the concept of IAO. 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.

2.1 ASHRAE Compliance

Before discussing the different cooling options and in particular the Munters Oasis™ 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 A1’ ASHRAE guidelines. It is therefore widely accepted that the equipment air intake temperatures be maintained within the Class A1 ASHRAE bands defined in Figure 4.

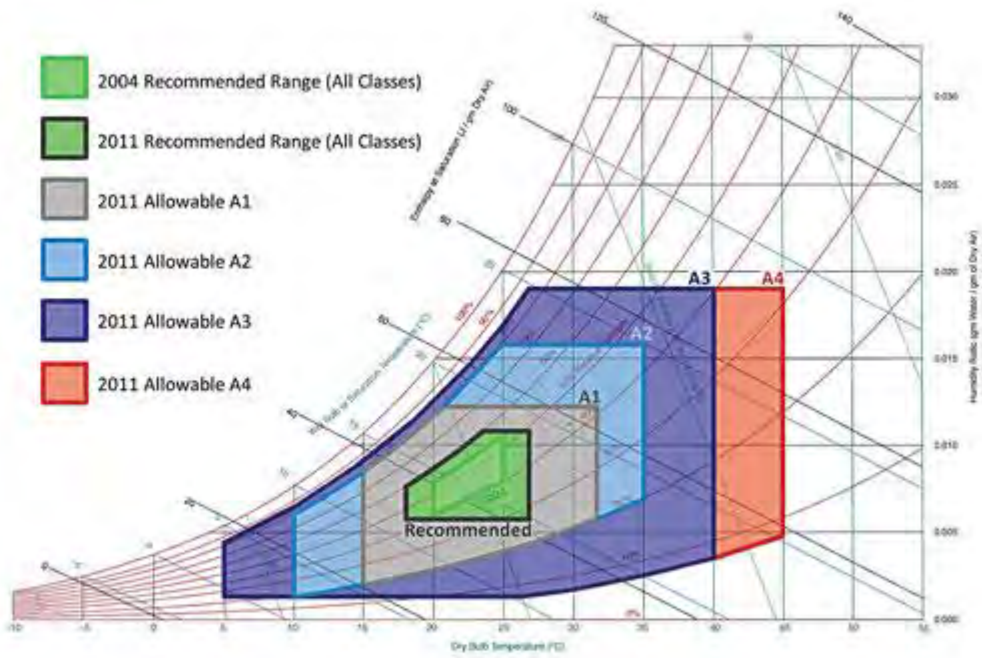

Figure 4: ASHRAE 2011 Environmental Classes for Data Centres

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 ‘Recommended Envelope’ region in Figure 4. 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 in the event of system failure. 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, regardless of the cooling strategies adopted.

The TRY weather profile for Beijing, China is displayed on the Psychometric chart in Figure 5. Also plotted on the figure are the regions that define the operation of a typical DAO system. As can be seen, the Beijing weather profile indicates a wide ranging climate with temperatures peaking above 35°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 5, 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.

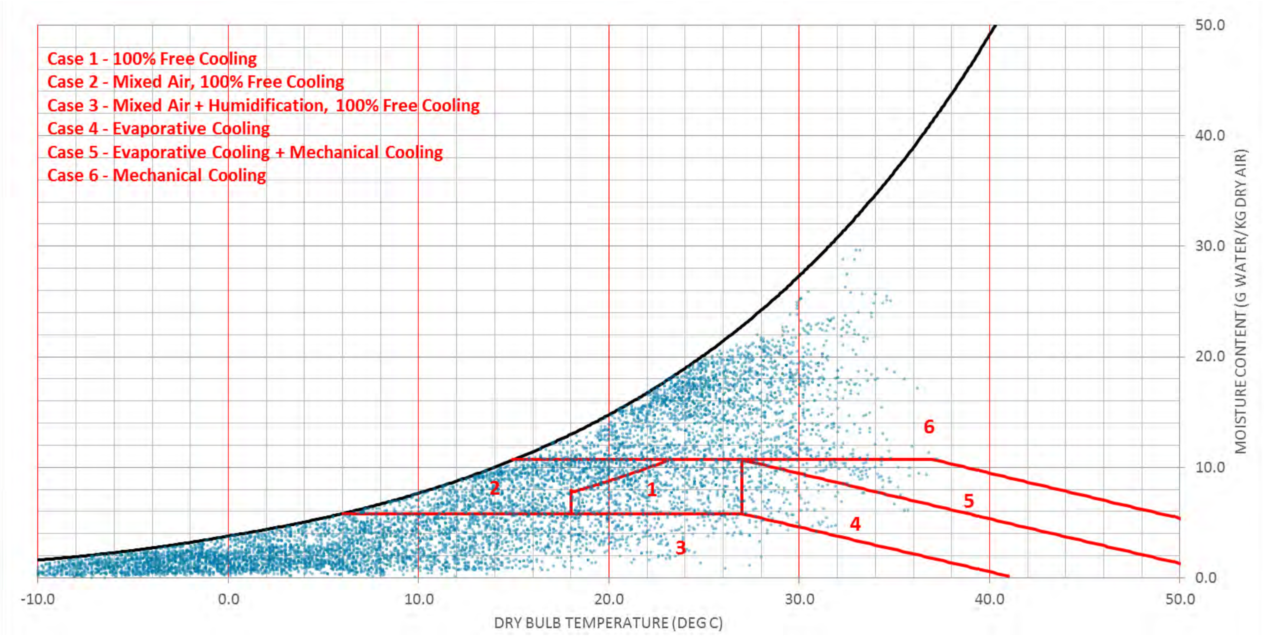

Figure 5: TRY Weather Data for Beijing, China and the implications of applying DAO in this region. The data is plotted on a Psychometric chart that is overlaid with the ASHRAE 'Class 1' Zone.

2.2 Efficiency Demands

It has been recognised that the power consumption of data centres is climbing steadily to meet the growing demands data storage and processing.

Location	2012	2013	Increase
Global	36,245	38,840	7%
Asia Pacific	9,750	10,375	6%
Latin America	2,380	2,740	15%
North America	10,810	11,550	7%
Europe	12,705	13,470	6%
MEA	600	705	18%
Malaysia	220	255	16%
Indonesia	100	110	10%
Singapore	930	1,020	10%
China (PRC)	1,560	1,700	9%
Other Markets	3,950	4,300	9%
India	1,250	1,300	4%
Australasia	1,420	1,380	-3%
Hong Kong	320	310	-3%

Figure 6: Data Centre growth worldwide, focusing on Australasia[ii]

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[iii].

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. IAO does offer a more scalable source of cooling that is better suited to modern demands for modular 'just in time' data centres whilst providing minimal maintenance requirements.

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 can be higher due to increased peak capacities.

2.3 Data Hall Contamination

Contamination of the data hall environment is a constant threat to data centre operations. The impacts of the contamination can range from a decrease in energy efficiency to a catastrophic failure. Contamination comes in two forms; particulate matter and gaseous.

External sources of contamination include vehicle exhausts, by-products from electricity generation, sea salt, natural and artificial fibres, plant pollens and wind-blown dust. Contaminating gases occur naturally or result from industrial processes. They can either act alone or together with other gases or particulate matter, forming compounds that oxidise metallic materials.

These contaminates can enter through the data hall though air conditioning, open doors, on clothing and any other items brought into the room.

Some cities and countries in Asia contain the highest air pollution levels in the world, with China of particular note. It is therefore critically important to consider methods of reducing the ingress of contamination in association with constant cleaning and operational practices.

The fact that the IAO does not utilise the outside air directly in the process maintains the same level of contaminate exposure as a tradition chiller and CRAH arrangement. Conversely a DAO system would utilise fresh air directly where ambient conditions arise, adding potential contamination to the data hall.

In 2011 ASHRAE released a whitepaper on Gaseous and Particulate Contamination Guidelines For Data Centers. It describes the risk to IT Equipment in data centres facilities that may have harmful environments resulting from the ingress of outdoor particulate and/or gaseous contamination. The document stated that for a small number of data centers, located mostly in the emerging markets, contamination can be a serious risk, and it provided insight into how to manage the contamination risk.

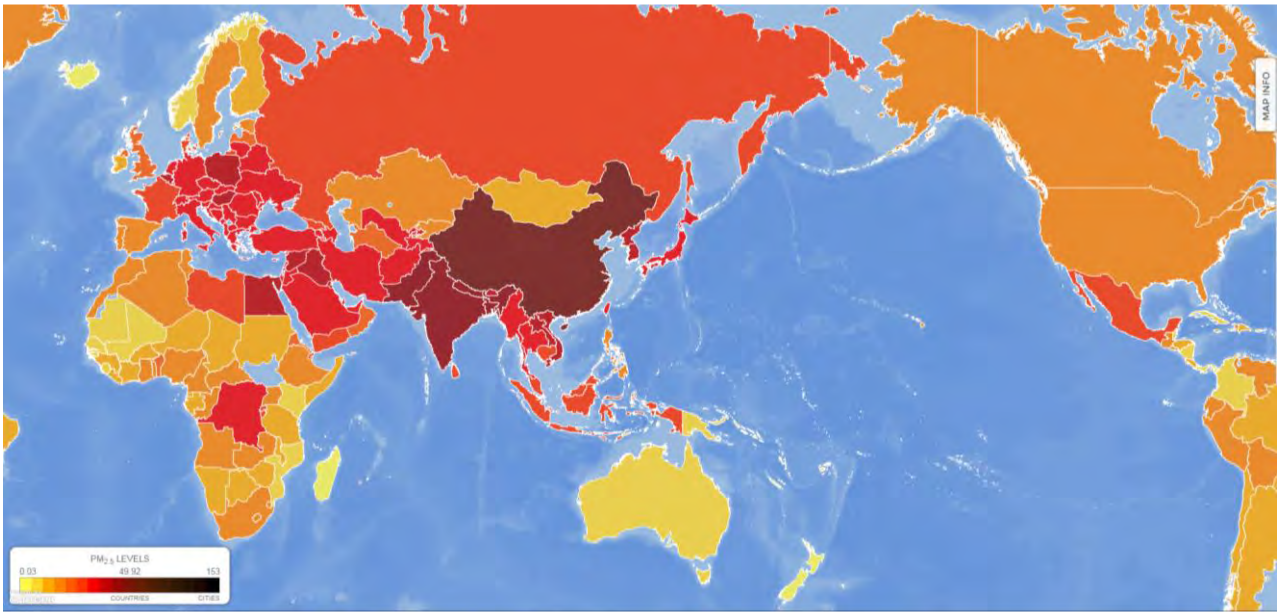

Figure 7: Global air pollution (PM2.5 levels)[iv]

2.4 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 approaches 12-14°C (i.e. 26°C IN, 38°C OUT), although some manufacturers are quoting much higher allowable ∆T's. In more traditional data centres operating in full recirculation mode with CRAC/CRAHs, a considerable amount of energy is required to cool this hot exhaust air by 12-14°C. This traditional concept with CRAC/CRAHs, chillers and pumps is demonstrated in Figure 8. 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.

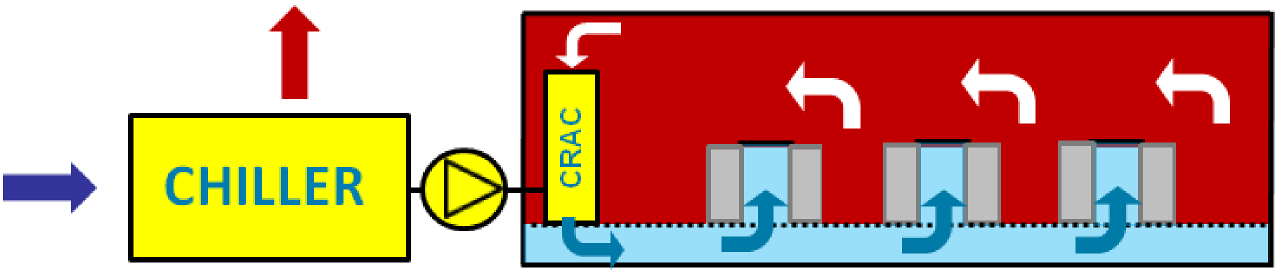

Figure 8: Traditional cooling utilising chillers and CRAHs

Fresh air cooling (i.e. no mechanical cooling) presents a viable option in favourable climates, 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.

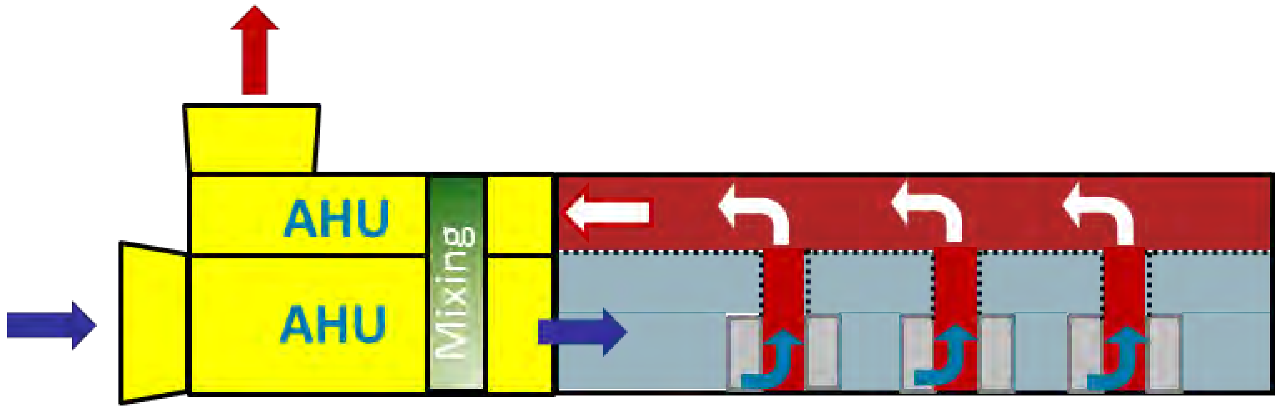

Figure 9: Direct fresh air optimised cooling, DAO

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°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 also reduce the Power Usage Effectiveness (PUE) of data centres.

The concept behind an outside 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)[v], Google[vi] and Yahoo (Lockport)[vii], thus demonstrating that this type of strategy is viable. The uptake of this concept has been suppressed due to concern over reliability due to the number moving components, risk of an external contamination impacts, and an unwillingness to move away from proven methods. This has led to IAO being explored as a preferred cooling alternative.

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 9). 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 aisles.

2.5 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 10, 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 an evaporative polymer tube air to air heat exchanger, and cooled down to a suitable temperature for re-delivery into the data hall.

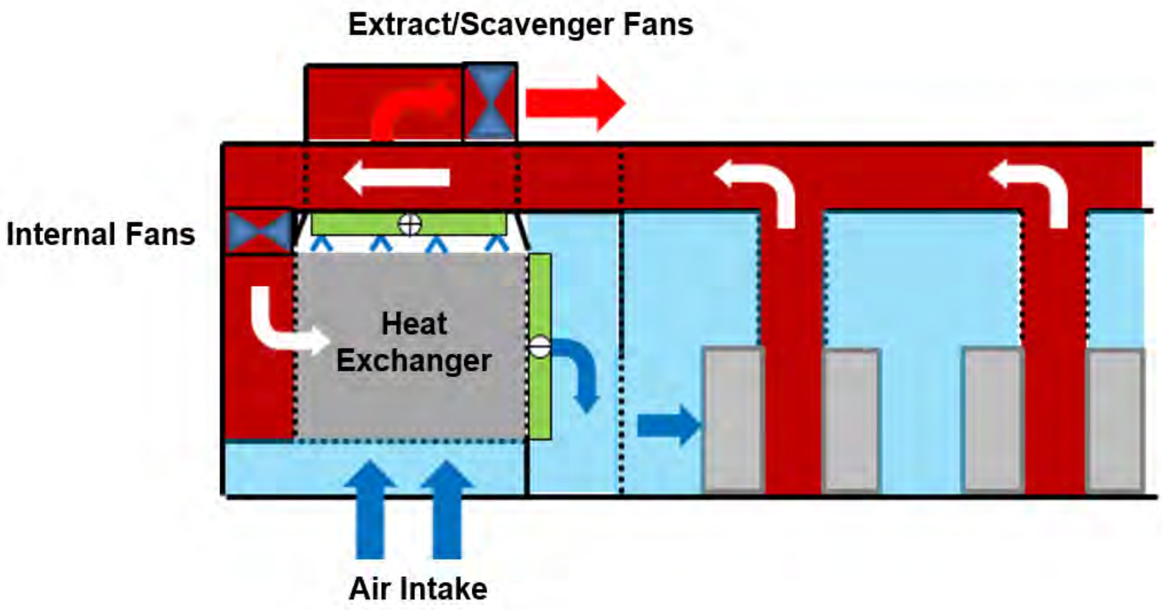

Figure 10: The application of Indirect Air Optimisation with Hot Aisle Containment (IAO).

2.6 IAO Using Munters Oasis

Based on information supplied by the manufacturer, it can be seen in Figure 11 that the majority of operating hours of the Oasis™ Indirect Evaporative Cooler will require evaporative cooling or a combination of evaporative and mechanical cooling. Below approximately 22°C WB, the air is cold enough to cool the data centre through the polymer heat exchanger without supplementary mechanical cooling. The 22°C WB temperature at which mechanical cooling has to be engaged will depend on the local climate, however the 'top-up' cooling is used to supplement the evaporative system.

It is important to note that the mechanical cooling top-up is different from the DAO system whereby the mechanical cooling needs to be sized to accommodate the full cooling load whilst operating in the recirculation mode.

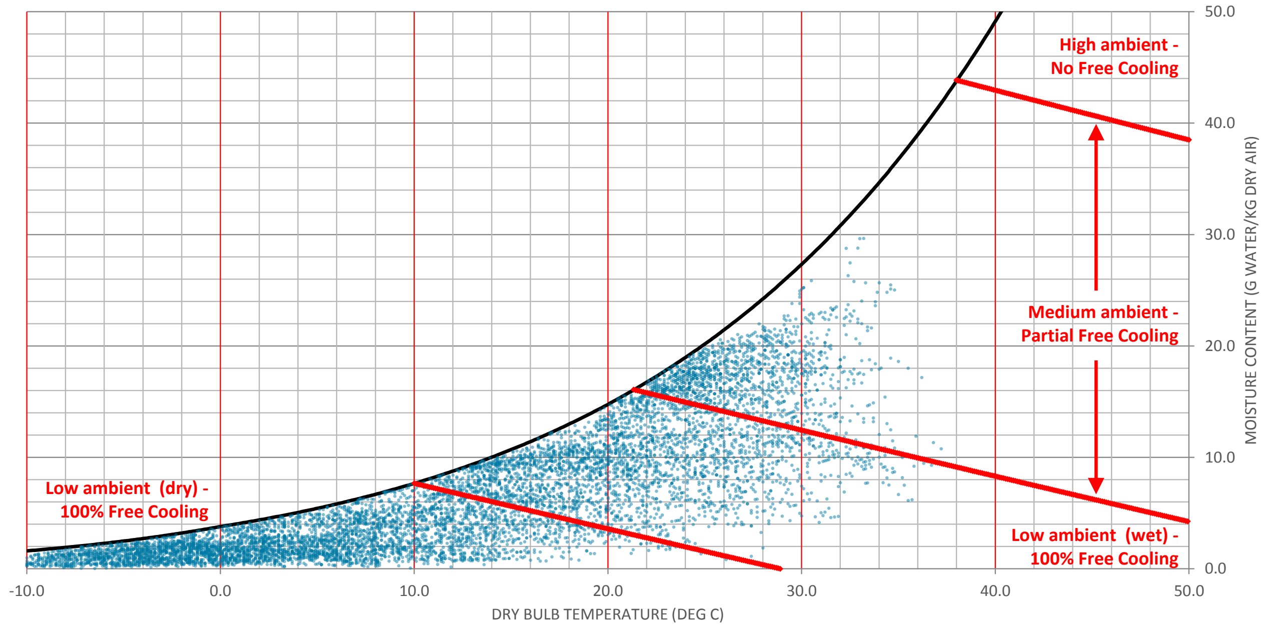

Figure 11:TRY Weather Data for Beijing and the Implications of Applying Evaporative Cooling with Oasis in this Region.

IAO using the Oasis™ 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 utilised in the cooling process. Typically, 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.

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3. Capital Costing

These costs are for guidance only and relate to the hypothetical 720kW test case, with prices provided for Singapore.

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 Description	Main Cooling Plant	Unit Cost (SGD $)	Total Cost (SGD $)
Oasis™ Indirect Evaporative Cooler	DCIE Oasis unit (×6)	$250,000	$1,500,000
	DCIE Oasis units for support spaces (×2)	$250,000	$500,000
	MUA/pressurisation AHU (x1)	$45,000	$45,000
	Ductwork	$80,000	$80,000
	Water storage for 2no. tanks	$45,000	$90,000
	Total		**$2,215,000**
Water Cooled Chilled Water with CRAH	Chillers (×3)	$120,000	$360,000
	Heat Rejection (x3)	$35,000	$105,000
	CRAC units (×14)	$880,000	$560,000
	Pumps, Pipework & Ancillaries	$45,000	$880,000
	Fresh Air AHU (x1)		$45,000
	Total		**$1,950,000**

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), including greater spatial take and increased capital costs for these options. Within the location by location results the peak electrical capacity is also shown, this reduction in electrical capacity will inform the support infrastructure savings, refer to Section 4.14 for further details of the potential savings. The cost savings from the reduced infrastructure can be considerable but depend highly on location and data hall redundancy levels. On a recent data centre project in US, the client was able to reduce incoming copper and size of generators by 20%.

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 aisles 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. With fewer interfaces between heat transfer mediums, fewer systems need to be verified and the ASHRAE sequence of commissioning levels is reduced.

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

4. Operational Costs

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

1. Harbin (HeiLongJiang), China
2. Urumqi (Xinjiang), China
3. Hohhot, Inner Mongolia
4. Beijing, China
5. Shijiazhuang (HeBei), China
6. Tokyo, Japan
7. Zhengzhou (Henan), China
8. Nanjing (Jiangsu), China
9. Chongqing, China
10. Shanghai, China
11. Wuhan (Hubei), China
12. Hangzhou (ZheJiang), China
13. Guangzhou (Guangdong), China
14. Hong Kong, Hong Kong
15. Manila, Philippines
16. Kuala Lumpur, Malaysia
17. Singapore, Singapore
18. Perth, Australia
19. Sydney, Australia
20. Melbourne, Australia

The calculation is based on the 720kW data hall (1000W/m²). The supply/return temperature is assumed to be 26/38°C for Munters Oasis™ option and for chilled water options (CHW temperature delta is 7°C). The Munters Oasis™ is cooled by in-built mechanical cooling whilst all other options are cooled by a centralised chillers of various configurations.

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.

The energy and water 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 Appendix A: - Basis of Calculations. Cundall have been involved in operational performance testing of the Munters Oasis™ units under different ambient conditions to verify the accuracy of these calculations.

The flat characteristic of the standard air cooled 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 cooler months. At the same time, free-cooling chiller efficiency is slightly lower than for standard air cooled chillers during design summer conditions and therefore their peak power consumption is higher. The DAO option provides a benefit over the standard air cooled chiller arrangement where ambient conditions allow.

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. 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. The results show savings of between 37% in Singapore and 72% in Melbourne are achievable when compared to a water cooled chiller system.

All costs in the following sections are shown in the local currency.

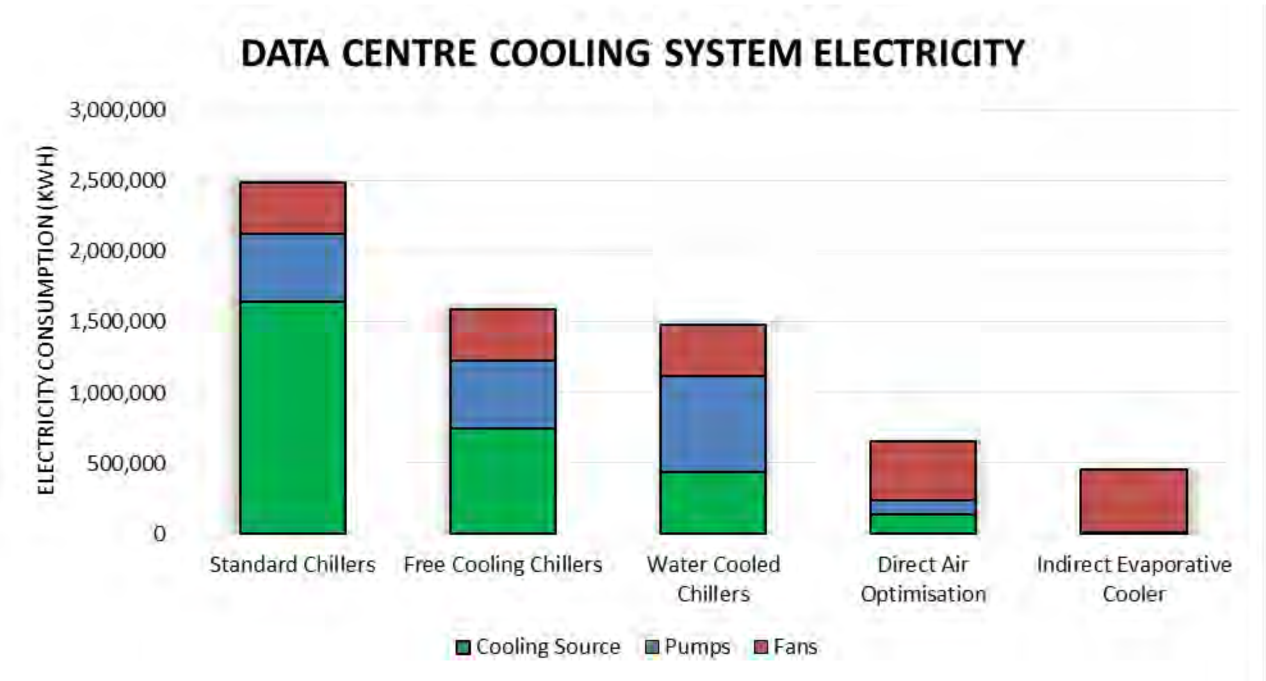
4.1 Harbin (HeiLongJiang), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Harbin.

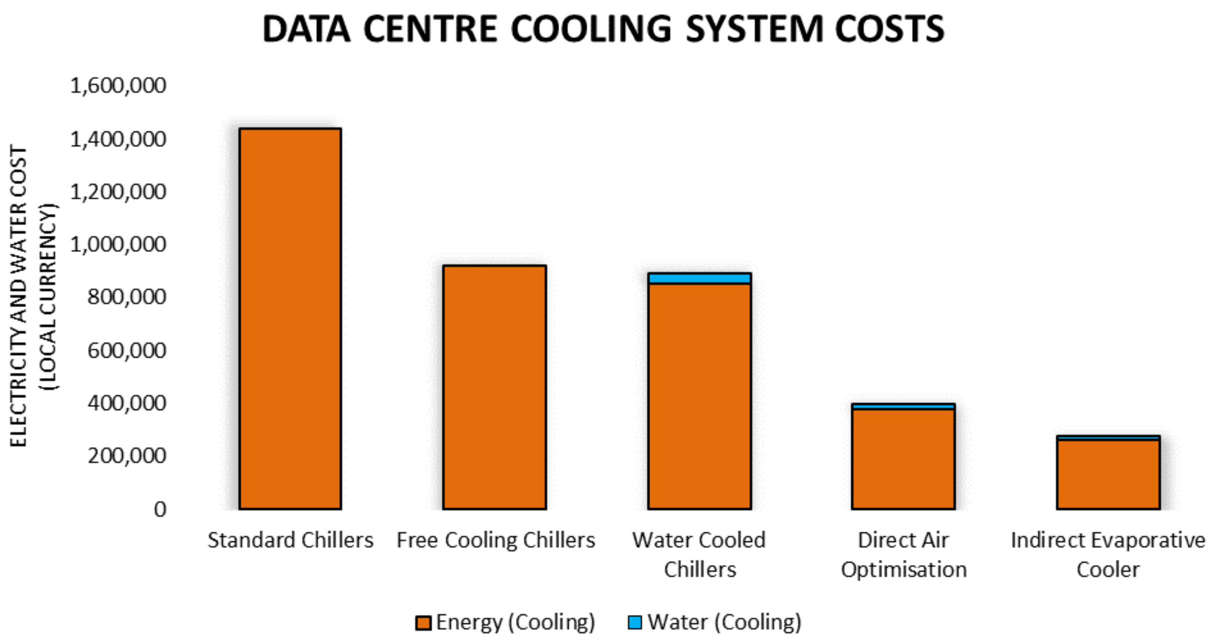
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[C]		1.39	1.25	1.23	1.10	1.07
WUE (l/kWh)		0.00	0.00	1.92	0.93	0.68
Energy Consumption [kWh]	Cooling Source[E]	1,646,921	746,318	435,567	136,133	9,257
	Fans	365,390	365,390	365,390	421,604	443,421
	CHW & CW Pumps	476,940	476,940	678,106	96,309	0
	Total	2,489,251	1,588,648	1,479,063	654,047	452,678
Peak Capacity (kW)	HVAC Peak Power	306	337	293	306	82
	Savings[A]	-4%	-15%	0%	-4%	72%
Water Consumption [kL]	Total[F]	0	0	12,130	5,874	4,297
	Savings[A]	100%	100%	0%	52%	65%
Carbon Emissions [kg CO_2]	Total	2,426,024	1,548,297	1,441,495	637,434	441,180
	Savings[A]	-68%	-7%	0%	56%	69%
Annual Costs[D] Cooling Only	Energy (Cooling)	1,438,787	918,239	854,899	378,039	261,648
	Water (Cooling)	0	0	37,604	18,208	13,322
	Total Costs (Cooling)	1,438,787	918,239	892,502	396,247	274,970
	Cost Savings [%][A]	-61%	-3%	0%	56%	69%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

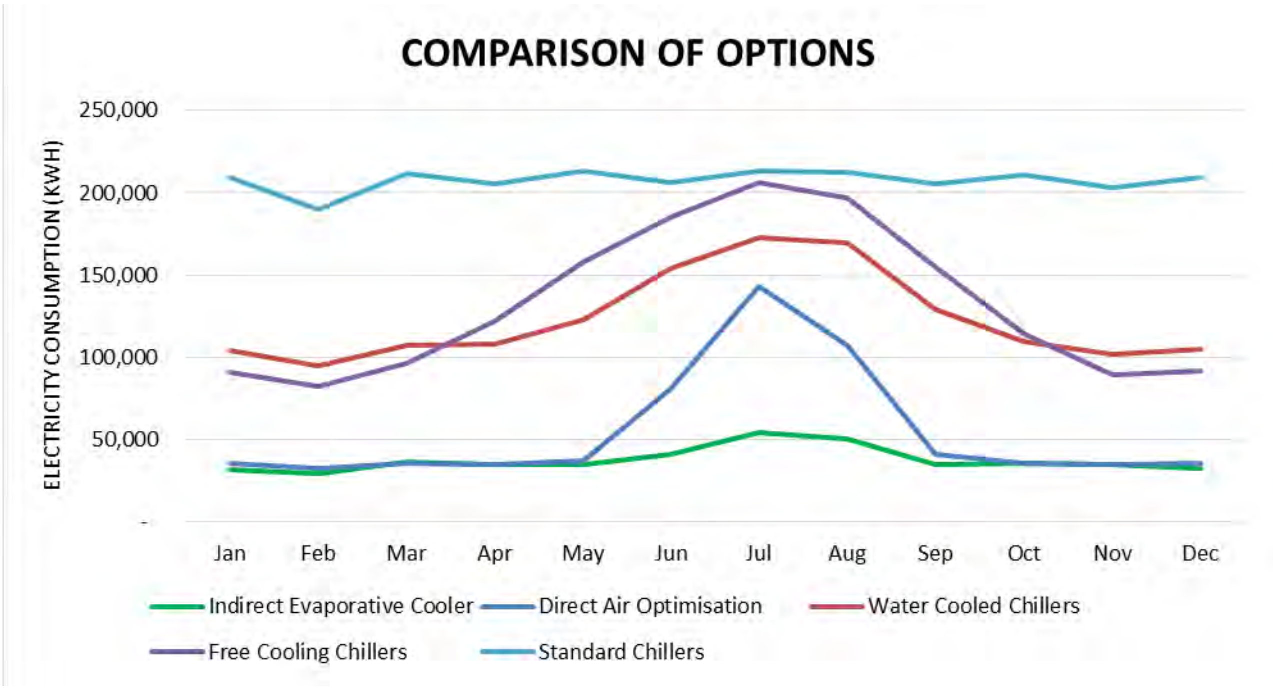
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



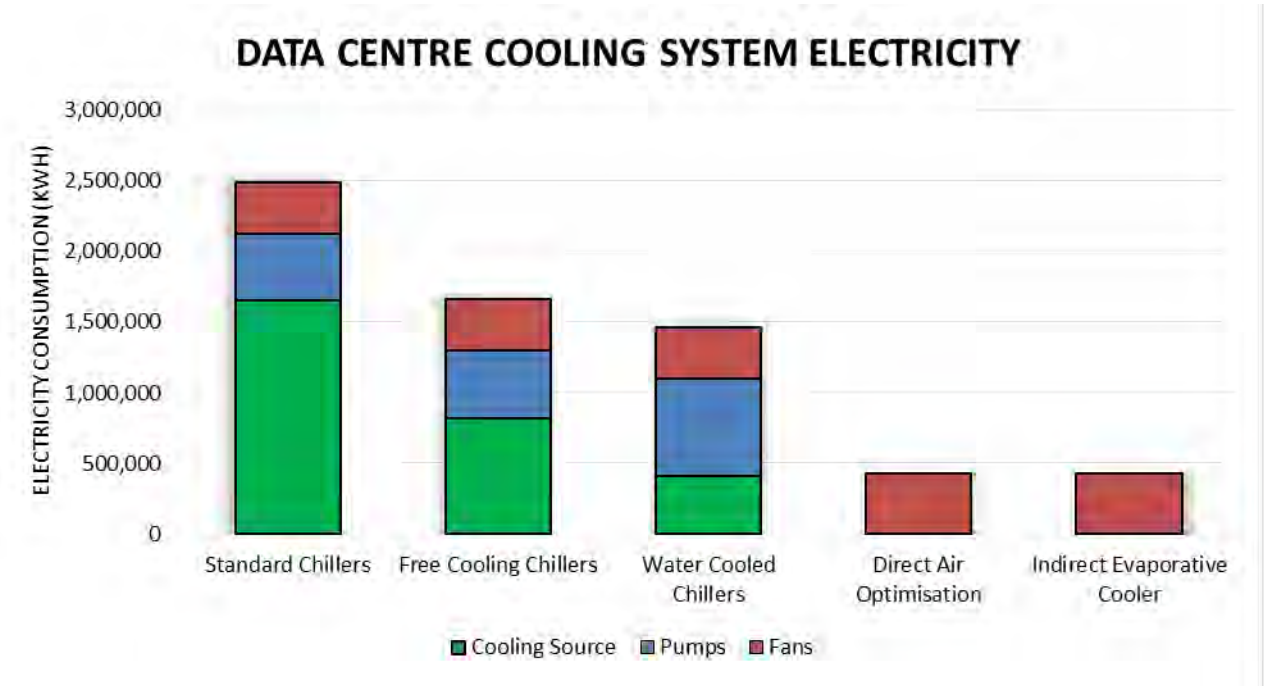
4.2 Urumqi (Xinjiang), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Urumqi.

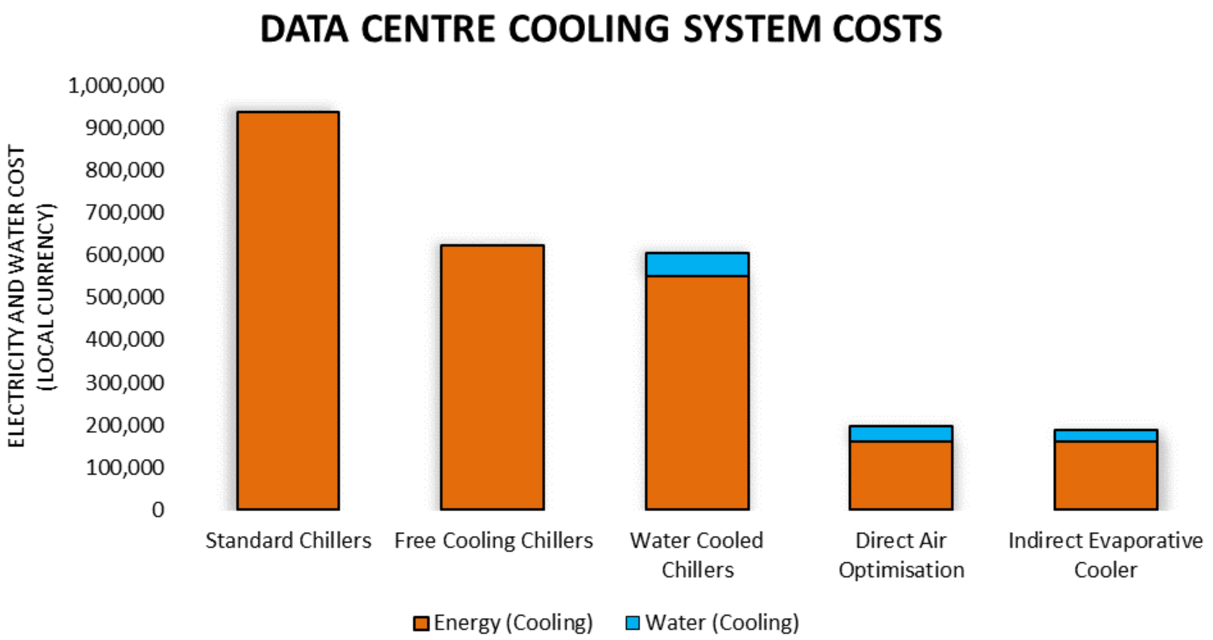
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[(C)]		1.40	1.26	1.23	1.07	1.07
WUE (l/kWh)		0.00	0.00	1.92	1.33	0.95
Energy Consumption [kWh]	Cooling Source[(E)]	1,649,885	818,555	413,077	2,375	81
	Fans	365,390	365,390	365,390	421,604	425,000
	CHW & CW Pumps	477,848	477,848	686,874	1,526	0
	Total	2,493,123	1,661,793	1,465,341	425,505	425,081
Peak Capacity (kW)	HVAC Peak Power	310	344	267	303	22
	Savings[(A)]	-16%	-29%	0%	-14%	92%
Water Consumption [kL]	Total[(F)]	0	0	12,121	8,387	5,979
	Savings[(A)]	100%	100%	0%	31%	51%
Carbon Emissions [kg CO_2]	Total	2,429,798	1,619,583	1,428,122	414,698	414,284
	Savings[(A)]	-70%	-13%	0%	71%	71%
Annual Costs[(D)] Cooling Only	Energy (Cooling)	937,414	624,834	550,968	159,990	159,830
	Water (Cooling)	0	0	53,819	37,240	26,549
	Total Costs (Cooling)	937,414	624,834	604,788	197,230	186,379
	Cost Savings [%][(A)]	-55%	-3%	0%	67%	69%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

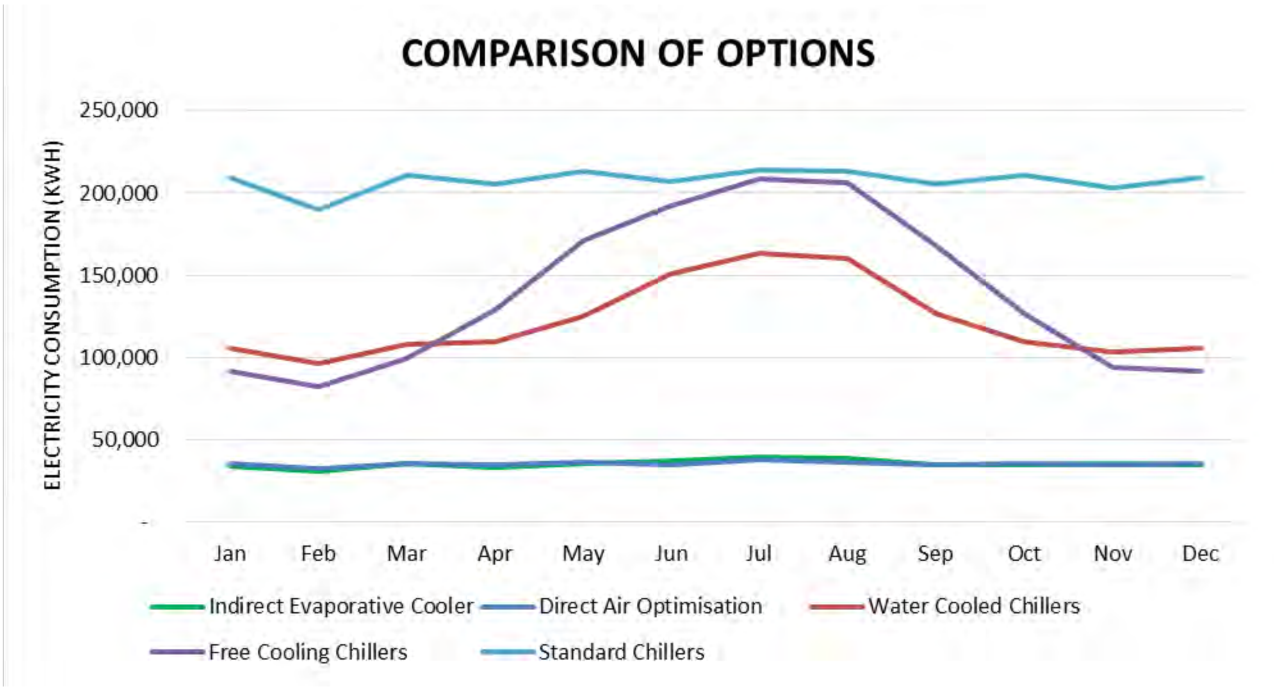
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



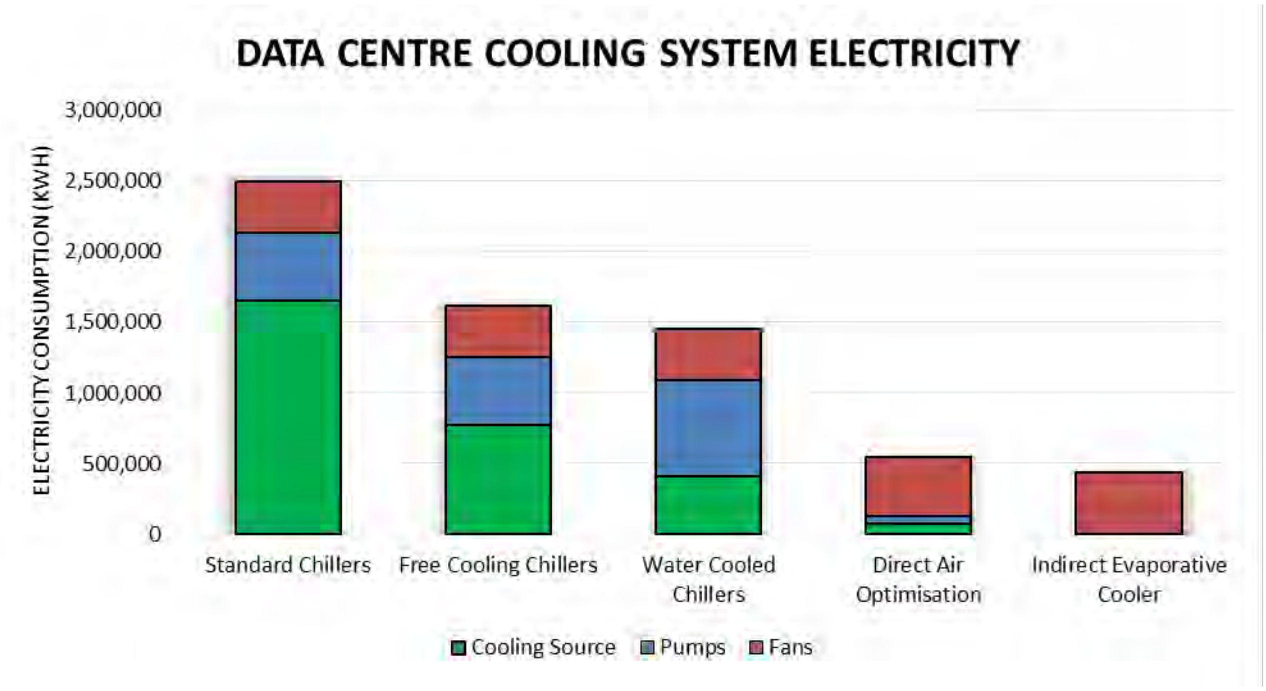
4.3 Hohhot, Inner Mongolia

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Hohhot.

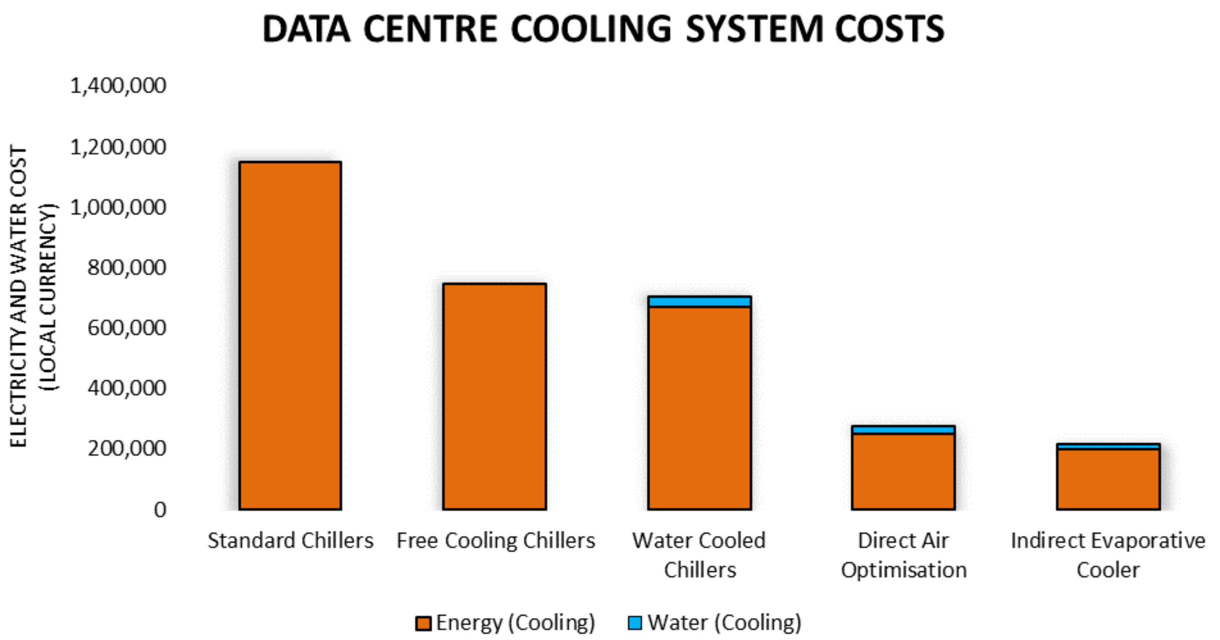
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.26	1.23	1.09	1.07
WUE (l/kWh)		0.00	0.00	1.93	1.28	0.80
Energy Consumption [kWh]	Cooling Source(E)	1,652,442	775,069	407,418	71,252	722
	Fans	365,390	365,390	365,390	421,604	433,233
	CHW & CW Pumps	478,631	478,631	680,237	52,165	0
	Total	2,496,463	1,619,090	1,453,045	545,021	433,954
Peak Capacity (kW)	HVAC Peak Power	312	339	275	300	26
	Savings(A)	-13%	-23%	0%	-9%	91%
Water Consumption [kL]	Total(F)	0	0	12,143	8,076	5,050
	Savings(A)	100%	100%	0%	33%	58%
Carbon Emissions [kg CO_2]	Total	2,433,052	1,577,965	1,416,138	531,177	422,932
	Savings(A)	-72%	-11%	0%	62%	70%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,148,373	744,781	668,401	250,710	199,619
	Water (Cooling)	0	0	36,429	24,227	15,149
	Total Costs (Cooling)	1,148,373	744,781	704,830	274,936	214,768
	Cost Savings [%](A)	-63%	-6%	0%	61%	70%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

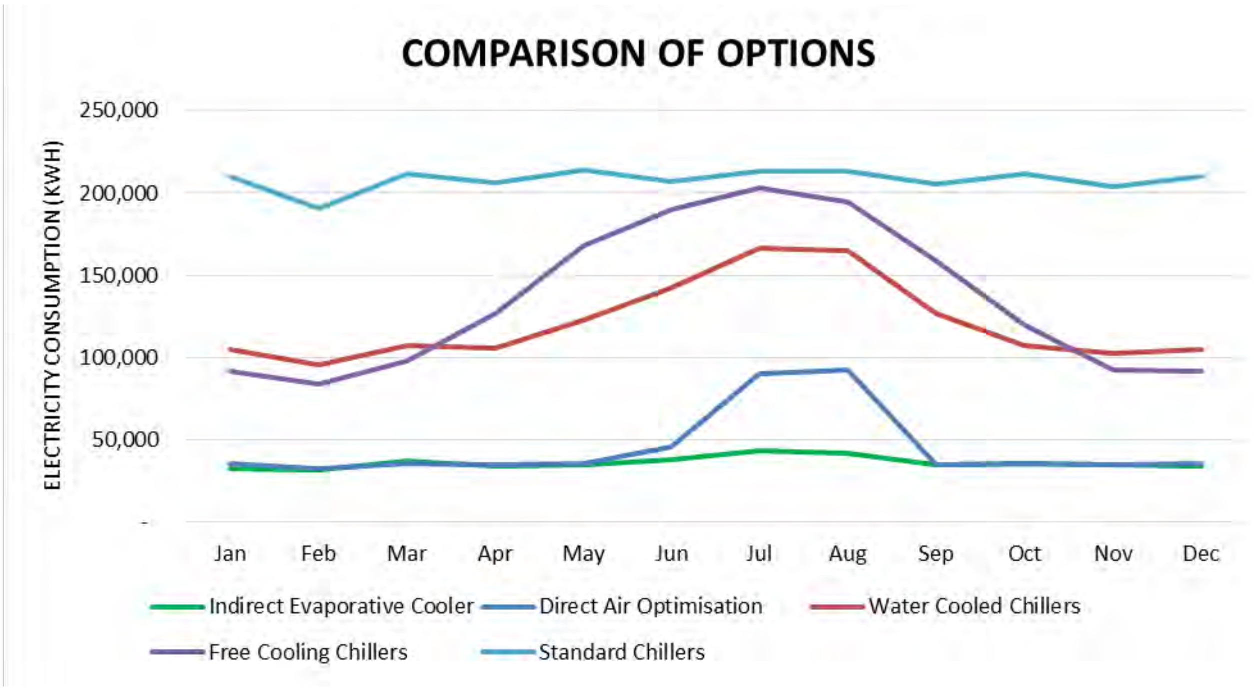
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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4.4 Beijing, China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Beijing.

		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.29	1.25	1.13	1.09
WUE (l/kWh)		0.00	0.00	1.94	1.67	1.28
Energy Consumption [kWh]	Cooling Source(E)	1,651,522	981,626	511,227	223,472	47,346
	Fans	365,390	365,390	365,390	421,604	499,006
	CHW & CW Pumps	478,349	478,349	669,197	145,968	0
	Total	2,495,261	1,825,366	1,545,814	791,045	546,352
Peak Capacity (kW)	HVAC Peak Power	311	345	320	305	144
	Savings(A)	3%	-8%	0%	5%	55%
Water Consumption [kL]	Total(F)	0	0	12,231	10,536	8,067
	Savings(A)	100%	100%	0%	14%	34%
Carbon Emissions [kg CO_2]	Total	2,431,881	1,779,001	1,506,550	770,952	532,475
	Savings(A)	-61%	-18%	0%	49%	65%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,671,825	1,222,995	1,035,695	530,000	366,056
	Water (Cooling)	0	0	75,956	65,430	50,096
	Total Costs (Cooling)	1,671,825	1,222,995	1,111,652	595,430	416,152
	Cost Savings [%](A)	-50%	-10%	0%	46%	63%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

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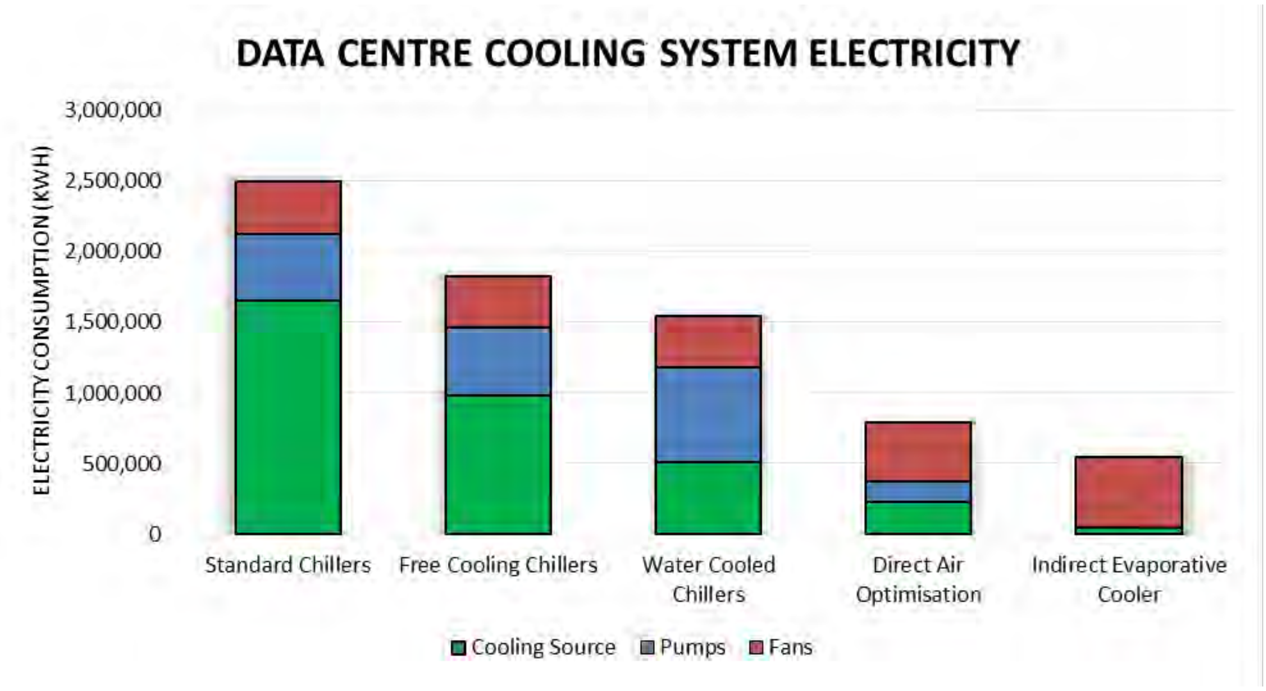
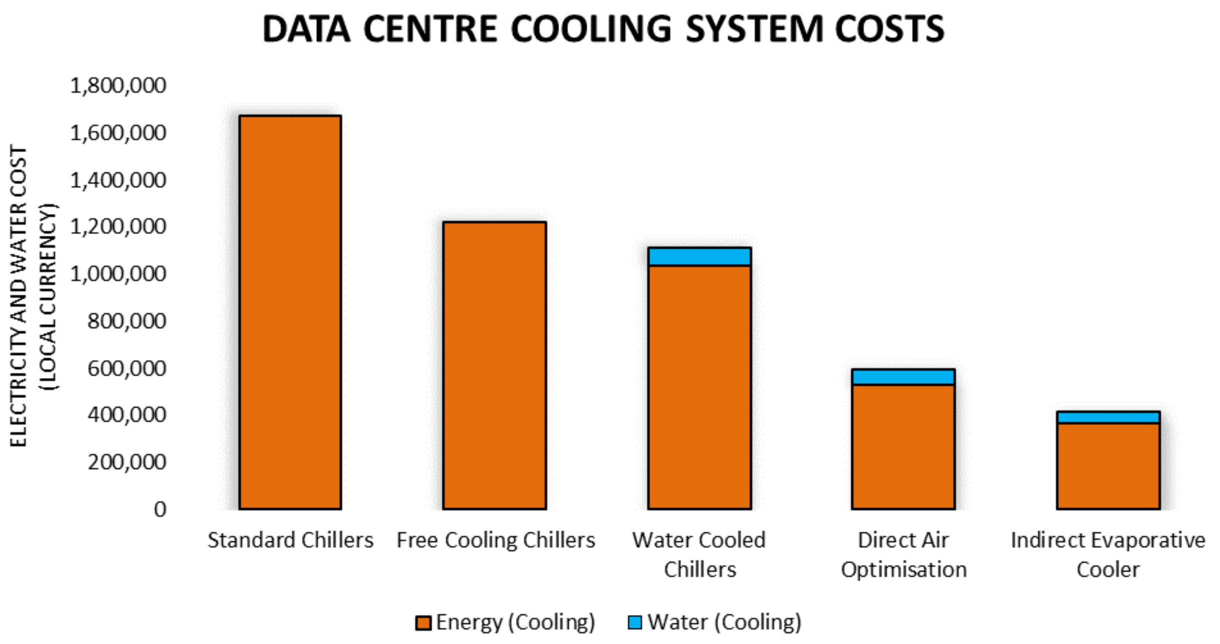
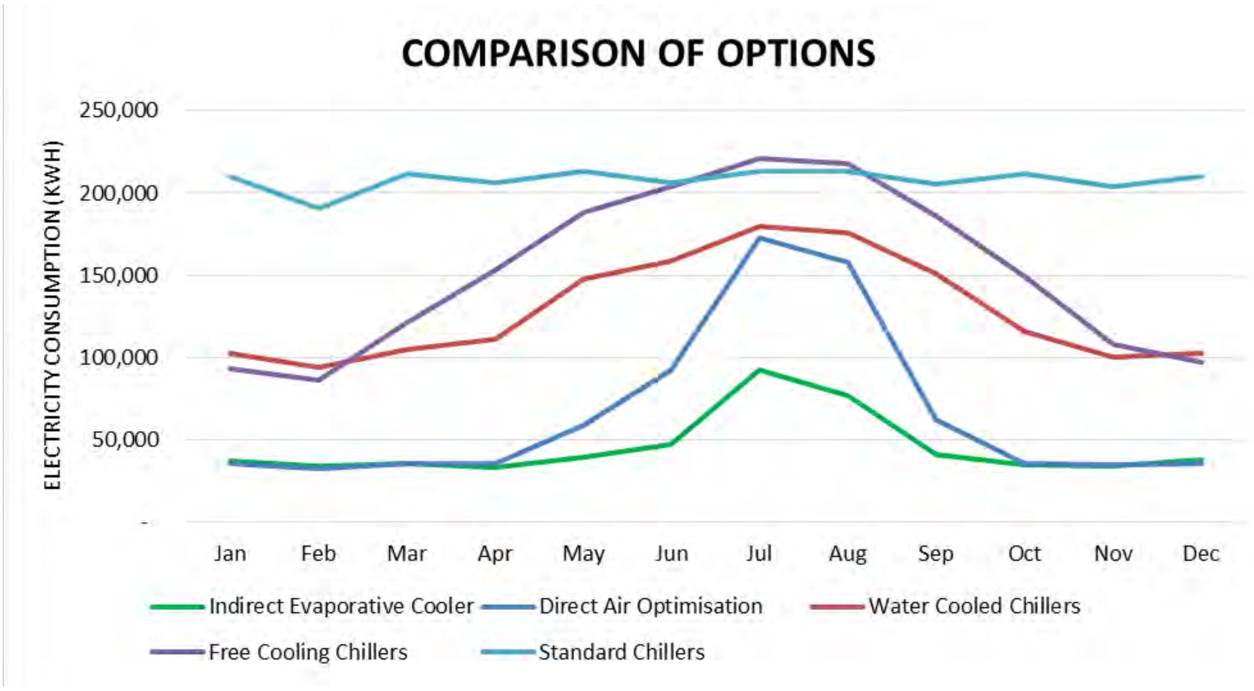


A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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4.5 Shijiazhuang (HeBei), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Shijiazhuang.

		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.30	1.25	1.13	1.09
WUE (l/kWh)		0.00	0.00	1.94	1.71	1.37
Energy Consumption [kWh]	Cooling Source(E)	1,649,590	1,021,022	536,232	254,143	42,569
	Fans	365,390	365,390	365,390	421,604	504,174
	CHW & CW Pumps	477,757	477,757	671,926	169,307	0
	Total	2,492,738	1,864,170	1,573,549	845,054	546,743
Peak Capacity (kW)	HVAC Peak Power	313	367	301	307	122
	Savings(A)	-4%	-22%	0%	-2%	60%
Water Consumption [kL]	Total(F)	0	0	12,225	10,783	8,619
	Savings(A)	100%	100%	0%	12%	29%
Carbon Emissions [kg CO_2]	Total	2,429,422	1,816,820	1,533,581	823,590	532,856
	Savings(A)	-58%	-18%	0%	46%	65%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,420,861	1,062,577	896,923	481,681	311,644
	Water (Cooling)	0	0	52,933	46,692	37,320
	Total Costs (Cooling)	1,420,861	1,062,577	949,856	528,373	348,963
	Cost Savings [%](A)	-50%	-12%	0%	44%	63%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
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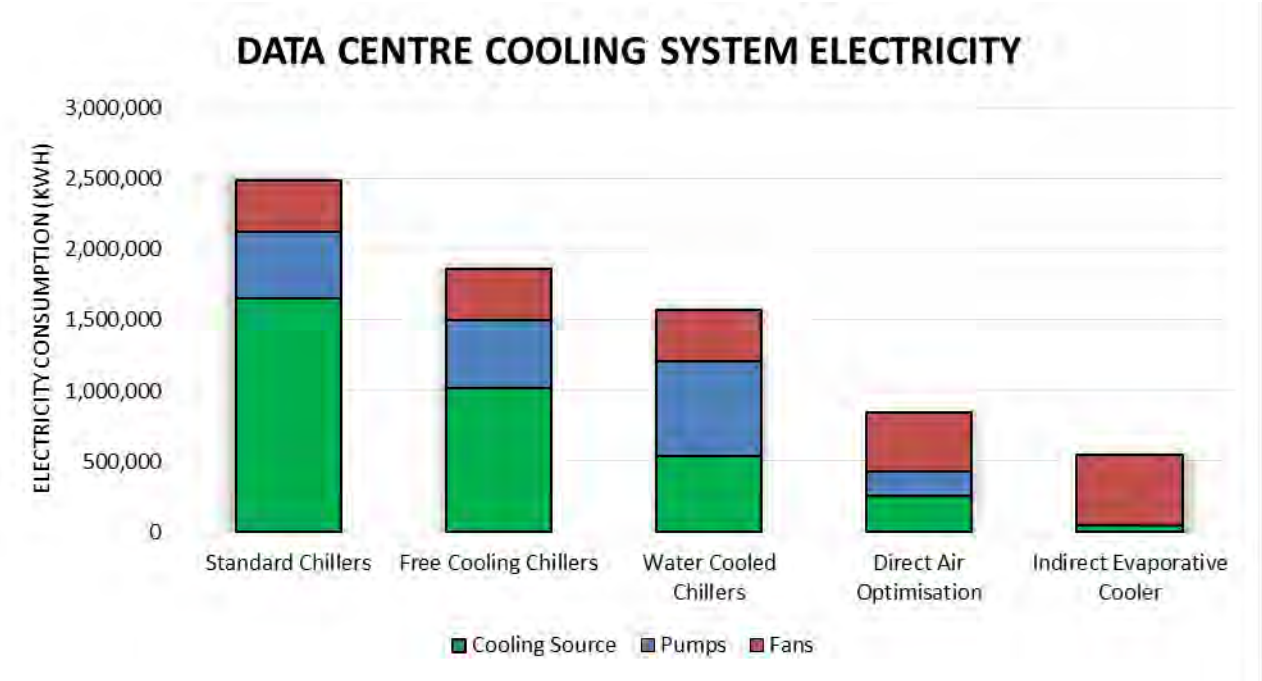
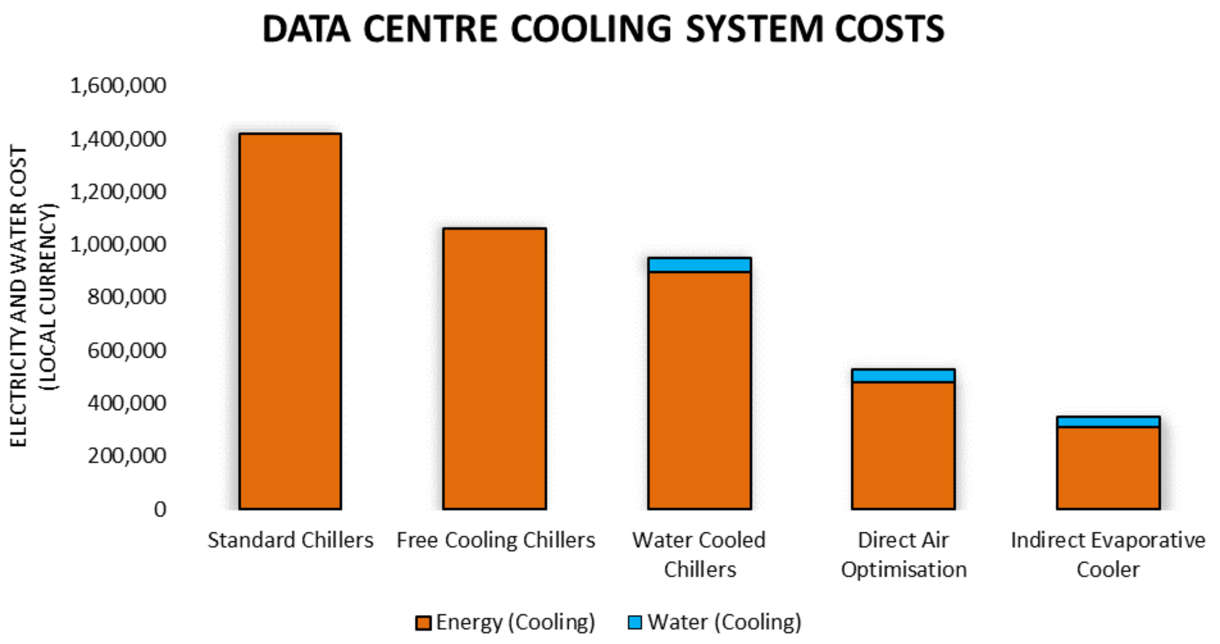
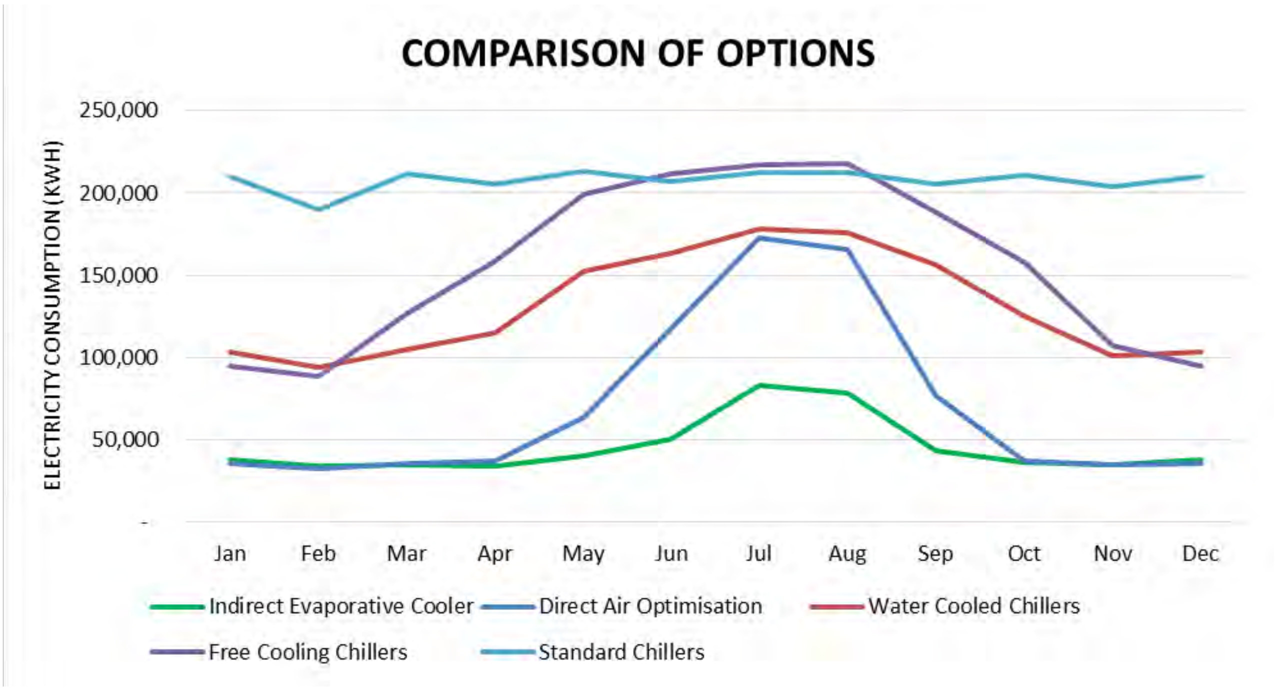
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



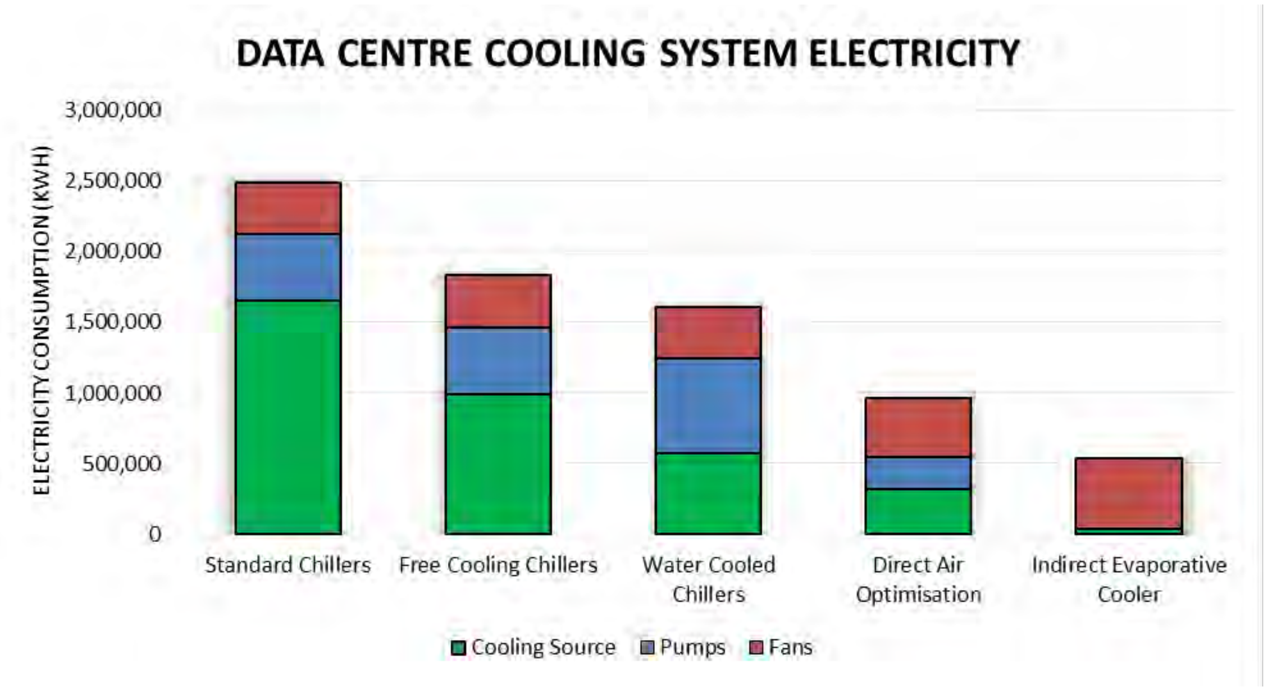
4.6 Tokyo, Japan

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Tokyo.

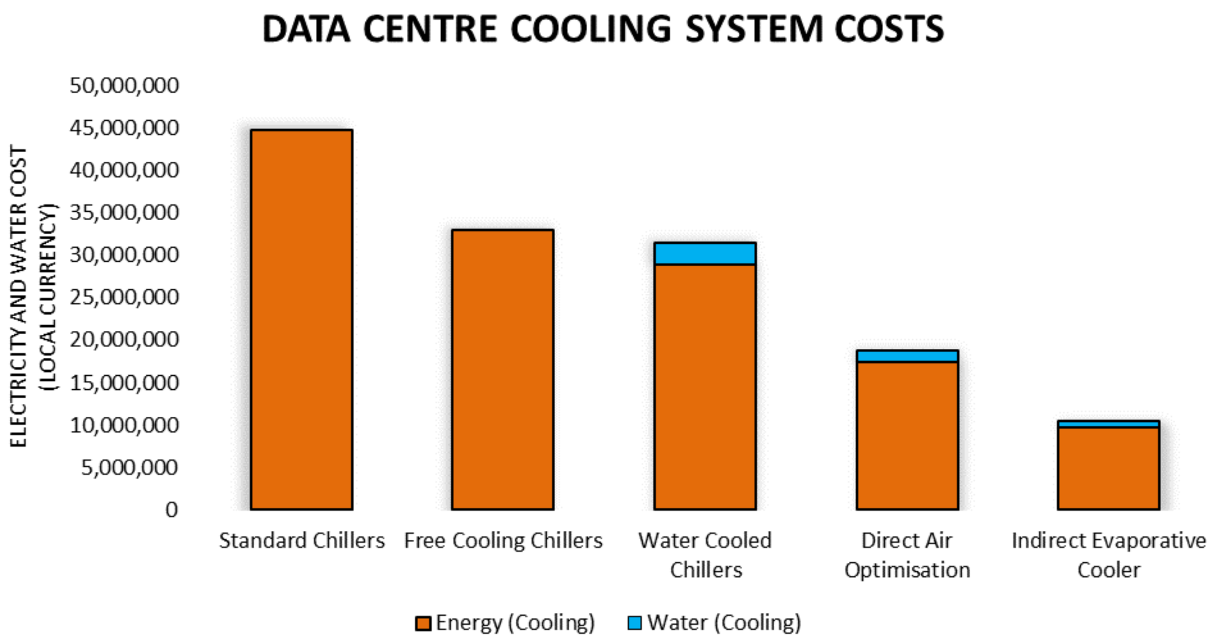
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.29	1.26	1.15	1.08
WUE (l/kWh)		0.00	0.00	1.95	1.11	0.58
Energy Consumption [kWh]	Cooling Source(E)	1,649,643	988,386	570,528	321,407	39,576
	Fans	365,390	365,390	365,390	421,604	496,394
	CHW & CW Pumps	477,774	477,774	673,949	223,321	0
	Total	2,492,807	1,831,550	1,609,867	966,332	535,969
Peak Capacity (kW)	HVAC Peak Power	307	342	318	307	109
	Savings(A)	4%	-7%	0%	3%	66%
Water Consumption [kL]	Total(F)	0	0	12,268	6,990	3,644
	Savings(A)	100%	100%	0%	43%	70%
Carbon Emissions [kg CO_2]	Total	1,105,062	811,926	713,654	428,375	237,595
	Savings(A)	-55%	-14%	0%	40%	67%
Annual Costs(D) Cooling Only	Energy (Cooling)	44,870,533	32,967,900	28,977,609	17,393,983	9,647,448
	Water (Cooling)	0	0	2,453,649	1,398,064	728,745
	Total Costs (Cooling)	44,870,533	32,967,900	31,431,258	18,792,047	10,376,193
	Cost Savings [%](A)	-43%	-5%	0%	40%	67%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

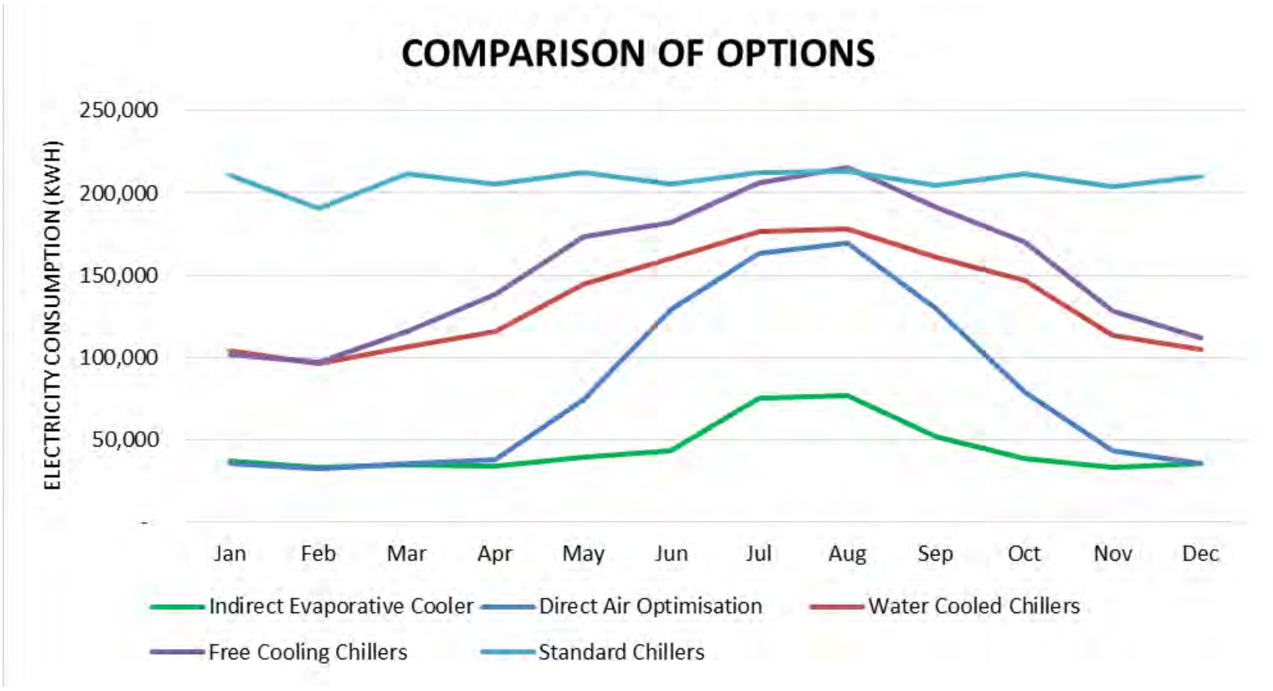
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



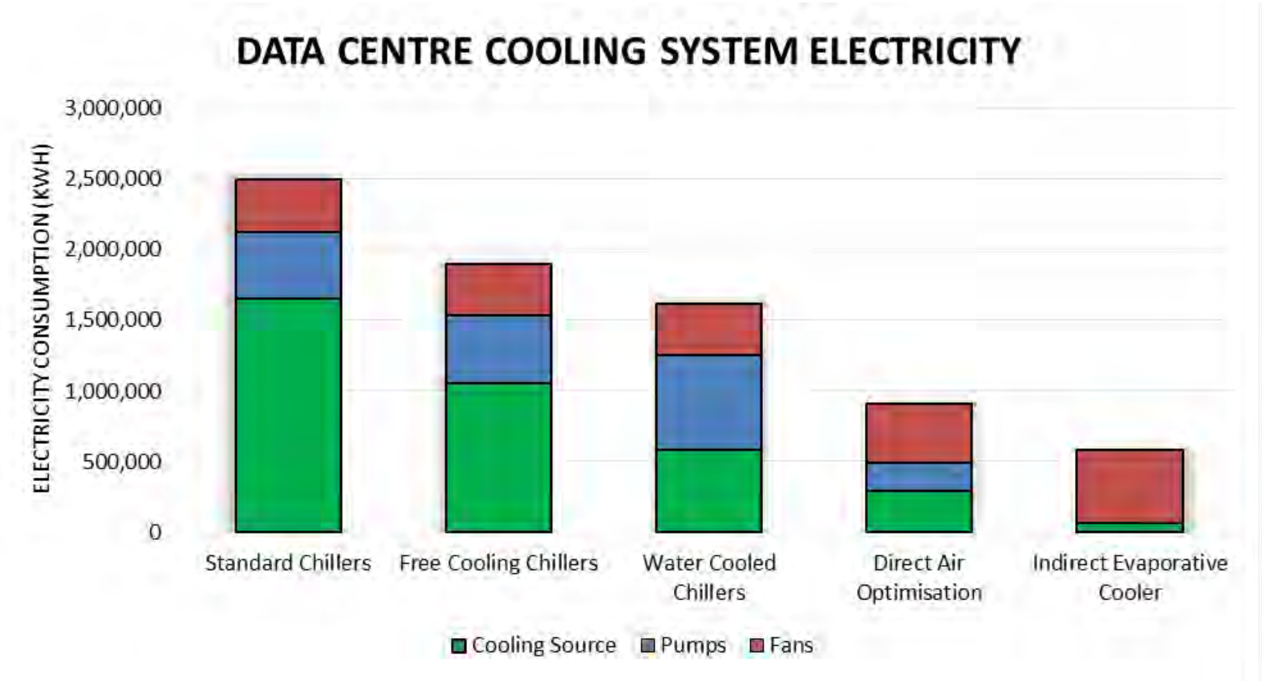
4.7 Zhengzhou (Henan), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Zhengzhou.

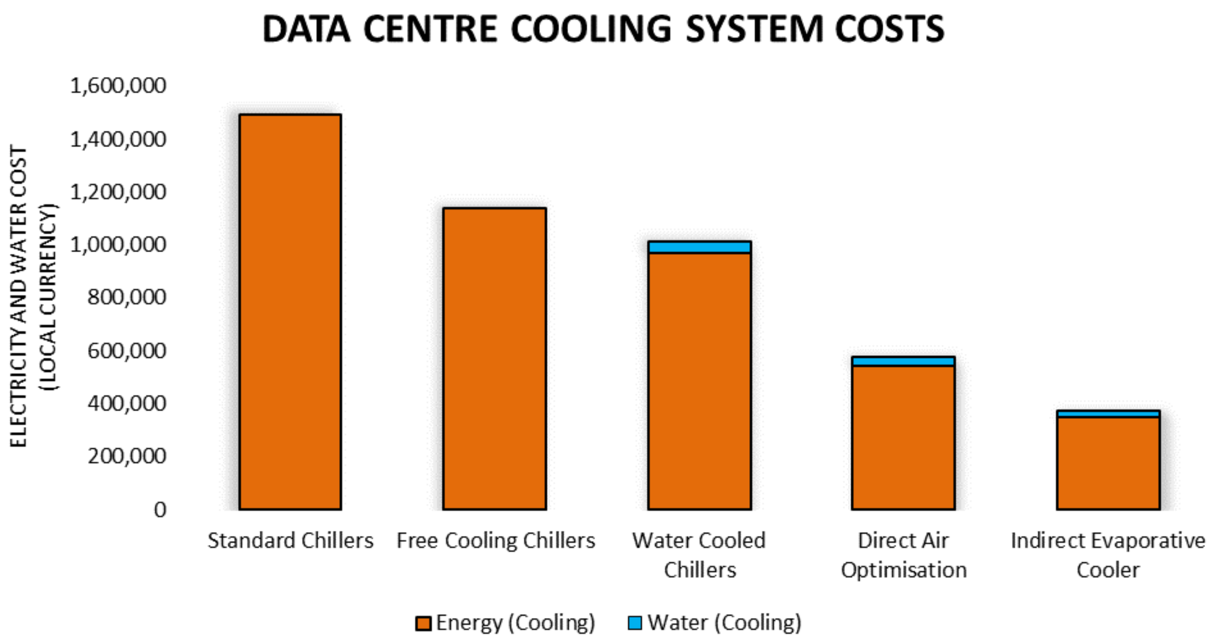
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[C]		1.40	1.30	1.26	1.14	1.09
WUE (l/kWh)		0.00	0.00	1.95	1.57	1.28
Energy Consumption [kWh]	Cooling Source[E]	1,650,615	1,058,371	578,902	293,408	62,294
	Fans	365,390	365,390	365,390	421,604	516,856
	CHW & CW Pumps	478,071	478,071	676,089	193,791	0
	Total	2,494,076	1,901,833	1,620,381	908,803	579,150
Peak Capacity (kW)	HVAC Peak Power	307	342	317	306	104
	Savings[A]	3%	-8%	0%	3%	67%
Water Consumption [kL]	Total[F]	0	0	12,268	9,873	8,056
	Savings[A]	100%	100%	0%	20%	34%
Carbon Emissions [kg CO_2]	Total	2,430,727	1,853,526	1,579,224	885,720	564,439
	Savings[A]	-54%	-17%	0%	44%	64%
Annual Costs[D] Cooling Only	Energy (Cooling)	1,493,952	1,139,198	970,608	544,373	346,911
	Water (Cooling)	0	0	39,870	32,088	26,180
	Total Costs (Cooling)	1,493,952	1,139,198	1,010,478	576,461	373,091
	Cost Savings [%][A]	-48%	-13%	0%	43%	63%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

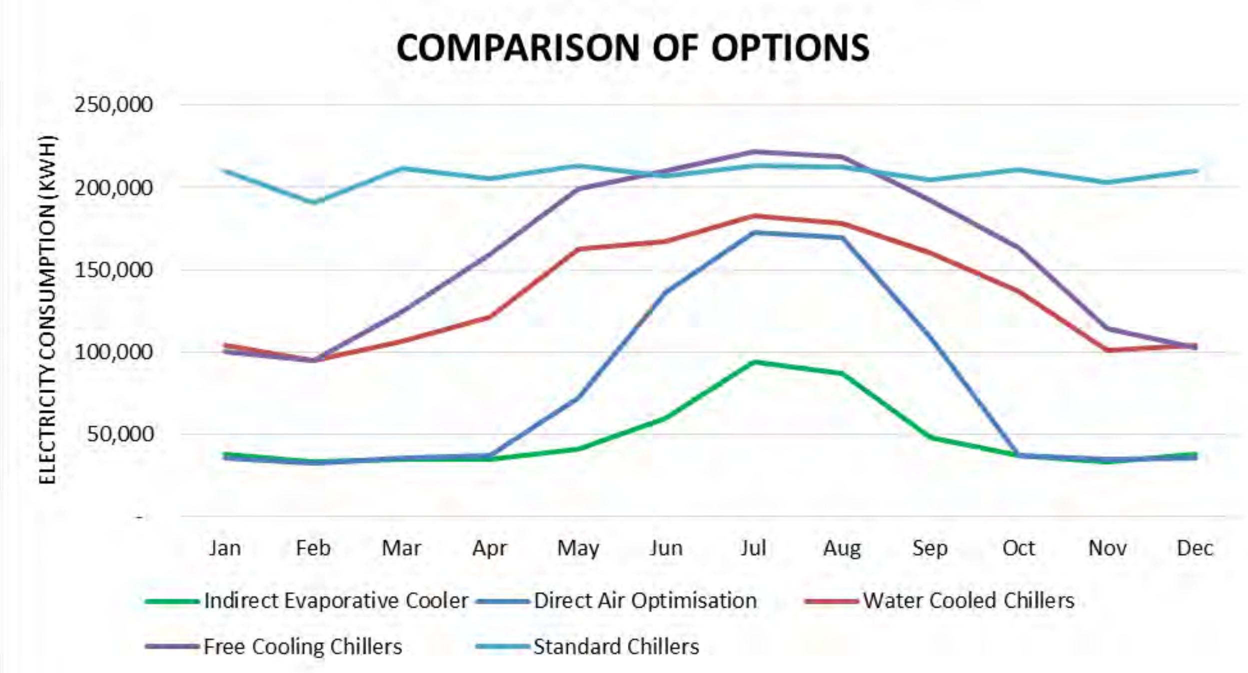
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



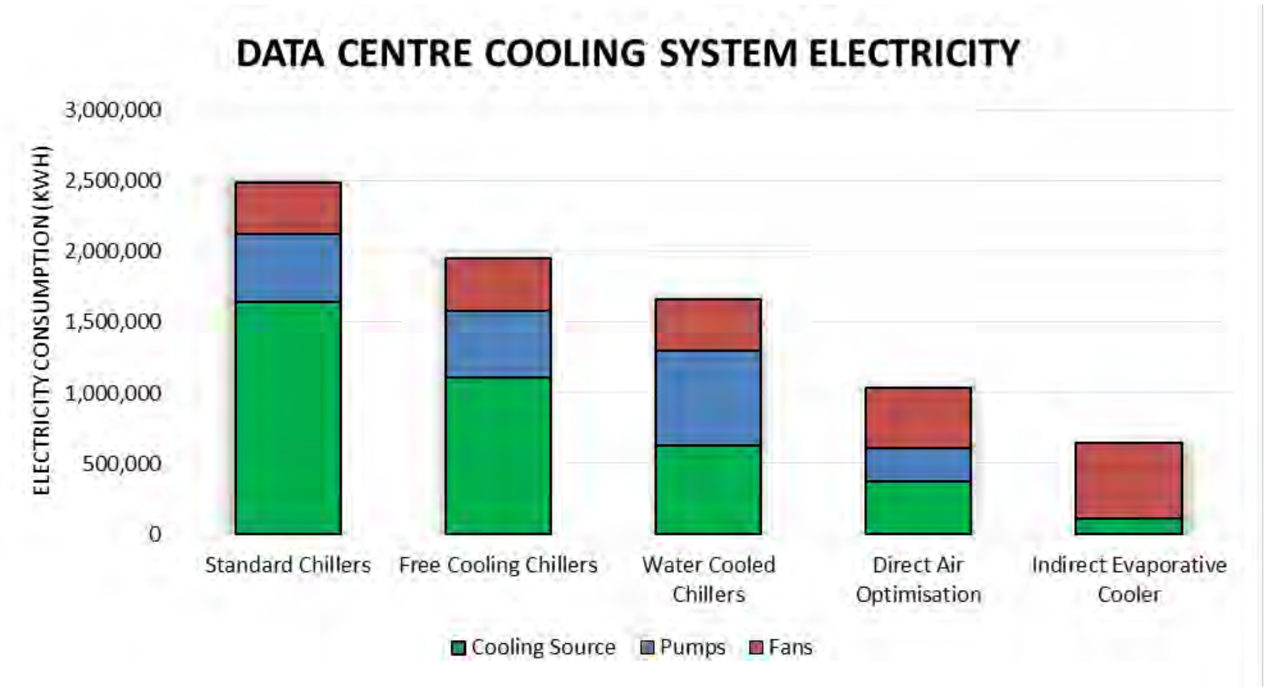
4.8 Nanjing (Jiangsu), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Nanjing.

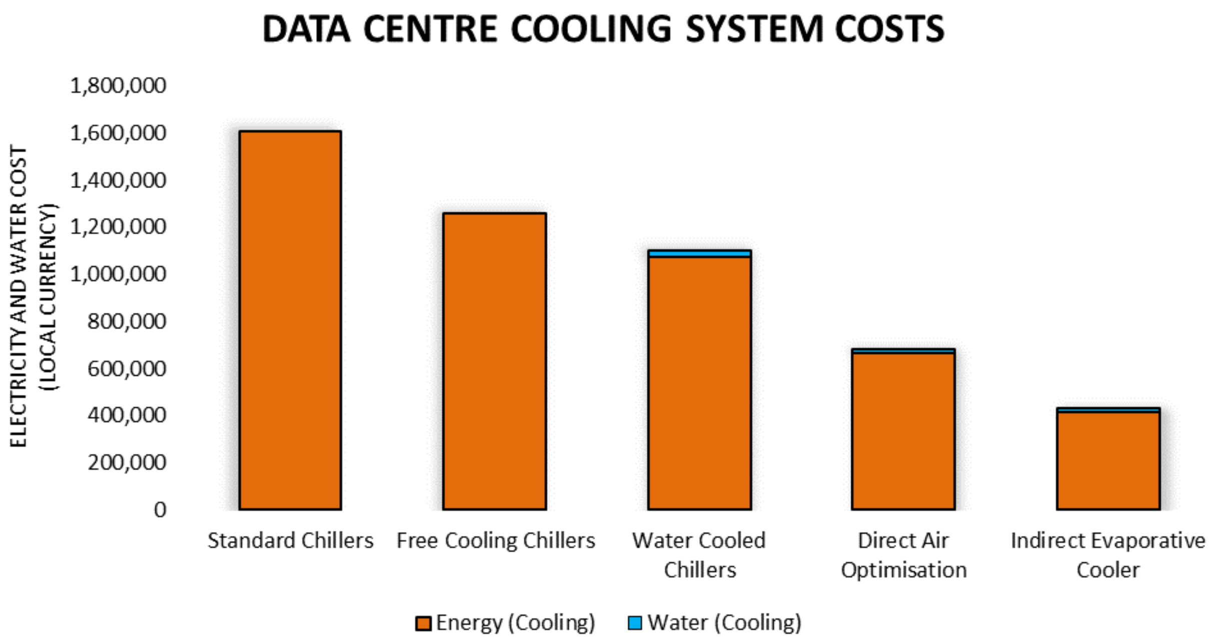
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.31	1.26	1.16	1.10
WUE (l/kWh)		0.00	0.00	1.95	1.29	1.12
Energy Consumption [kWh]	Cooling Source(E)	1,648,834	1,106,344	625,956	372,150	106,065
	Fans	365,390	365,390	365,390	421,604	538,215
	CHW & CW Pumps	477,526	477,526	674,477	239,120	0
	Total	2,491,750	1,949,260	1,665,824	1,032,875	644,279
Peak Capacity (kW)	HVAC Peak Power	306	341	322	307	108
	Savings(A)	5%	-6%	0%	4%	66%
Water Consumption [kL]	Total(F)	0	0	12,323	8,136	7,073
	Savings(A)	100%	100%	0%	34%	43%
Carbon Emissions [kg CO_2]	Total	2,428,460	1,899,749	1,623,512	1,006,640	627,915
	Savings(A)	-50%	-17%	0%	38%	61%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,607,179	1,257,273	1,074,456	666,204	415,560
	Water (Cooling)	0	0	24,029	15,866	13,792
	Total Costs (Cooling)	1,607,179	1,257,273	1,098,486	682,070	429,353
	Cost Savings [%](A)	-46%	-14%	0%	38%	61%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

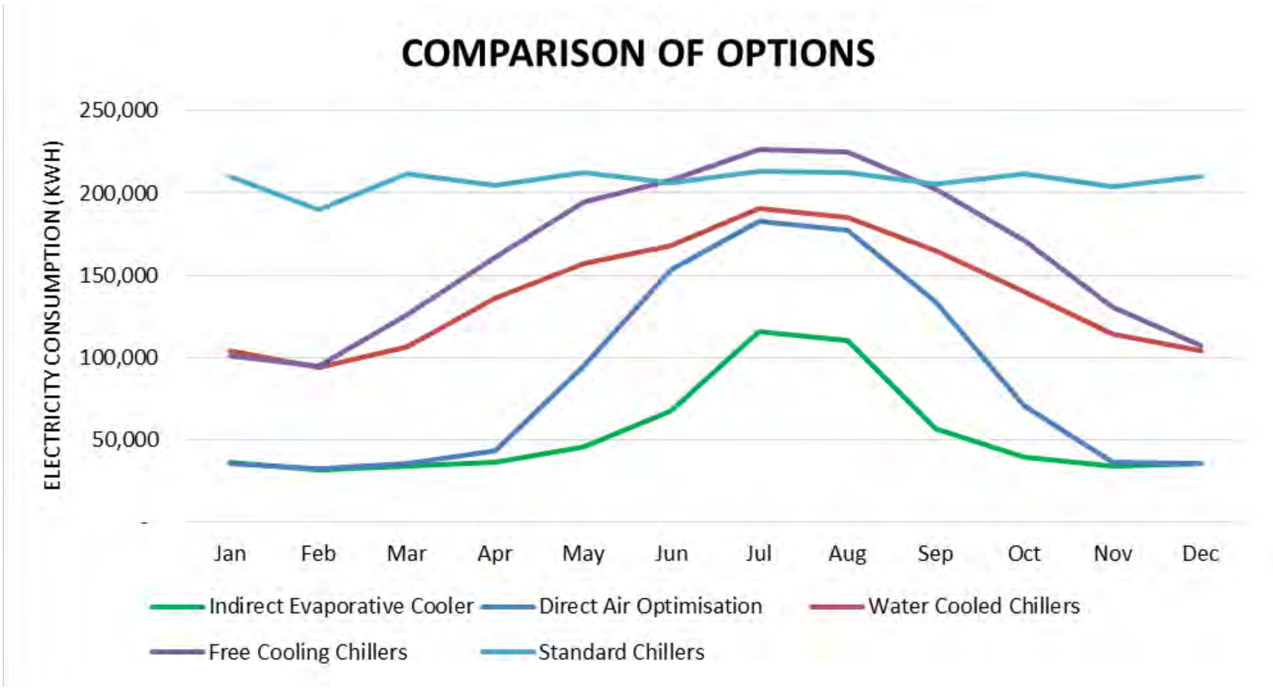
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



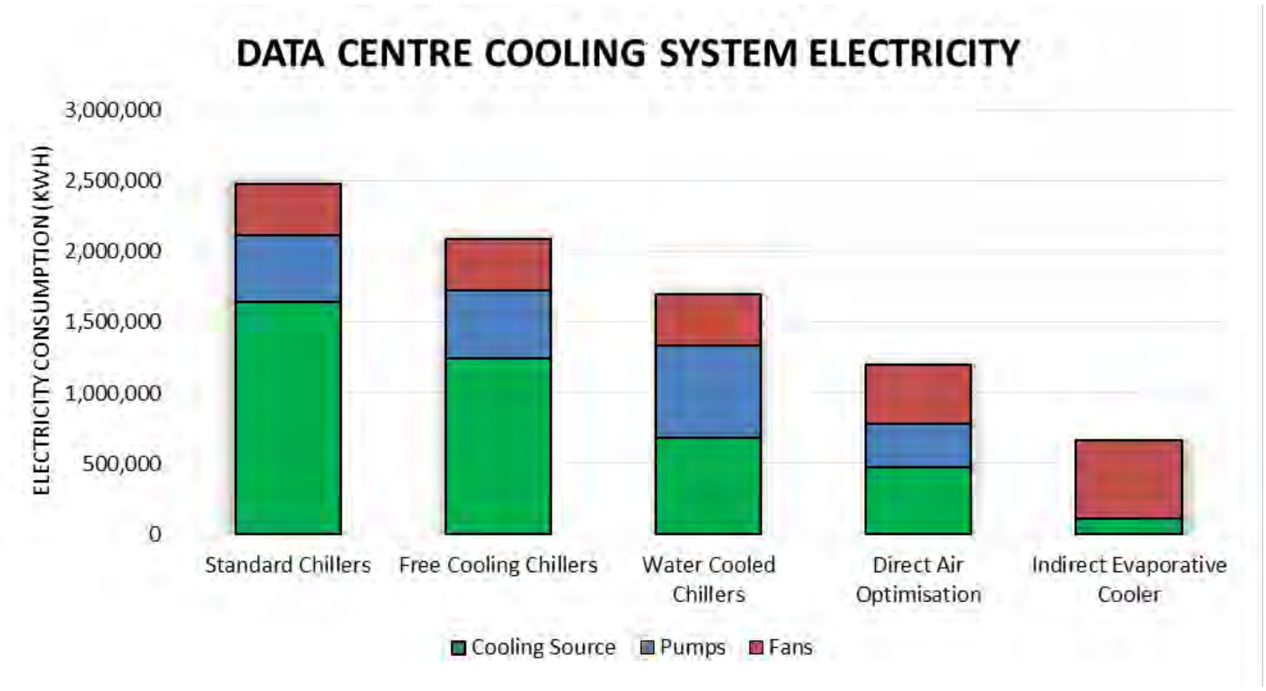
4.9 Chongqing, China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Chongqing.

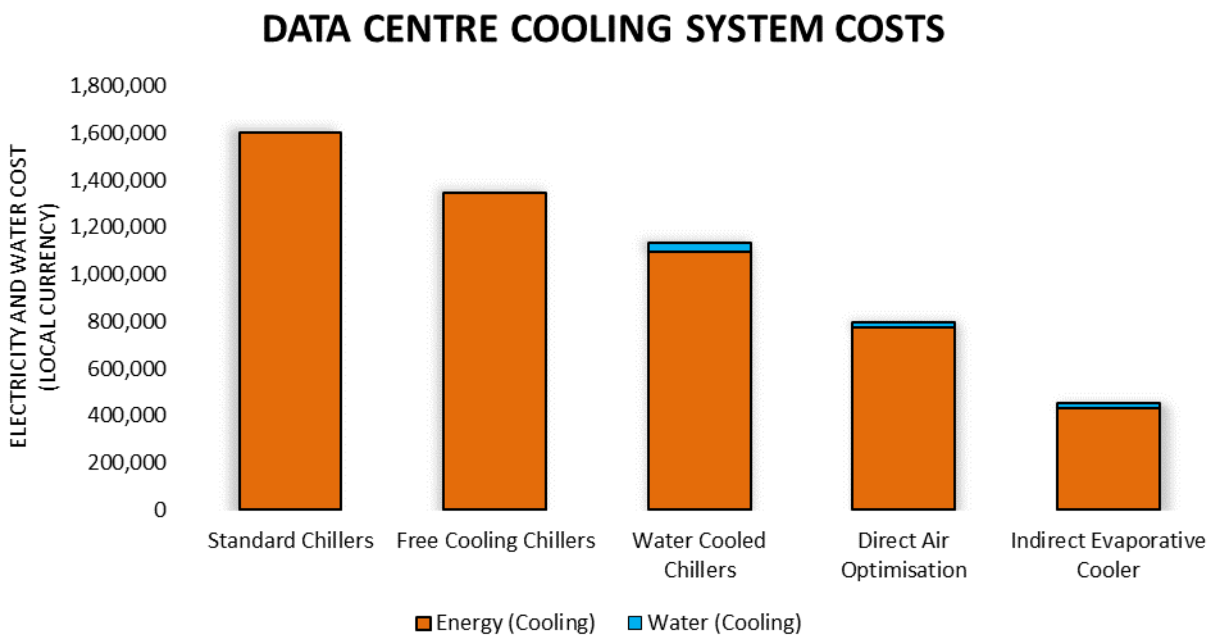
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.39	1.33	1.27	1.19	1.11
WUE (l/kWh)		0.00	0.00	1.95	1.16	1.20
Energy Consumption [kWh]	Cooling Source(E)	1,642,552	1,248,611	677,743	468,477	104,817
	Fans	365,390	365,390	365,390	421,604	559,230
	CHW & CW Pumps	475,603	475,603	656,232	310,583	0
	Total	2,483,545	2,089,604	1,699,365	1,200,664	664,047
Peak Capacity (kW)	HVAC Peak Power	314	351	328	307	126
	Savings(A)	4%	-7%	0%	6%	62%
Water Consumption [kL]	Total(F)	0	0	12,282	7,313	7,538
	Savings(A)	100%	100%	0%	40%	39%
Carbon Emissions [kg CO_2]	Total	2,420,462	2,036,528	1,656,201	1,170,167	647,180
	Savings(A)	-46%	-23%	0%	29%	61%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,601,886	1,347,794	1,096,090	774,428	428,310
	Water (Cooling)	0	0	39,917	23,768	24,500
	Total Costs (Cooling)	1,601,886	1,347,794	1,136,007	798,196	452,810
	Cost Savings [%](A)	-41%	-19%	0%	30%	60%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

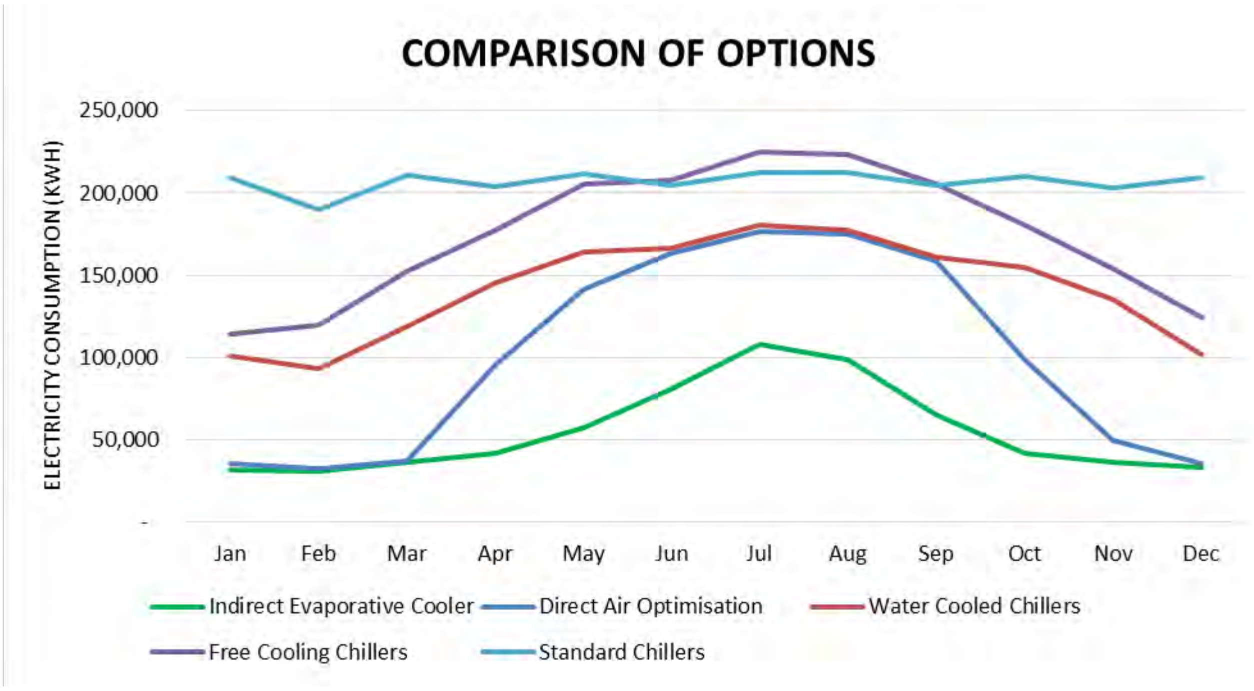
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



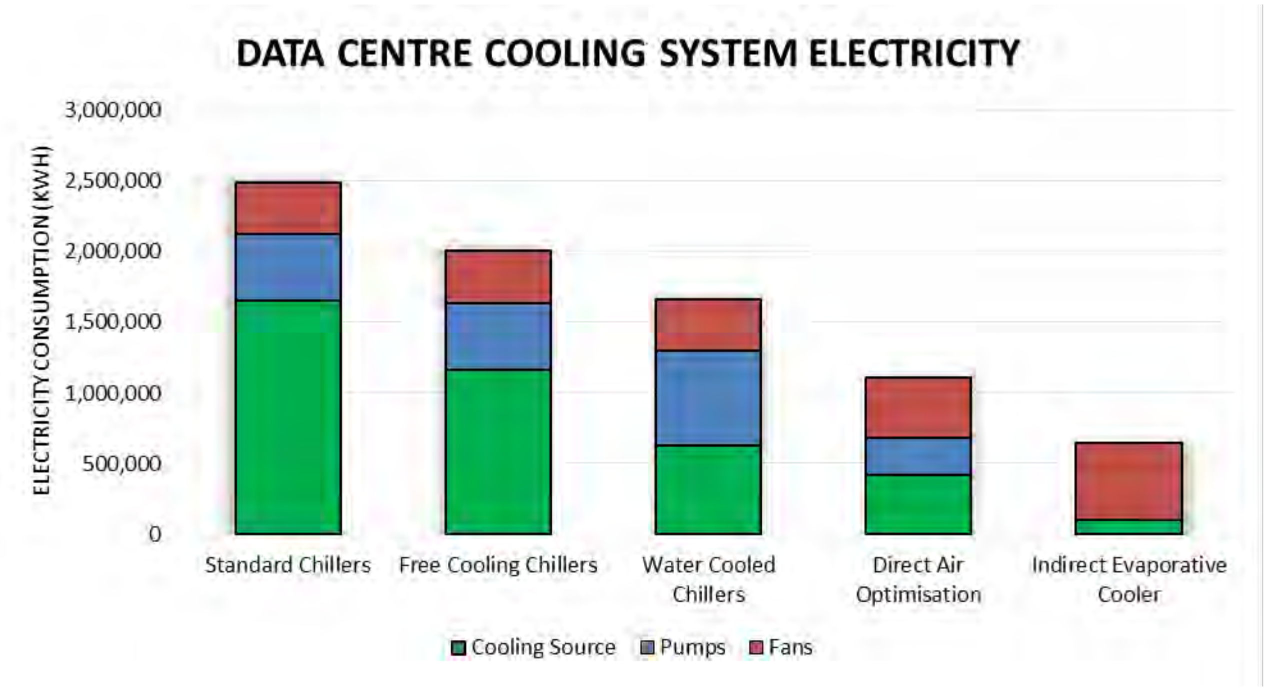
4.10 Shanghai, China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Shanghai.

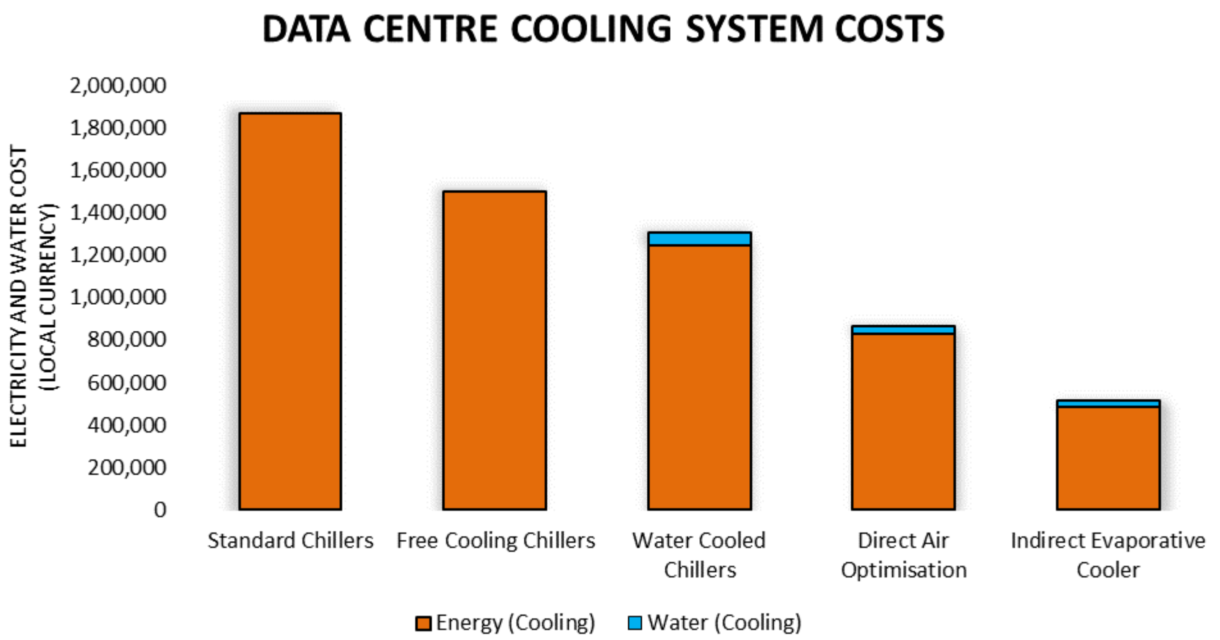
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.32	1.26	1.18	1.10
WUE (l/kWh)		0.00	0.00	1.95	1.23	0.99
Energy Consumption [kWh]	Cooling Source(E)	1,649,902	1,160,275	631,078	414,080	102,589
	Fans	365,390	365,390	365,390	421,604	544,335
	CHW & CW Pumps	477,853	477,853	667,206	271,683	0
	Total	2,493,145	2,003,519	1,663,675	1,107,367	646,924
Peak Capacity (kW)	HVAC Peak Power	312	341	324	307	127
	Savings(A)	4%	-5%	0%	5%	61%
Water Consumption [kL]	Total(F)	0	0	12,315	7,732	6,252
	Savings(A)	100%	100%	0%	37%	49%
Carbon Emissions [kg CO_2]	Total	2,429,819	1,952,629	1,621,417	1,079,240	630,492
	Savings(A)	-50%	-20%	0%	33%	61%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,869,859	1,502,639	1,247,756	830,525	485,193
	Water (Cooling)	0	0	61,573	38,659	31,260
	Total Costs (Cooling)	1,869,859	1,502,639	1,309,329	869,185	516,453
	Cost Savings [%](A)	-43%	-15%	0%	34%	61%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

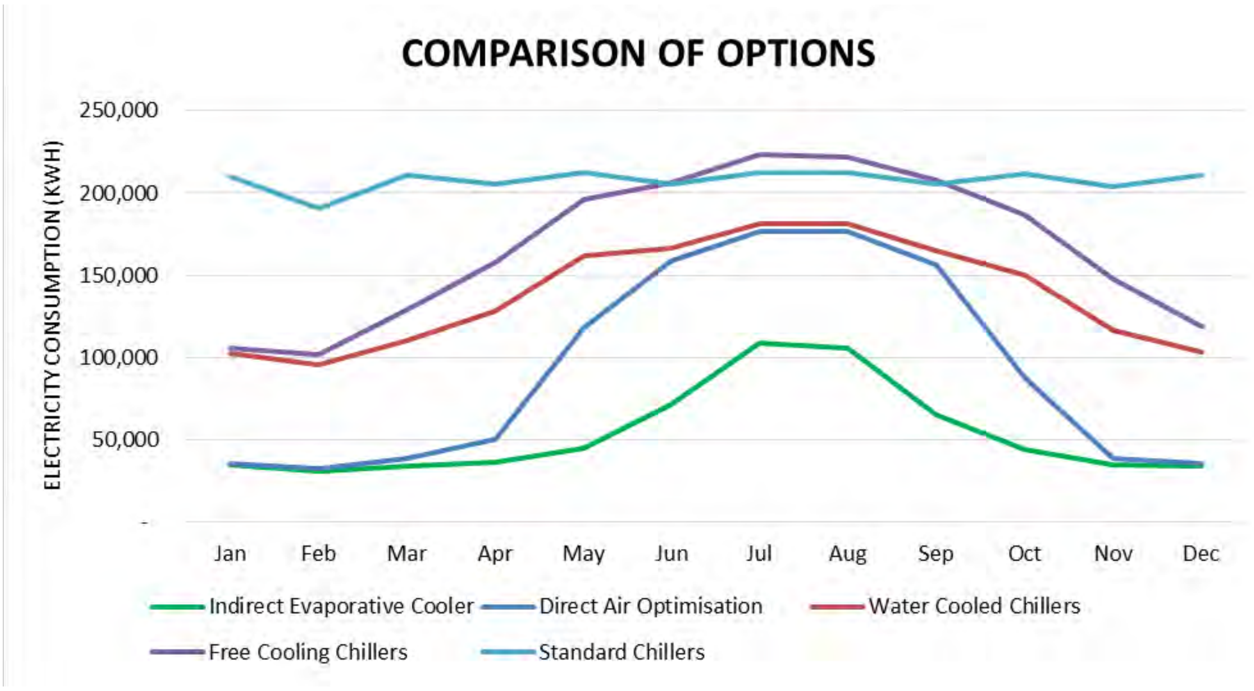
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



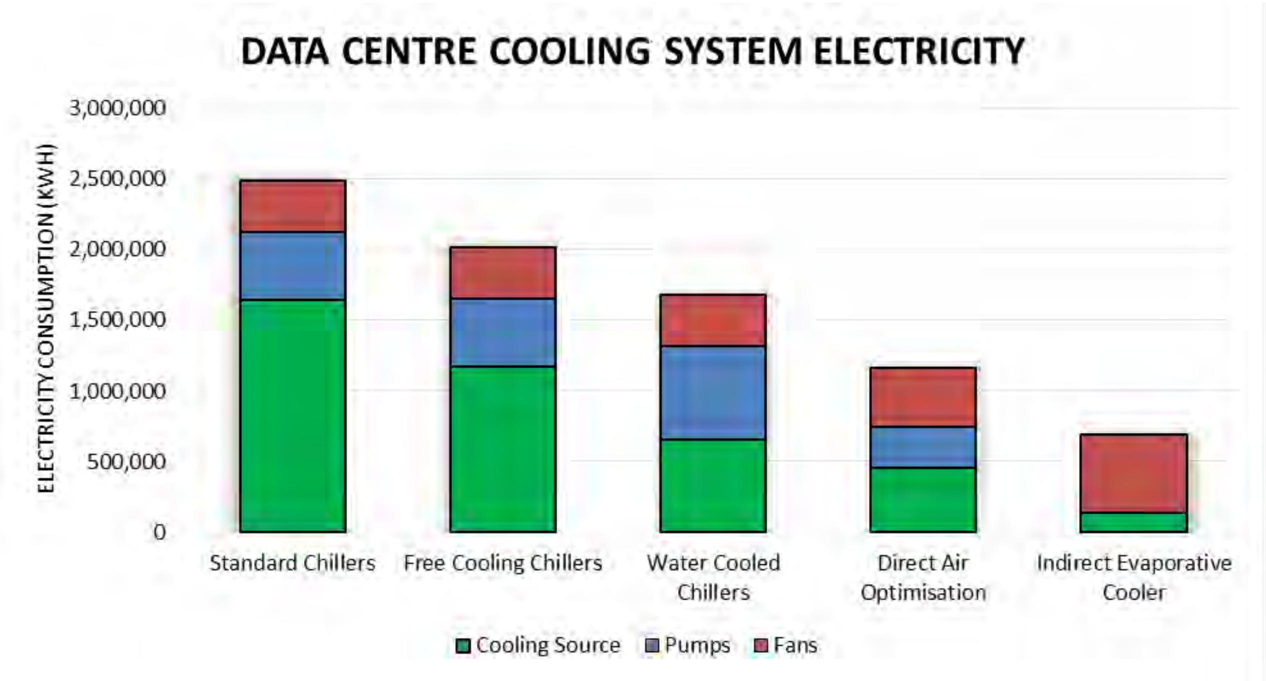
4.11 Wuhan (Hubei), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Wuhan.

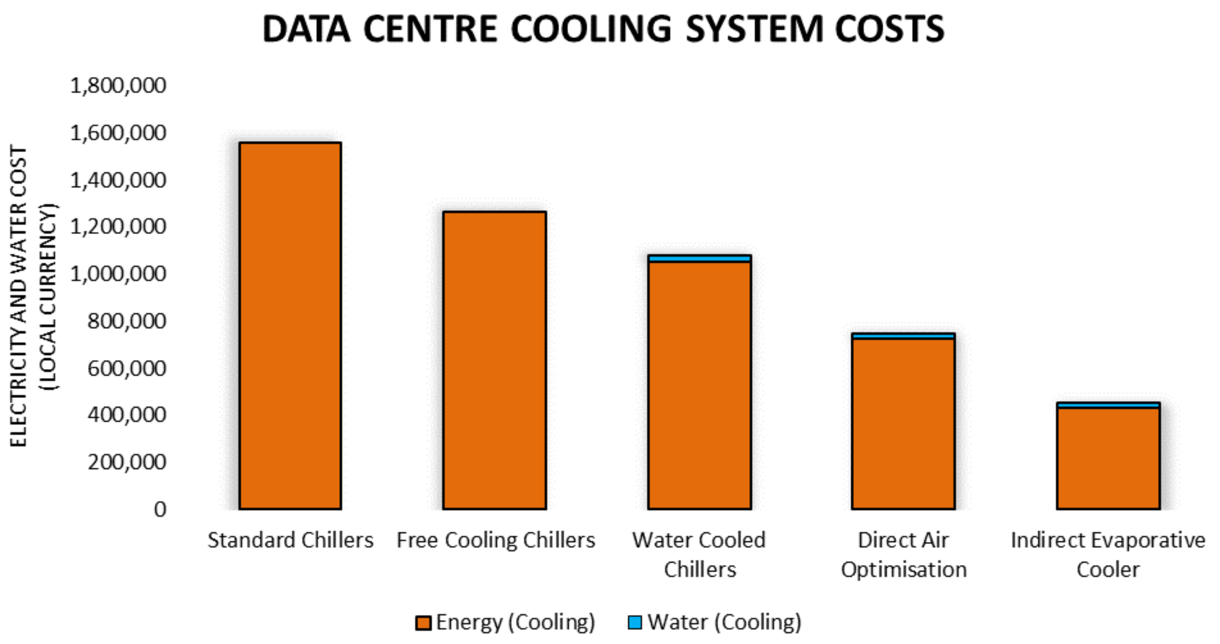
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[C]		1.40	1.32	1.27	1.18	1.11
WUE (l/kWh)		0.00	0.00	1.96	1.33	1.37
Energy Consumption [kWh]	Cooling Source[E]	1,648,551	1,176,510	656,968	453,982	132,705
	Fans	365,390	365,390	365,390	421,604	558,939
	CHW & CW Pumps	477,439	477,439	662,016	288,352	0
	Total	2,491,380	2,019,339	1,684,374	1,163,939	691,643
Peak Capacity (kW)	HVAC Peak Power	314	350	327	306	150
	Savings[A]	4%	-7%	0%	6%	54%
Water Consumption [kL]	Total[F]	0	0	12,331	8,413	8,650
	Savings[A]	100%	100%	0%	32%	30%
Carbon Emissions [kg CO_2]	Total	2,428,099	1,968,048	1,641,591	1,134,375	674,076
	Savings[A]	-48%	-20%	0%	31%	59%
Annual Costs[D] Cooling Only	Energy (Cooling)	1,557,113	1,262,087	1,052,734	727,462	432,277
	Water (Cooling)	0	0	28,979	19,772	20,327
	Total Costs (Cooling)	1,557,113	1,262,087	1,081,713	747,233	452,604
	Cost Savings [%][A]	-44%	-17%	0%	31%	58%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

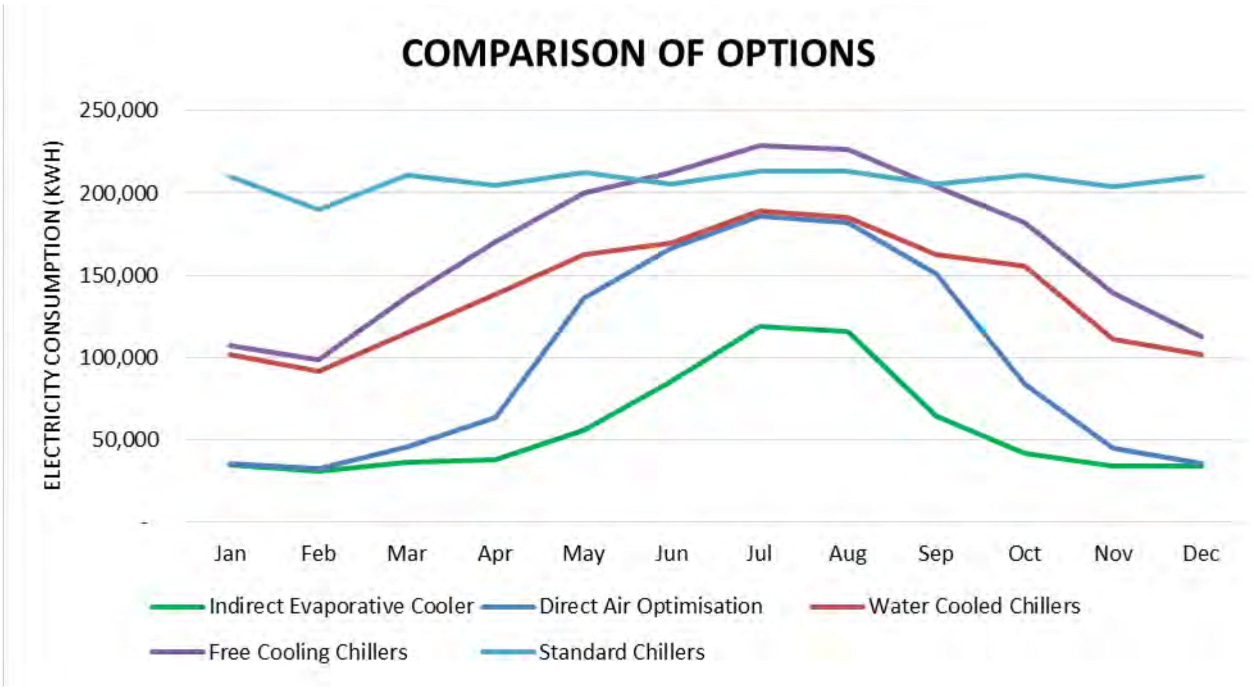
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



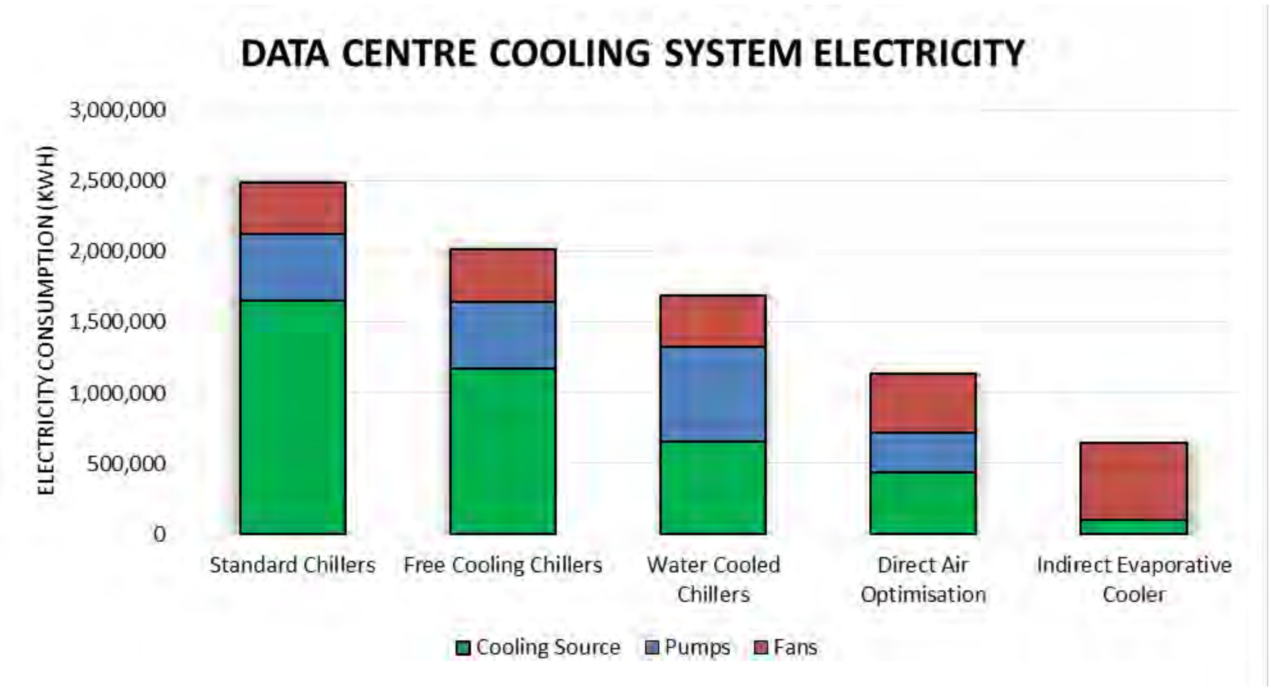
4.12 Hangzhou (ZheJiang), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Hangzhou.

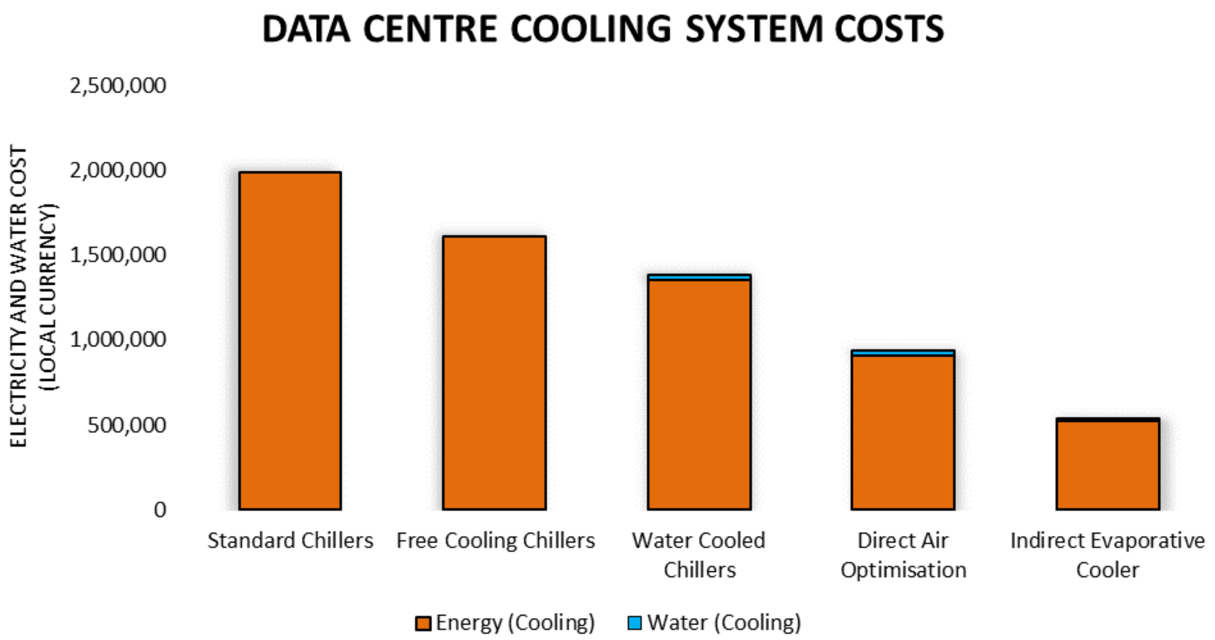
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[C]		1.40	1.32	1.27	1.18	1.10
WUE (l/kWh)		0.00	0.00	1.95	1.38	1.15
Energy Consumption [kWh]	Cooling Source[E]	1,649,107	1,169,432	653,238	432,583	101,811
	Fans	365,390	365,390	365,390	421,604	546,979
	CHW & CW Pumps	477,609	477,609	670,684	286,096	0
	Total	2,492,107	2,012,432	1,689,312	1,140,283	648,790
Peak Capacity (kW)	HVAC Peak Power	308	343	324	307	103
	Savings[A]	5%	-6%	0%	5%	68%
Water Consumption [kL]	Total[F]	0	0	12,315	8,693	7,280
	Savings[A]	100%	100%	0%	29%	41%
Carbon Emissions [kg CO_2]	Total	2,428,807	1,961,316	1,646,403	1,111,320	632,310
	Savings[A]	-48%	-19%	0%	33%	62%
Annual Costs[D] Cooling Only	Energy (Cooling)	1,993,685	1,609,945	1,351,450	912,226	519,032
	Water (Cooling)	0	0	32,635	23,037	19,292
	Total Costs (Cooling)	1,993,685	1,609,945	1,384,084	935,263	538,324
	Cost Savings [%][A]	-44%	-16%	0%	32%	61%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

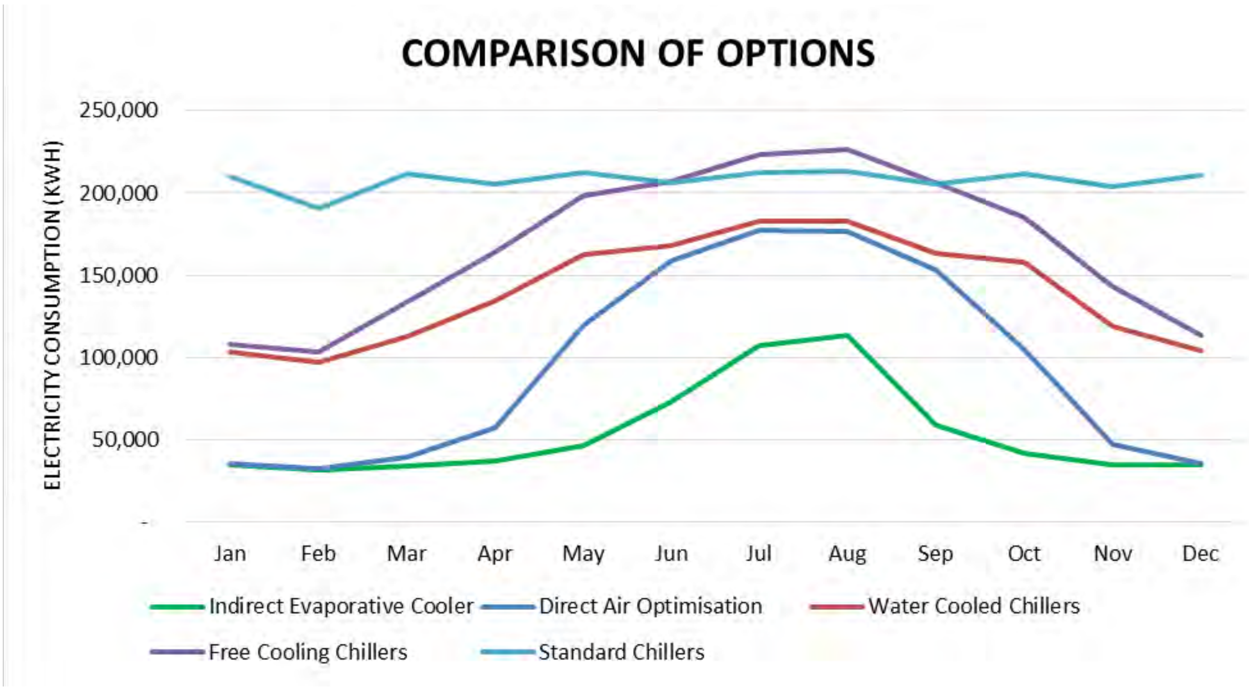
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



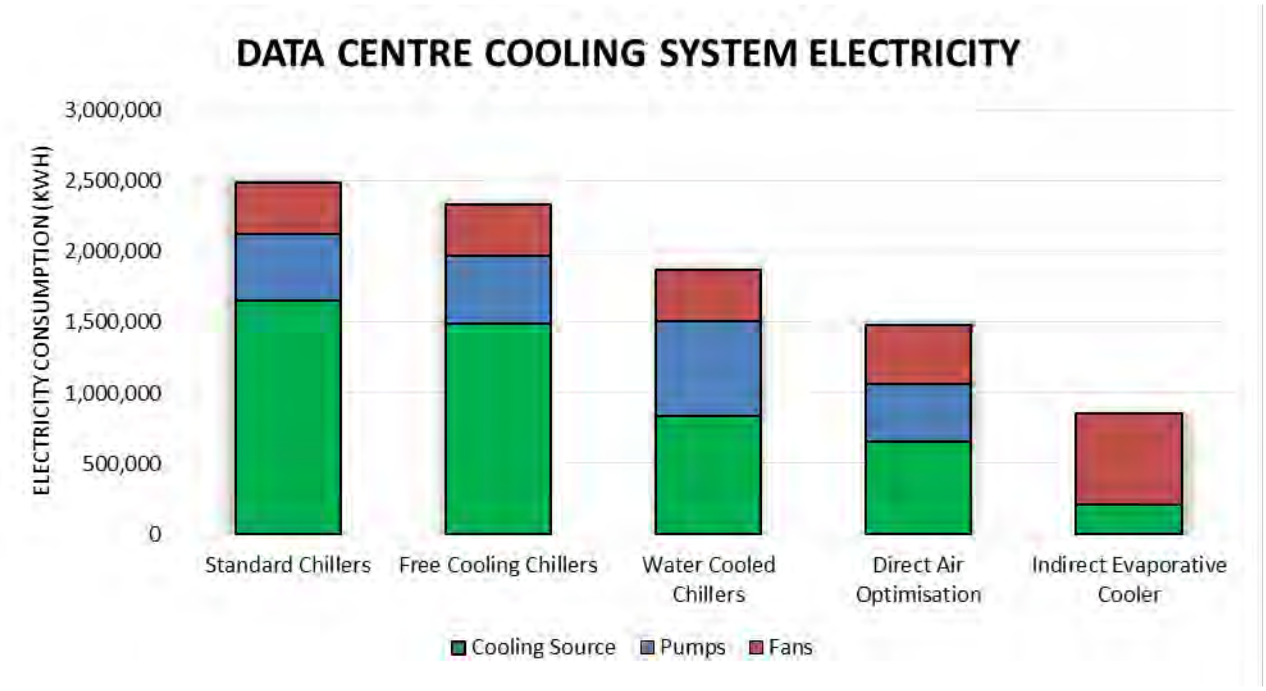
4.13 Guangzhou (Guangdong), China

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Guangzhou

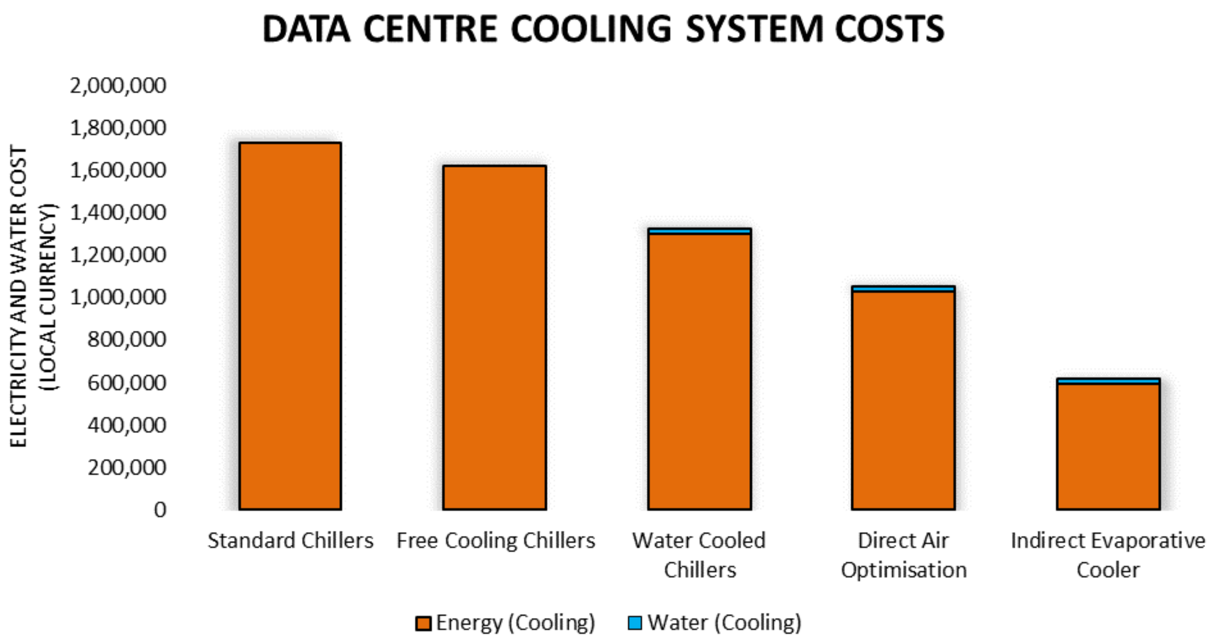
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.37	1.30	1.24	1.14
WUE (l/kWh)		0.00	0.00	1.97	1.59	1.54
Energy Consumption [kWh]	Cooling Source(E)	1,649,026	1,493,337	836,981	652,666	212,367
	Fans	365,390	365,390	365,390	421,604	644,727
	CHW & CW Pumps	477,585	477,585	670,409	410,812	0
	Total	2,492,002	2,336,313	1,872,780	1,485,082	857,094
Peak Capacity (kW)	HVAC Peak Power	314	350	326	307	133
	Savings(A)	4%	-7%	0%	6%	59%
Water Consumption [kL]	Total(F)	0	0	12,446	10,008	9,735
	Savings(A)	100%	100%	0%	20%	22%
Carbon Emissions [kg CO_2]	Total	2,428,705	2,276,970	1,825,212	1,447,361	835,324
	Savings(A)	-33%	-25%	0%	21%	54%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,729,449	1,621,401	1,299,709	1,030,647	594,823
	Water (Cooling)	0	0	27,381	22,017	21,417
	Total Costs (Cooling)	1,729,449	1,621,401	1,327,090	1,052,664	616,240
	Cost Savings [%](A)	-30%	-22%	0%	21%	54%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

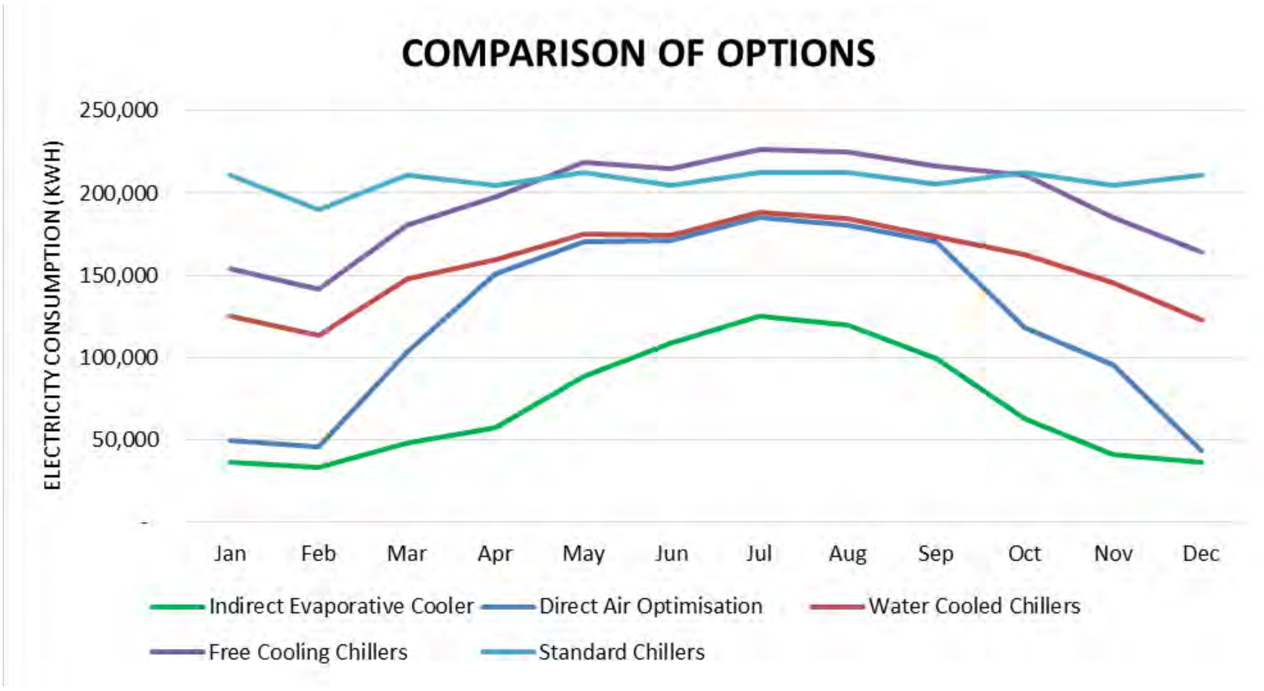
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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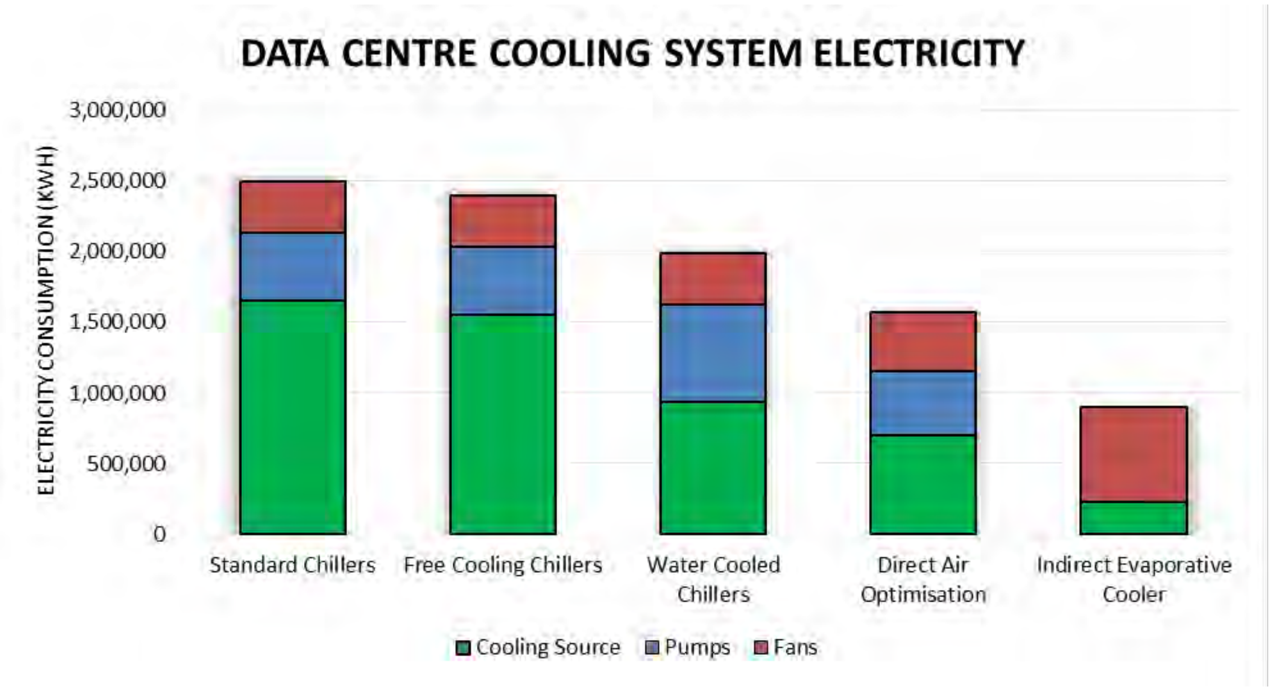
4.14 Hong Kong, SAR, PRC

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Hong Kong SAR, PRC.

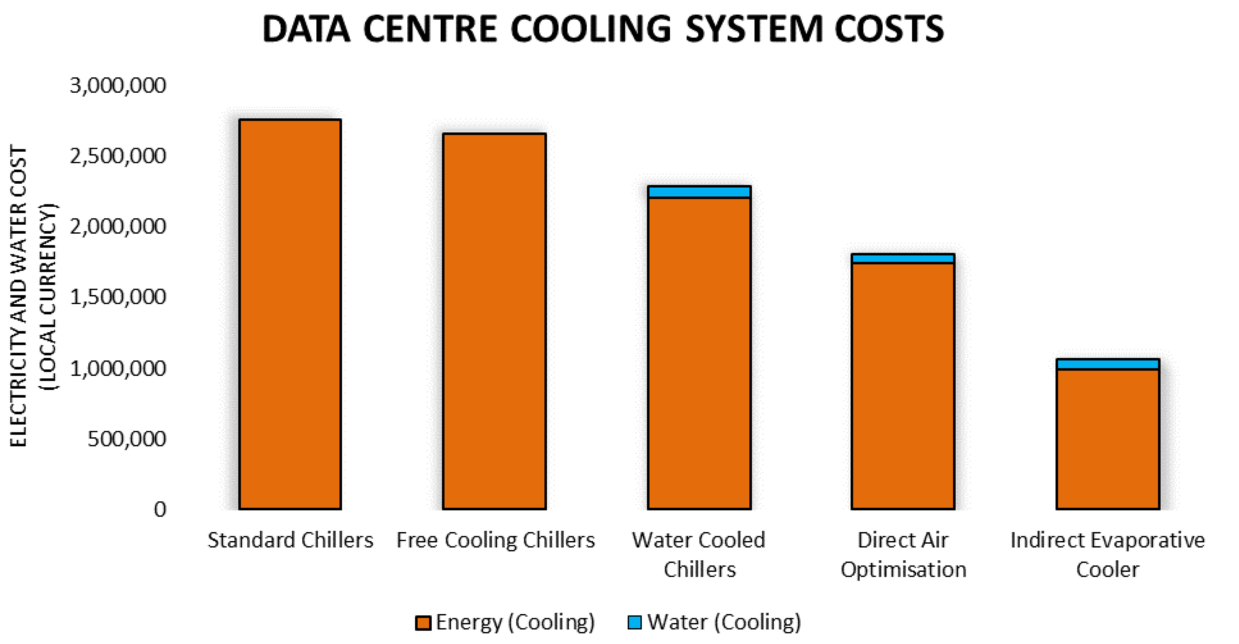
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.38	1.32	1.25	1.14
WUE (l/kWh)		0.00	0.00	1.98	1.56	1.50
Energy Consumption [kWh]	Cooling Source(E)	1,652,312	1,557,980	935,324	699,475	228,128
	Fans	365,390	365,390	365,390	421,604	667,152
	CHW & CW Pumps	478,591	478,591	688,428	450,590	0
	Total	2,496,293	2,401,961	1,989,143	1,571,669	895,280
Peak Capacity (kW)	HVAC Peak Power	306	342	318	305	97
	Savings(A)	4%	-7%	0%	4%	70%
Water Consumption [kL]	Total(F)	0	0	12,513	9,833	9,483
	Savings(A)	100%	100%	0%	21%	24%
Carbon Emissions [kg CO_2]	Total	1,963,584	1,889,382	1,564,660	1,236,275	704,227
	Savings(A)	-25%	-21%	0%	21%	55%
Annual Costs(D) Cooling Only	Energy (Cooling)	2,765,893	2,661,373	2,203,970	1,741,409	991,970
	Water (Cooling)	0	0	88,968	69,916	67,423
	Total Costs (Cooling)	2,765,893	2,661,373	2,292,938	1,811,324	1,059,393
	Cost Savings [%](A)	-21%	-16%	0%	21%	54%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

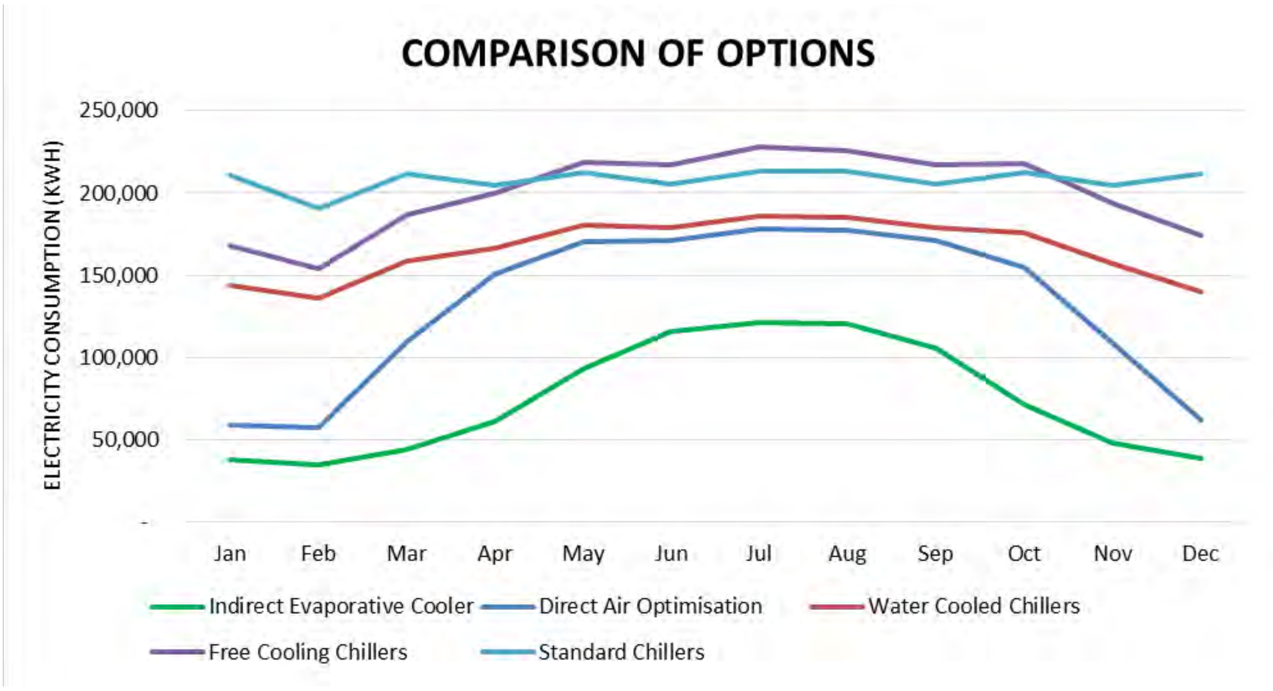
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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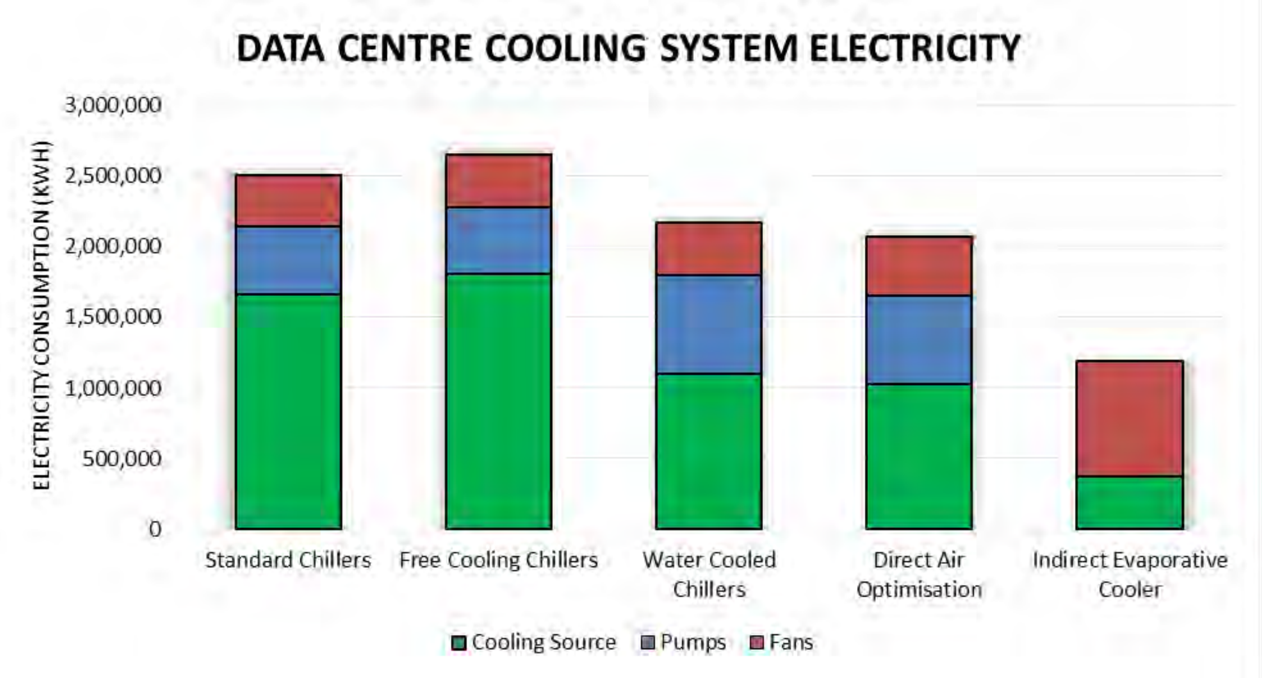
4.15 Manila, Philippines

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Manila.

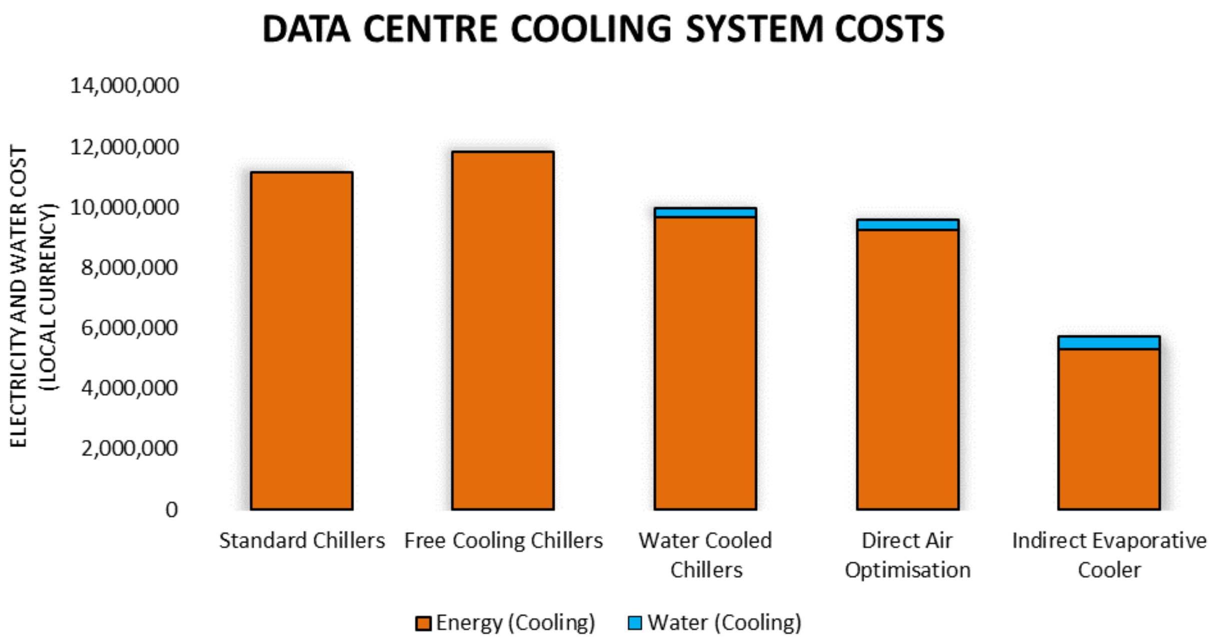
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.42	1.34	1.33	1.19
WUE (l/kWh)		0.00	0.00	2.02	2.06	2.66
Energy Consumption [kWh]	Cooling Source(E)	1,659,179	1,803,755	1,098,870	1,025,315	373,033
	Fans	365,390	365,390	365,390	421,604	820,242
	CHW & CW Pumps	480,693	480,693	702,494	628,118	0
	Total	2,505,262	2,649,839	2,166,755	2,075,038	1,193,276
Peak Capacity (kW)	HVAC Peak Power	307	342	319	307	118
	Savings(A)	4%	-7%	0%	4%	63%
Water Consumption [kL]	Total(F)	0	0	12,741	12,979	16,802
	Savings(A)	100%	100%	0%	-2%	-32%
Carbon Emissions [kg CO_2]	Total	1,319,522	1,395,670	1,141,230	1,092,922	628,498
	Savings(A)	-16%	-22%	0%	4%	45%
Annual Costs(D) Cooling Only	Energy (Cooling)	11,163,449	11,807,683	9,655,059	9,246,367	5,317,237
	Water (Cooling)	0	0	319,407	325,387	421,225
	Total Costs (Cooling)	11,163,449	11,807,683	9,974,466	9,571,754	5,738,462
	Cost Savings [%](A)	-12%	-18%	0%	4%	42%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

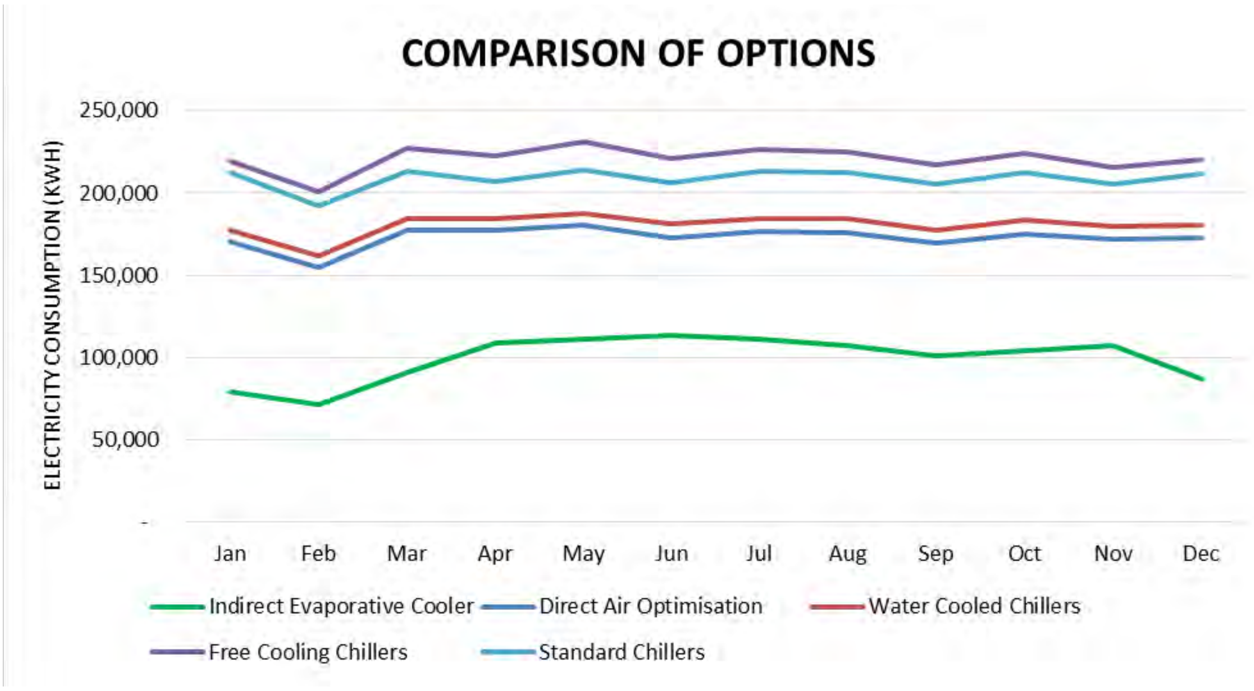
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



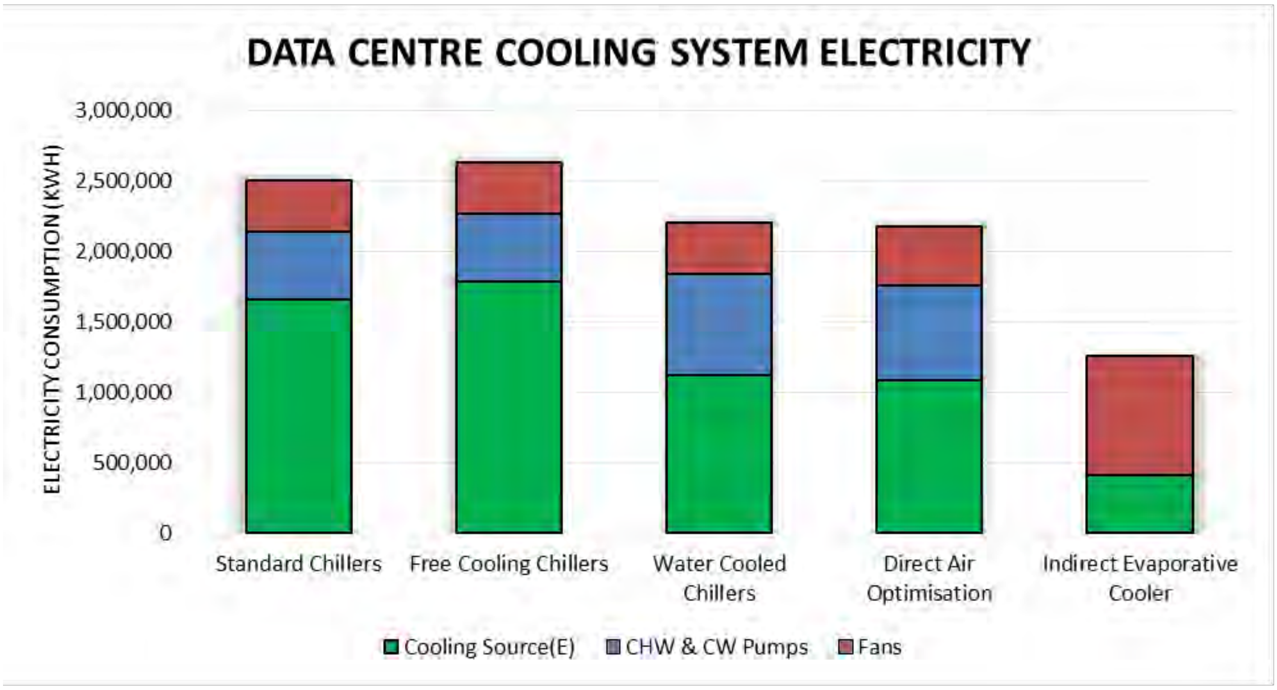
4.16 Kuala Lumpur, Malaysia

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Kuala Lumpur.

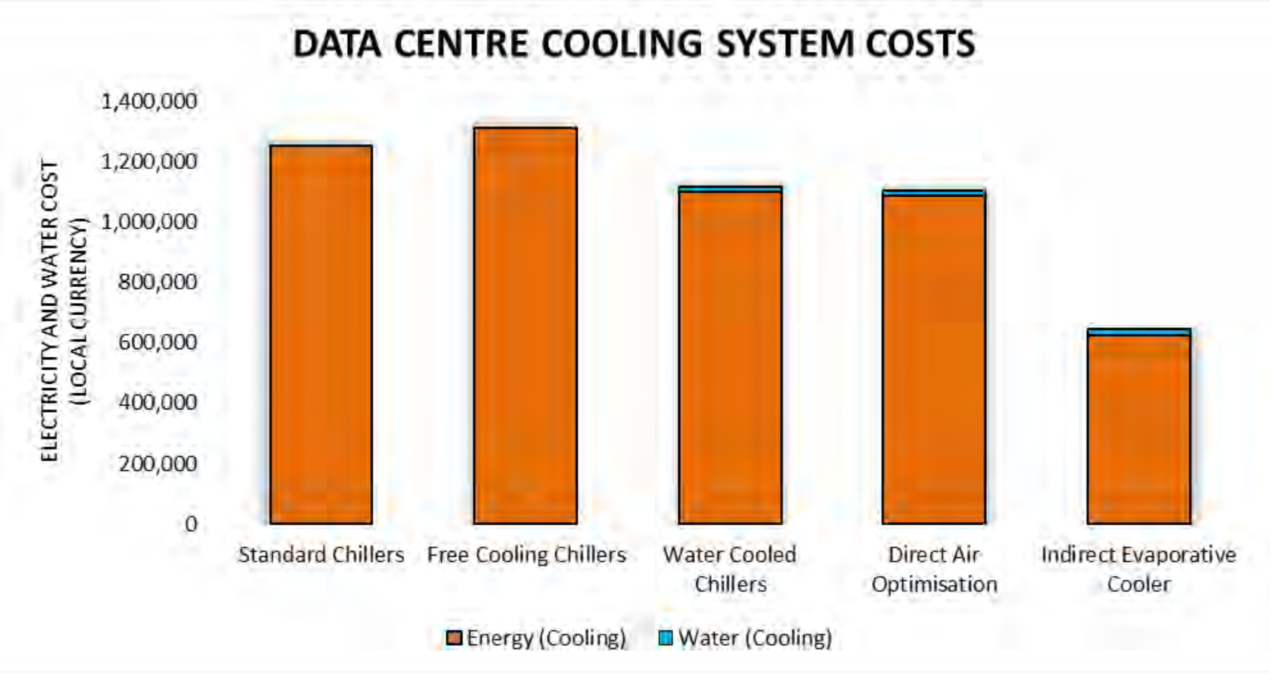
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.42	1.35	1.34	1.20
WUE (l/kWh)		0.00	0.00	2.02	2.02	2.23
Energy Consumption [kWh]	Cooling Source(E)	1,658,888	1,780,036	1,118,897	1,086,896	407,258
	Fans	365,390	365,390	365,390	421,604	844,817
	CHW & CW Pumps	480,604	480,604	717,649	666,712	0
	Total	2,504,883	2,626,030	2,201,936	2,175,212	1,252,075
Peak Capacity (kW)	HVAC Peak Power	307	342	312	261	123
	Savings(A)	2%	-10%	0%	16%	61%
Water Consumption [kL]	Total(F)	0	0	12,743	12,731	14,084
	Savings(A)	100%	100%	0%	0%	-11%
Carbon Emissions [kg CO_2]	Total	1,878,662	1,969,523	1,651,452	1,631,409	939,056
	Savings(A)	-14%	-19%	0%	1%	43%
Annual Costs(D) Cooling Only	Energy (Cooling)	1,252,441	1,313,015	1,100,968	1,087,606	626,038
	Water (Cooling)	0	0	16,820	16,805	18,591
	Total Costs (Cooling)	1,252,441	1,313,015	1,117,789	1,104,411	644,629
	Cost Savings [%](A)	-12%	-17%	0%	1%	42%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

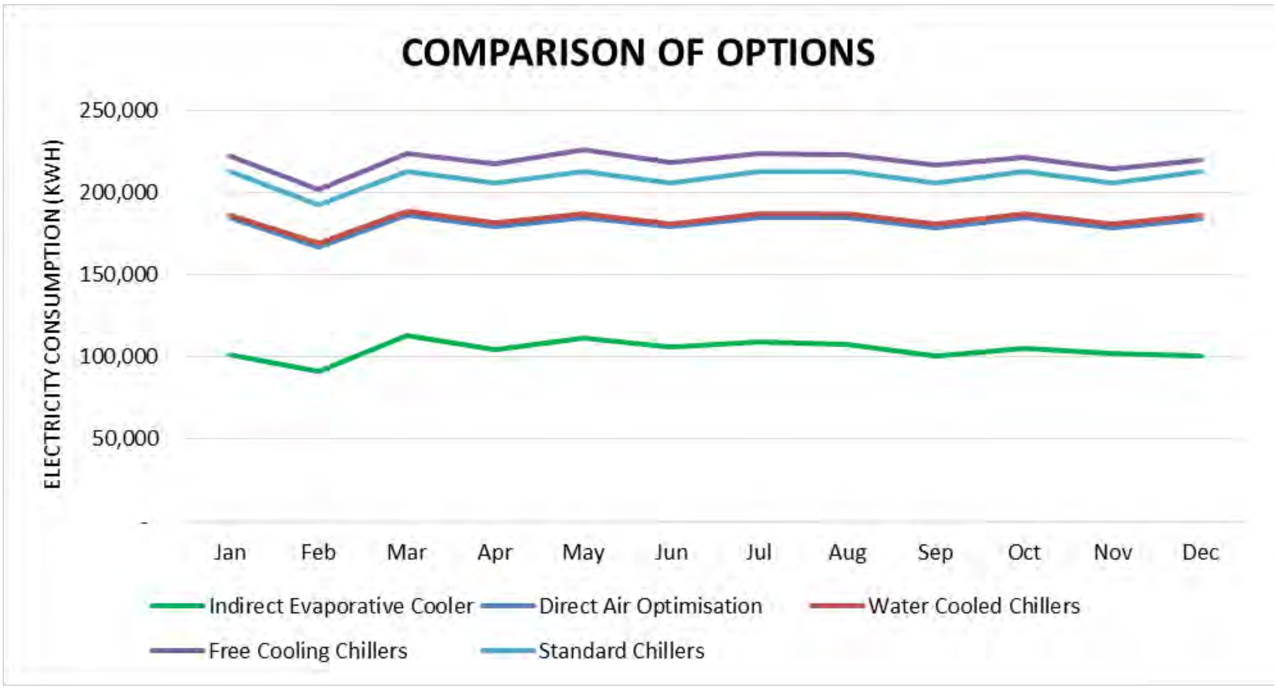
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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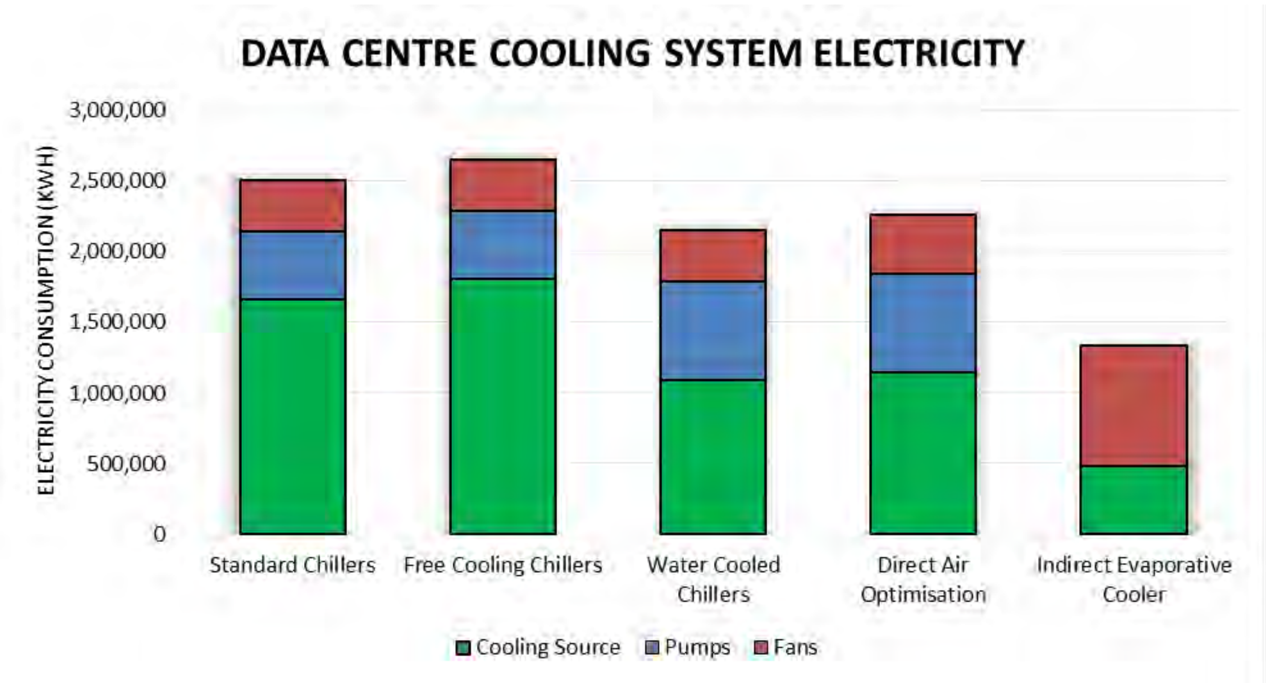
4.17 Singapore, Singapore

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Singapore.

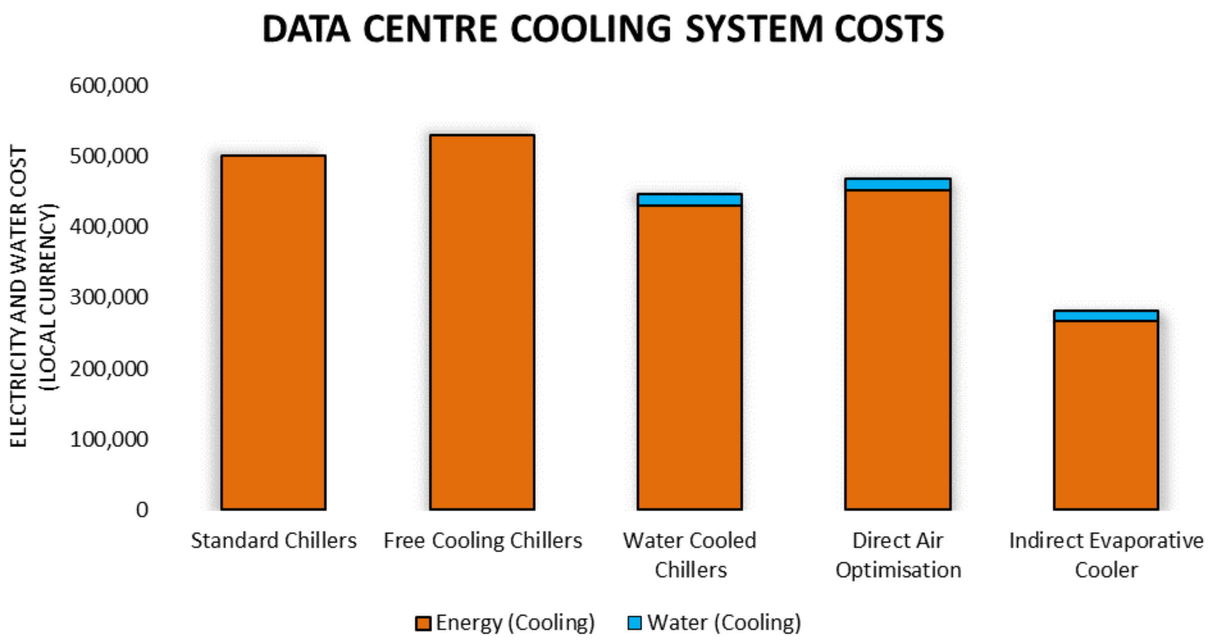
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)[(C)]		1.40	1.42	1.34	1.36	1.21
WUE (l/kWh)		0.00	0.00	2.02	2.02	1.96
Energy Consumption [kWh]	Cooling Source[(E)]	1,661,037	1,805,360	1,088,223	1,142,805	479,473
	Fans	365,390	365,390	365,390	421,604	855,737
	CHW & CW Pumps	481,262	481,262	700,601	700,577	0
	Total	2,507,689	2,652,012	2,154,214	2,264,986	1,335,210
Peak Capacity (kW)	HVAC Peak Power	308	344	321	287	96
	Savings[(A)]	4%	-7%	0%	10%	70%
Water Consumption [kL]	Total[(F)]	0	0	12,740	12,746	12,335
	Savings[(A)]	100%	100%	0%	0%	3%
Carbon Emissions [kg CO_2]	Total	1,429,383	1,511,647	1,227,902	1,291,042	761,070
	Savings[(A)]	-16%	-23%	0%	-5%	38%
Annual Costs[(D)] Cooling Only	Energy (Cooling)	501,538	530,402	430,843	452,997	267,042
	Water (Cooling)	0	0	15,288	15,295	14,802
	Total Costs (Cooling)	501,538	530,402	446,131	468,293	281,844
	Cost Savings [%][(A)]	-12%	-19%	0%	-5%	37%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

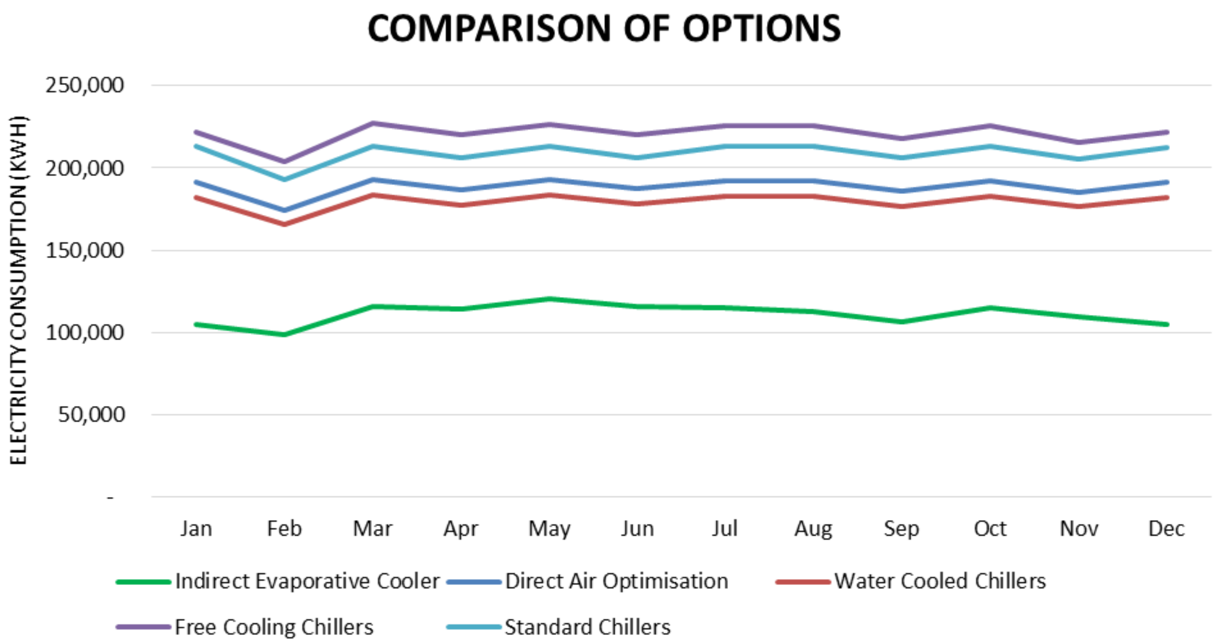
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



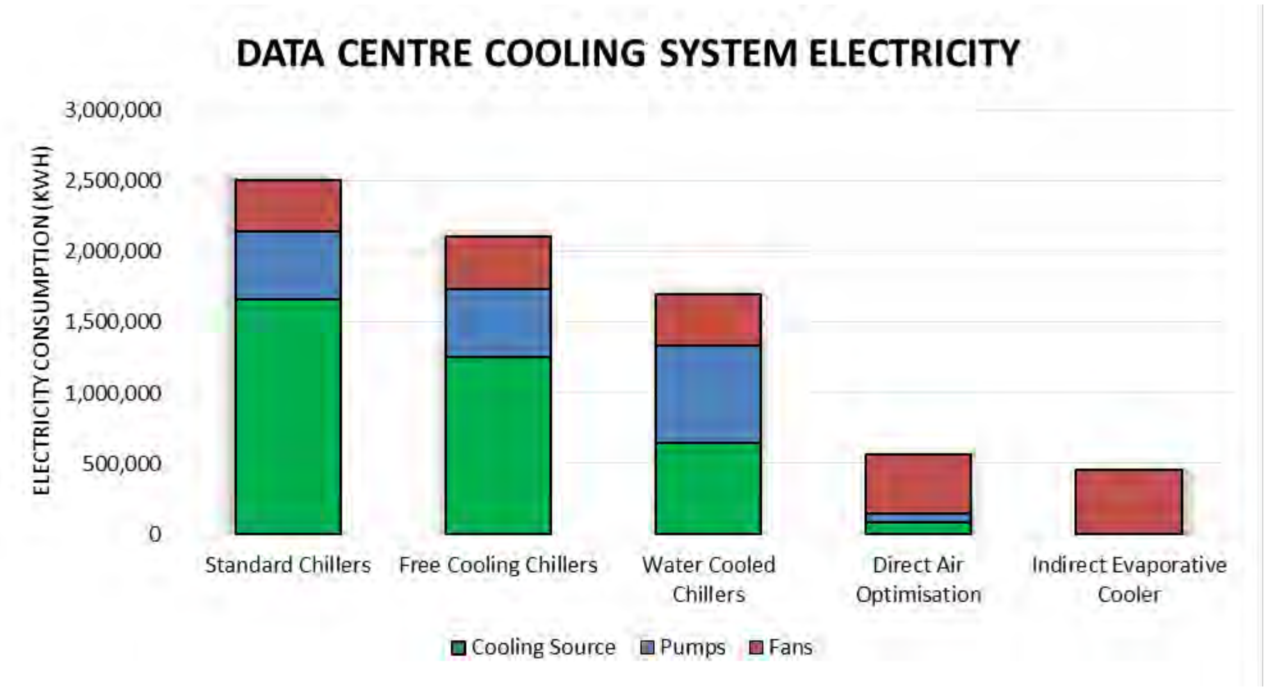
4.18 Perth, Australia

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Perth.

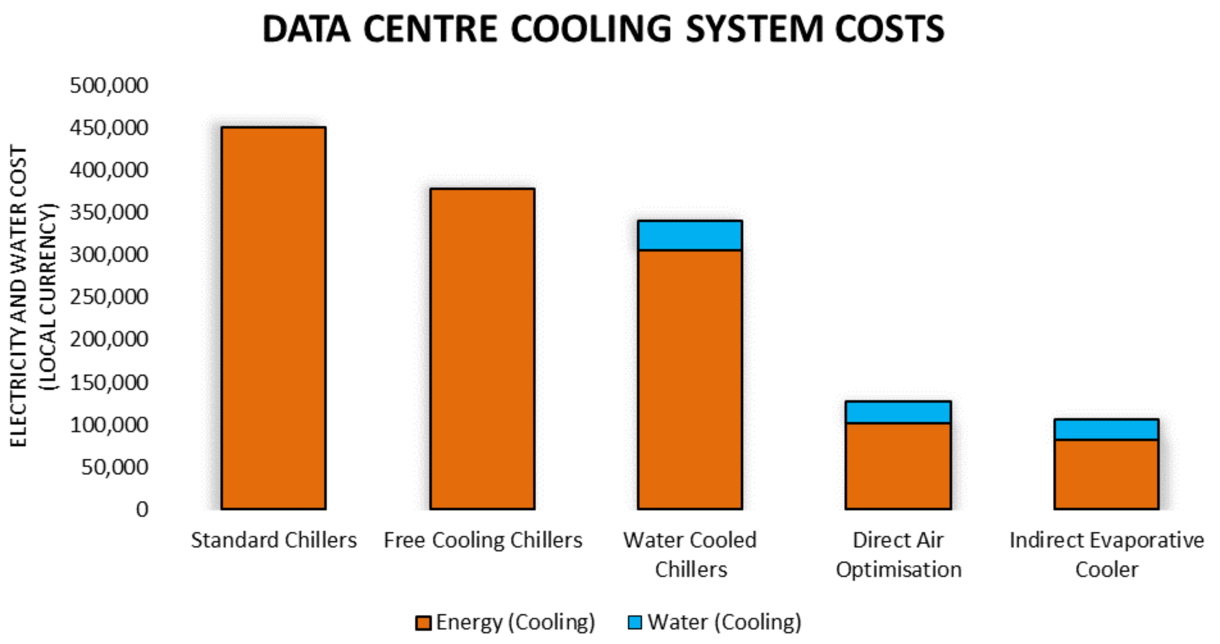
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.33	1.27	1.09	1.07
WUE (l/kWh)		0.00	0.00	1.96	1.44	1.36
Energy Consumption [kWh]	Cooling Source(E)	1,662,788	1,257,482	642,711	82,987	915
	Fans	365,390	365,390	365,390	421,604	452,495
	CHW & CW Pumps	481,798	481,798	690,278	60,291	0
	Total	2,509,976	2,104,671	1,698,379	564,882	453,410
Peak Capacity (kW)	HVAC Peak Power	312	388	289	290	25
	Savings(A)	-8%	-34%	0%	0%	91%
Water Consumption [kL]	Total(F)	0	0	12,343	9,099	8,592
	Savings(A)	100%	100%	0%	26%	30%
Carbon Emissions [kg CO_2]	Total	2,488,641	2,086,781	1,683,942	560,080	449,556
	Savings(A)	-48%	-24%	0%	67%	73%
Annual Costs(D) Cooling Only	Energy (Cooling)	451,796	378,841	305,708	101,679	81,614
	Water (Cooling)	0	0	34,561	25,477	24,059
	Total Costs (Cooling)	451,796	378,841	340,269	127,156	105,672
	Cost Savings [%](A)	-33%	-11%	0%	63%	69%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

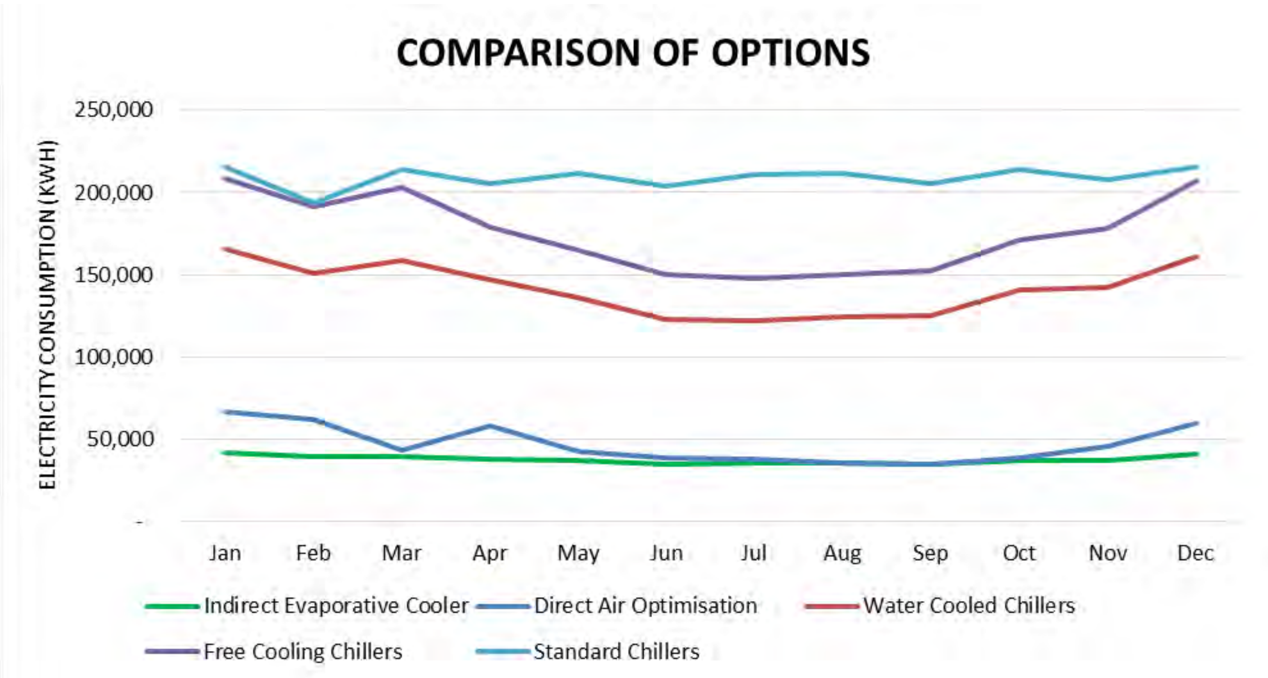
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



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4.19 Sydney, Australia

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Sydney.

		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.33	1.27	1.14	1.07
WUE (l/kWh)		0.00	0.00	1.95	1.05	0.99
Energy Consumption [kWh]	Cooling Source(E)	1,656,882	1,247,584	678,056	257,161	2,757
	Fans	365,390	365,390	365,390	421,604	468,293
	CHW & CW Pumps	479,990	479,990	690,739	188,719	0
	Total	2,502,262	2,092,964	1,734,186	867,484	471,050
Peak Capacity (kW)	HVAC Peak Power	310	385	287	306	38
	Savings(A)	-8%	-34%	0%	-6%	87%
Water Consumption [kL]	Total(F)	0	0	12,316	6,621	6,255
	Savings(A)	100%	100%	0%	46%	49%
Carbon Emissions [kg CO_2]	Total	2,480,993	2,075,174	1,719,445	860,111	467,046
	Savings(A)	-44%	-21%	0%	50%	73%
Annual Costs(D) Cooling Only	Energy (Cooling)	450,407	376,734	312,153	156,147	84,789
	Water (Cooling)	0	0	27,094	14,566	13,762
	Total Costs (Cooling)	450,407	376,734	339,248	170,713	98,551
	Cost Savings [%](A)	-33%	-11%	0%	50%	71%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
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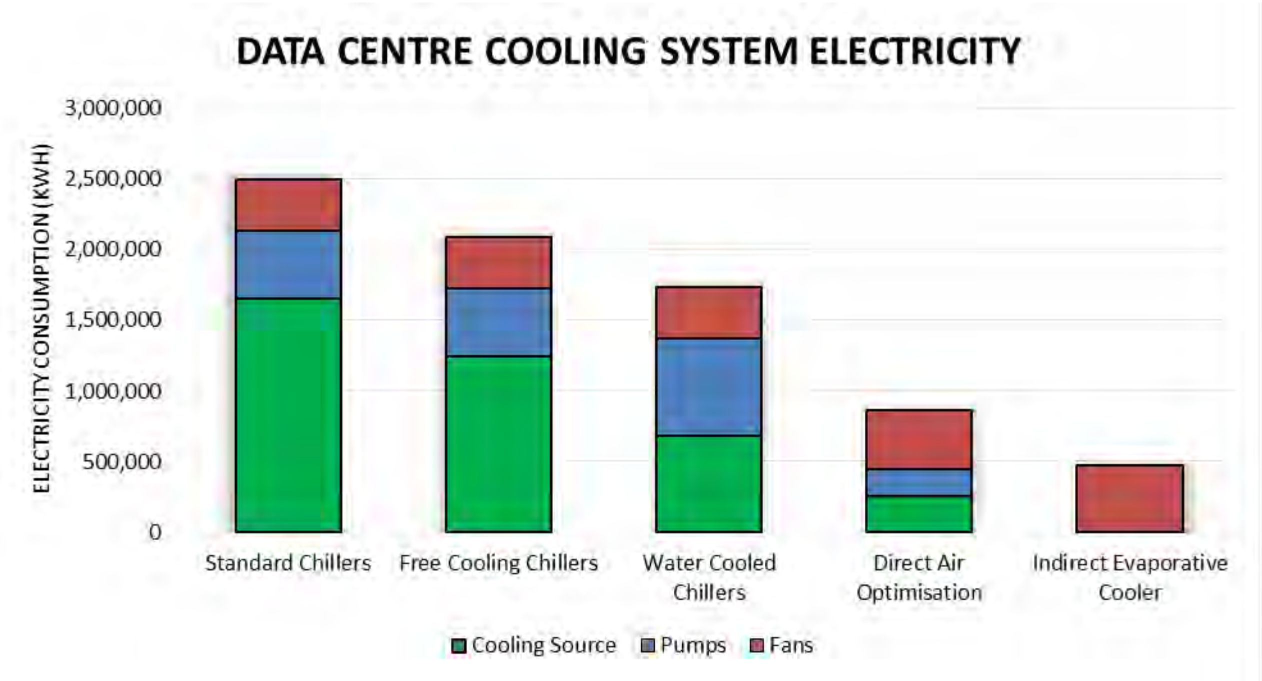
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



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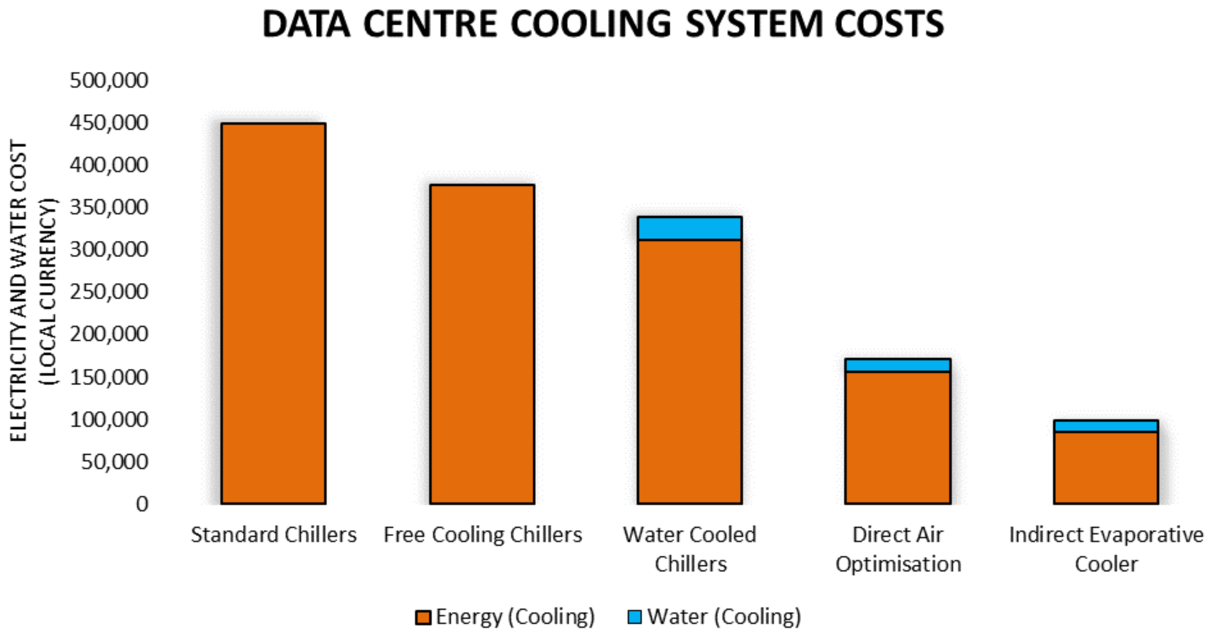
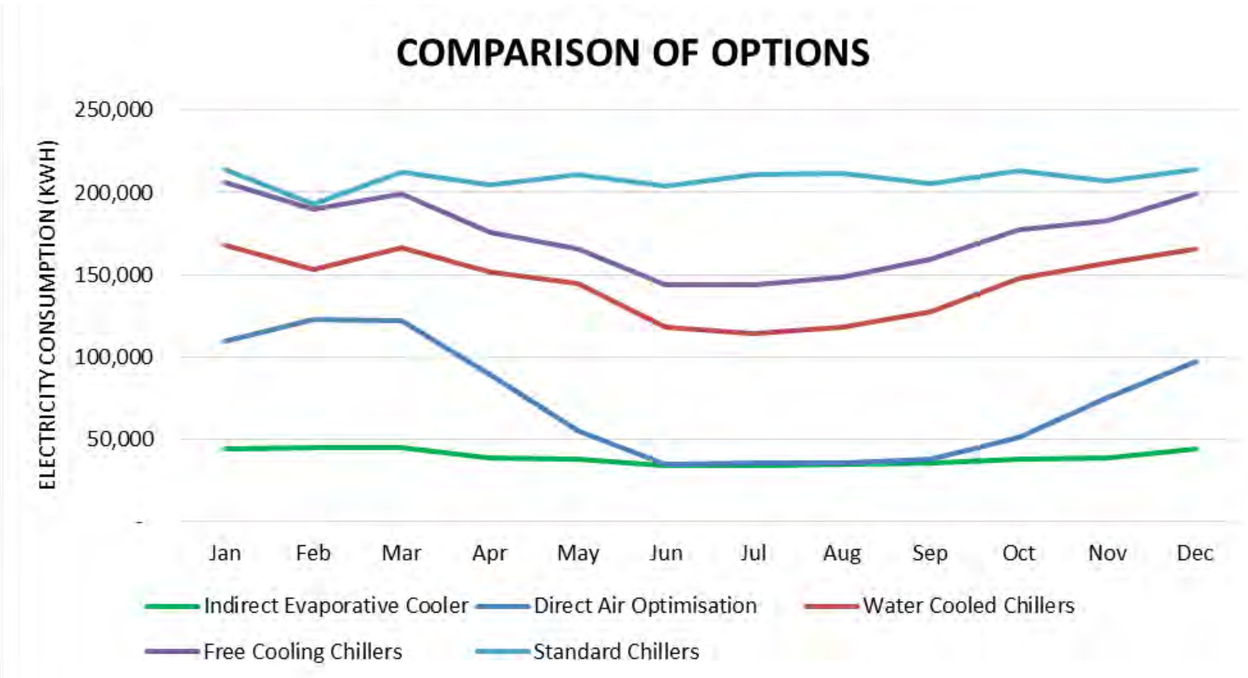
A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



CUNDALL

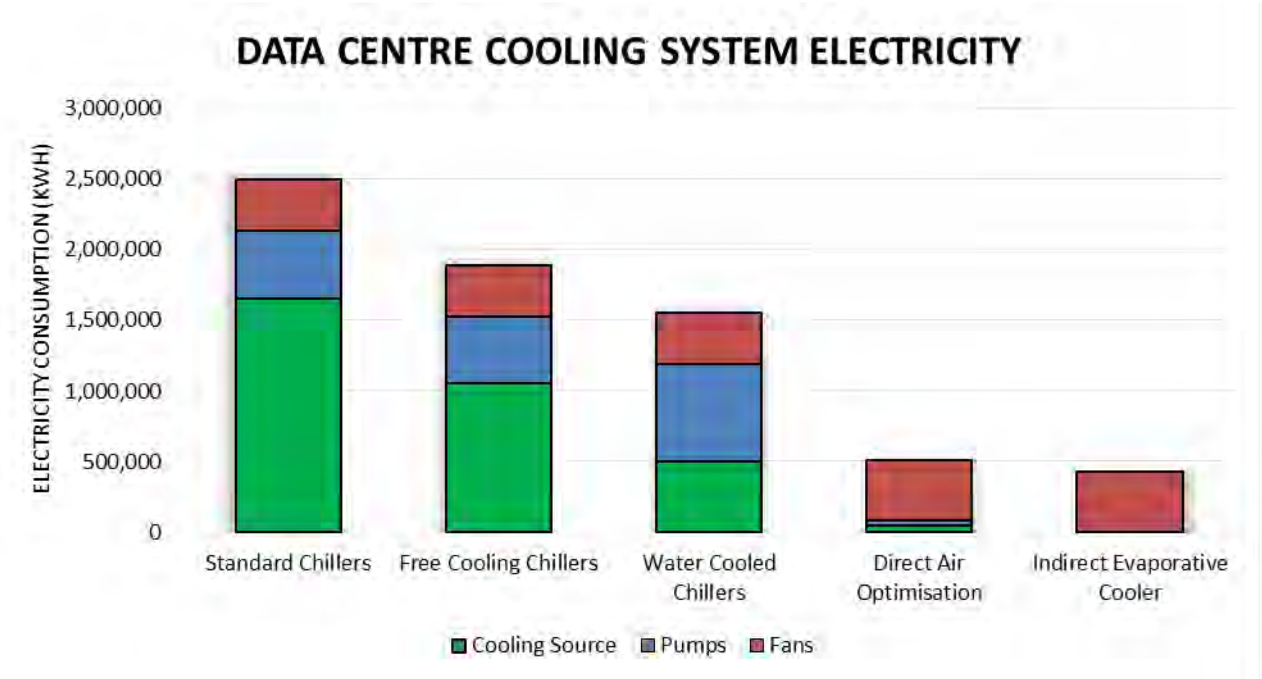
4.20 Melbourne, Australia

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 A: - Basis of Calculations. The data has been gathered using TRY weather data for Melbourne.

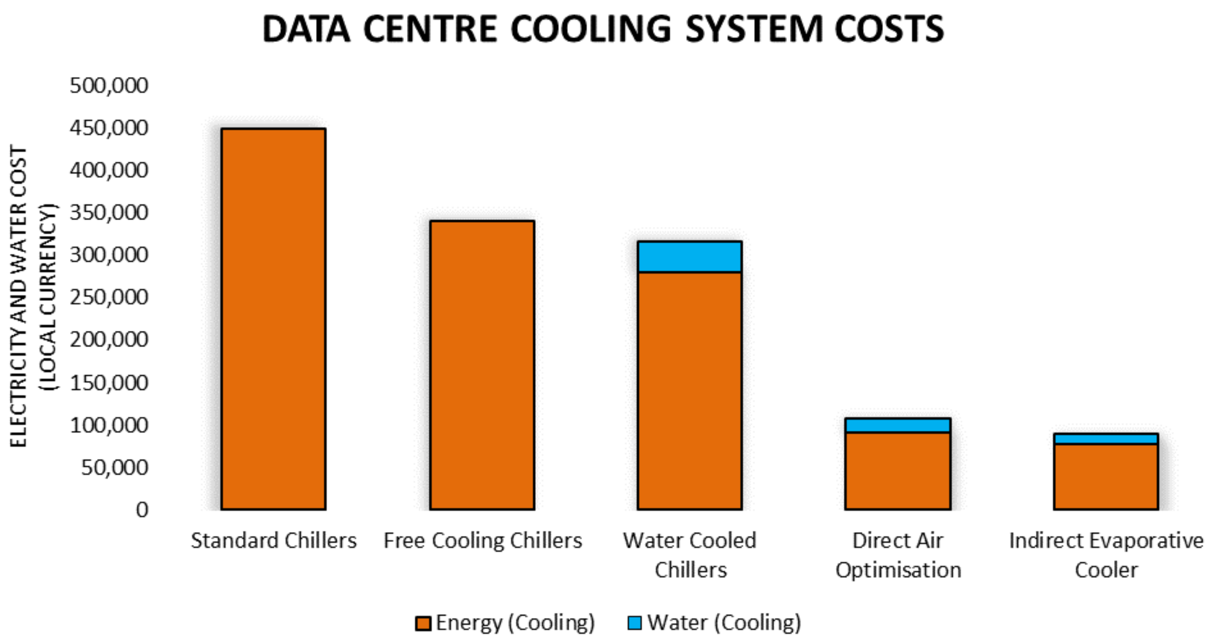
		Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
PUE (partial)(C)		1.40	1.30	1.25	1.08	1.07
WUE (l/kWh)		0.00	0.00	1.94	0.86	0.67
Energy Consumption [kWh]	Cooling Source(E)	1,652,960	1,050,046	498,737	49,119	7
	Fans	365,390	365,390	365,390	421,604	430,591
	CHW & CW Pumps	478,789	478,789	693,958	35,671	0
	Total	2,497,140	1,894,225	1,558,086	506,394	430,598
Peak Capacity (kW)	HVAC Peak Power	309	345	267	274	4
	Savings(A)	-16%	-29%	0%	-3%	99%
Water Consumption [kL]	Total(F)	0	0	12,232	5,444	4,255
	Savings(A)	100%	100%	0%	55%	65%
Carbon Emissions [kg CO_2]	Total	2,475,914	1,878,125	1,544,842	502,089	426,938
	Savings(A)	-60%	-22%	0%	67%	72%
Annual Costs(D) Cooling Only	Energy (Cooling)	449,485	340,961	280,455	91,151	77,508
	Water (Cooling)	0	0	35,474	15,786	12,340
	Total Costs (Cooling)	449,485	340,961	315,930	106,937	89,847
	Cost Savings [%](A)	-42%	-8%	0%	66%	72%

A - All savings figures shown are compared to the "Water Cooled Chillers".
B - Total Cooling COP figure includes energy spent on chillers, evaporative cooling and fans (CRAC units or IAO units)
C - PUE (partial) includes cooling system of the data hall only, thus excludes UPS cooling system, electrical losses, fresh air ventilation, etc
D - The cost of electricity and water is given in Appendix A: - Basis of Calculations, and is shown in the local currency in these results.
E - The cooling source for indicates with a chilled water system for the chiller options and DAO, or unitary DX for IAO.
F - The DAO system is connects to a water cooled chiller, hence the water consumption.

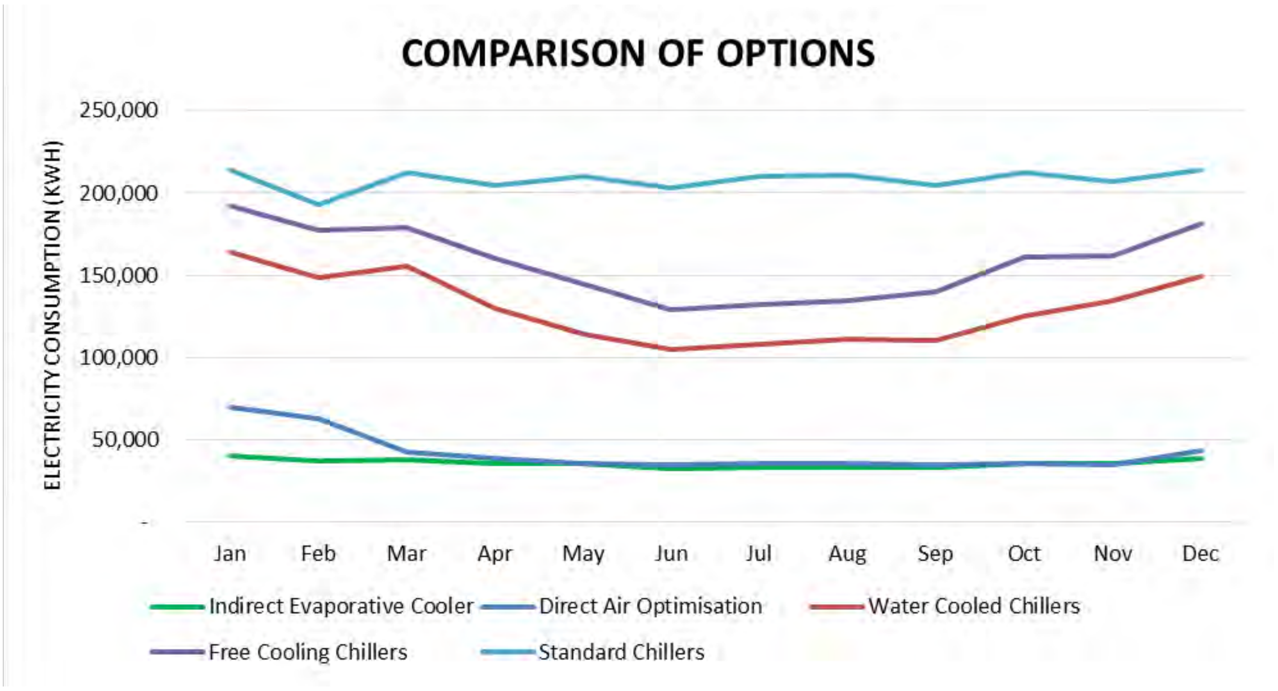
A graphical representation of the common data centre cooling systems electricity consumption is shown below, with a breakdown of energy consumption between cooling source, pumps and fans (CRAHs or IAO).



A graphical representation of the common data centre cooling systems electricity and water costs is shown below, all costs are shown in the local currency.



A graphical representation of the common data centre cooling systems electricity consumption of a month by month basis is shown below.



5. Conclusions

This report has compared the operational efficiency of the Oasis™ Indirect Evaporative Cooler compared to a range of chiller water options and Direct Air Optimisation. 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 key benefits of the Munters Oasis™ Indirect Evaporative Cooler are as follows:

- Operational energy savings, leading to operational cost savings.
- Peak electrical demand savings, leading to operational cost savings and capital cost savings in electrical support systems.
- Operational water savings when compared to water cooled chillers, leading to operational cost savings.
- Low PUE allowing effective marketing to energy conscious clients
- Reduced contamination potential when compared to a Direct Air Optimisation system.
- Effective in the implementation of a modular stage by stage design allowing deferred commitment of capital costs.
- Low maintenance requirements.

The main benefit of focus that has been examined and demonstrated in this report is the annual energy consumption reductions as a result of using the Oasis™ 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.
- DAO can only utilise free cooling when conditions do not exceed the maximum moisture content recommended by ASHRAE TC 9.9. These conditions seldom occur particularly in the tropical climates included in the study. IAO can utilise the free cooling provided by the evaporative process at any moisture content level as the outside air does not enter the data hall.

The summary of electricity savings for each location, as compared to water cooled chillers with CRAH is shown below. Where the figures show a negative sign it indicates an increase in consumption. The table has been sorted based on the electrical savings compared to water cooled chillers, largest to smallest savings.

Location	Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
19. Sydney, Australia	-44%	-21%	0%	50%	73%
18. Perth, Australia	-48%	-24%	0%	67%	73%
20. Melbourne, Australia	-60%	-22%	0%	67%	72%
02. Urumqi, China	-70%	-13%	0%	71%	71%
03. Hohhot, Inner Mongolia	-72%	-11%	0%	62%	70%
01. Harbin, China	-68%	-7%	0%	56%	69%
06. Tokyo, Japan	-55%	-14%	0%	40%	67%
04. Beijing, China	-61%	-18%	0%	49%	65%
05. Shijiazhuang, China	-58%	-18%	0%	46%	65%
07. Zhengzhou, China	-54%	-17%	0%	44%	64%
12. Hangzhou, China	-48%	-19%	0%	33%	62%
10. Shanghai, China	-50%	-20%	0%	33%	61%
09. Chongqing, China	-46%	-23%	0%	29%	61%
08. Nanjing, China	-50%	-17%	0%	38%	61%
11. Wuhan, China	-48%	-20%	0%	31%	59%
14. Hong Kong, Hong Kong	-25%	-21%	0%	21%	55%
13. Guangzhou, China	-33%	-25%	0%	21%	54%
15. Manila, Philippines	-16%	-22%	0%	4%	45%
16. Kuala Lumpur, Malaysia	-14%	-19%	0%	1%	43%
17. Singapore, Singapore	-16%	-23%	0%	-5%	38%

The results show that in all locations an IAC solution provides significant energy savings over all options, including DAO. The results show that Singapore achieves significant savings at 38% compared to the water cooled chiller. The lower than average savings are associated with consistently high wet bulb temperatures, decreasing the impact of the evaporative cooling.

Air cooled chilled water systems have minimal water needs, however water cooled systems have significant water consumption. In comparison Indirect Evaporative Cooler utilises water in the evaporative cooling process. Typically a IAO unit will utilise DX cooling with no water requirements. The summary of relative water consumption for each location, as compared to water cooled chillers with CRAH is shown below. Where the figures show a negative sign it indicates an increase in consumption. The table has been sorted based on the water savings compared to water cooled chillers, largest to smallest savings.

Location	Standard Chillers	Free Cooling Chillers	Water Cooled Chillers	Direct Air Optimisation	Indirect Evaporative Cooler
06. Tokyo, Japan	100%	100%	0%	43%	70%
20. Melbourne, Australia	100%	100%	0%	55%	65%
01. Harbin, China	100%	100%	0%	52%	65%
03. Hohhot, Inner Mongolia	100%	100%	0%	33%	58%
02. Urumqi, China	100%	100%	0%	31%	51%
19. Sydney, Australia	100%	100%	0%	46%	49%
10. Shanghai, China	100%	100%	0%	37%	49%
08. Nanjing, China	100%	100%	0%	34%	43%
12. Hangzhou, China	100%	100%	0%	29%	41%
09. Chongqing, China	100%	100%	0%	40%	39%
04. Beijing, China	100%	100%	0%	14%	34%
07. Zhengzhou, China	100%	100%	0%	20%	34%
18. Perth, Australia	100%	100%	0%	26%	30%
11. Wuhan, China	100%	100%	0%	32%	30%
05. Shijiazhuang, China	100%	100%	0%	12%	29%
14. Hong Kong, Hong Kong	100%	100%	0%	21%	24%
13. Guangzhou, China	100%	100%	0%	20%	22%
17. Singapore, Singapore	100%	100%	0%	0%	3%
16. Kuala Lumpur, Malaysia	100%	100%	0%	0%	-11%
15. Manila, Philippines	100%	100%	0%	-2%	-32%

Appendix A: - Basis of Calculations

Technical Schedules

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 Singapore provided by Munters.

Design Parameter	Design Criteria	Comments
Design Cooling Load	144 kW per unit (720kW total)	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	26^{o}C db	Air needs to be supplied to the servers within the boundaries of the ASHRAE 'Class 1' conditions.
Data Hall Return	38^{o}C db	A typical target ΔT for this type of application would be 12^{o}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 m^3/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^2/s	Dependent on unit configuration and duty.
Supply Fan Pressure	200 Pa	Pressure is dependent on unit duty and filtration requirements (external)
Extract Fan Pressure	210 Pa	Pressure 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, conservative estimates utilised.
Unit Size (WxLxH) mm	3940 x 6895 x 4149	The design of the unit is adaptable to specific requirements and dimensions will vary accordingly
Unit Weight	6600kgs	The design of the unit is adaptable to specific requirements and unit weight will vary accordingly

Basis of Calculations – Munters Oasis™

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 1000 W/m² for 720m² data hall, therefore the total IT load for the data hall will be 720kW. The total annual IT electrical energy consumption will be 6,307,200 kWh.

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 provided by Munters. Energy associated with the scavenger fans has been taken as a variable figure based on the data provided by Munters which has been developed based on the scavenger volume required to achieve the heat exchanger efficiency in order to maintain a the supply air temperature.

The DX Condensers Energy Efficiency Ratio (EER), as defined in the following table, which was based on typical DX operation, 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.

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 following summarise a number of assumptions used in calculation of the energy and water consumption of the Munters Oasis™ unit as well as the costs of water and electricity associated with various locations.

Parameter	Value
Supply set point Temperature to the Data Hall [°C]	26°C
Return set point Temperature from the Data Hall [°C]	38°C
Maximum scavenger air volume to supply air volume	1.1
Process Air Fan power at 63m³/s (kW)	41.7 kW
Process Air Fan Heat Gain [K]	0.7°C
Scavenger Air Fan SFP [W/l/s]	Variable, max 1.0
Proportion of circulation air filtrated	25%
Heat recovery efficiency (DRY)	Variable
Heat recovery efficiency (WET)	Variable
DX Cooling Efficiency (SEER)	4.0
DX cooling active only when off-coil temperature of the process air is equal or higher than supply set point temperature	
Water use excess (loss, due to conductivity control/bleed rate)	25%
Minimum outside temperature for evaporative cooling [°C]	Variable

Location by location utility costs and carbon coefficients are shown below, shown in the location currency.

Location	Electricity Rate	Water Rate	Carbon Coefficient
01. Harbin (HeiLongJiang), China	0.58 RMB￥/kWh	3.1 RMB￥/m³	0.97 kg CO_2/kWh
02. Urumqi (Xinjiang), China	0.38 RMB￥/kWh	4.44 RMB￥/m³	0.97 kg CO_2/kWh
03. Hohhot, Inner Mongolia	0.46 RMB￥/kWh	3 RMB￥/m³	0.97 kg CO_2/kWh
04. Beijing, China	0.67 RMB￥/kWh	6.21 RMB￥/m³	0.97 kg CO_2/kWh
05. Shijiazhuang (HeBei), China	0.57 RMB￥/kWh	4.33 RMB￥/m³	0.97 kg CO_2/kWh
06. Tokyo, Japan	18 ¥ yen/kWh	200 ¥ yen/m³	0.44 kg CO_2/kWh
07. Zhengzhou (Henan), China	0.6 RMB￥/kWh	3.25 RMB￥/m³	0.97 kg CO_2/kWh
08. Nanjing (Jiangsu), China	0.65 RMB￥/kWh	1.95 RMB￥/m³	0.97 kg CO_2/kWh
09. Chongqing, China	0.65 RMB￥/kWh	3.25 RMB￥/m³	0.97 kg CO_2/kWh
10. Shanghai, China	0.75 RMB￥/kWh	5 RMB￥/m³	0.97 kg CO_2/kWh
11. Wuhan (Hubei), China	0.63 RMB￥/kWh	2.35 RMB￥/m³	0.97 kg CO_2/kWh
12. Hangzhou (ZheJiang), China	0.8 RMB￥/kWh	2.65 RMB￥/m³	0.97 kg CO_2/kWh
13. Guangzhou (Guangdong), China	0.69 RMB￥/kWh	2.2 RMB￥/m³	0.97 kg CO_2/kWh
14. Hong Kong, Hong Kong	1.11 HKD $/kWh	7.11 HKD $/m³	0.79 kg CO_2/kWh
15. Manila, Philippines	4.46 PHP ₱/kWh	25.07 PHP ₱/m³	0.53 kg CO_2/kWh
16. Kuala Lumpur, Malaysia	0.5 MYR/m²	1.32 MYR/m²	0.75 kg CO_2/kWh
17. Singapore, Singapore	0.2 SGD $/kWh	1.2 SGD $/m²	0.57 kg CO_2/kWh
18. Perth, Australia	0.18 AUD $/kWh	2.8 AUD $/m²	0.99 kg CO_2/kWh
19. Sydney, Australia	0.18 AUD $/kWh	2.2 AUD $/m²	0.99 kg CO_2/kWh
20. Melbourne, Australia	0.18 AUD $/kWh	2.9 AUD $/m²	0.99 kg CO_2/kWh

Basis of Calculations - 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)

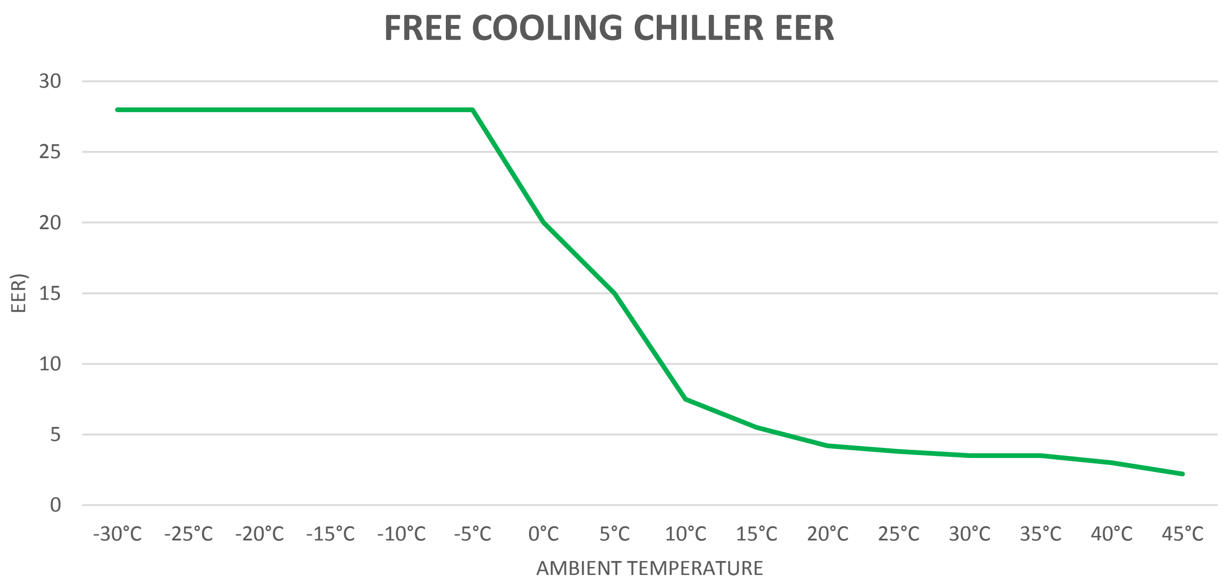
Pumps were modelled based on the assumed pressure head of the primary and secondary pumps, temperature difference between flow and return and efficiency of the motors.

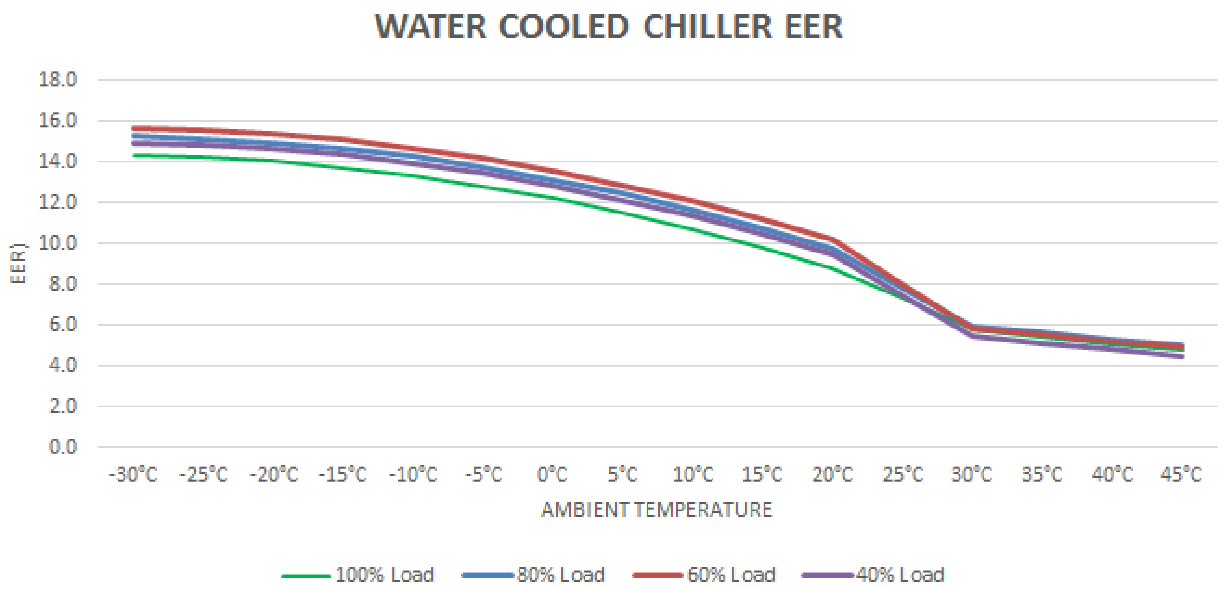
Finally, fans within CRAC units were assumed to run at constant speed (due to the constant maximum cooling load) with volume calculated based on the cooling capacity and air temperature difference (return – supply).

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

Parameter	Value
Supply set point Temperature to the Data Hall [°C]	26°C
Return set point Temperature from the Data Hall [°C]	38°C
CRAC unit Fan SFP [W/l/s]	0.65
DAO CRAC unit Fan SFP [W/l/s]	0.75
CRAC unit Fan Heat Gain [K]	1
Chilled Water DT (Flow – Return) [K]	7
Pumps Efficiency [%]	66%
Pressure Head of the Primary Pumps [m]	15
Pressure Head of the Secondary Pumps [m]	20

Various chiller EERs are shown following, the standard chiller arrangement is assumed to have a flat EER of 4.1.


FREE COOLING CHILLER EER
30
25
20
15
10
5
0
EER)
-30°C
-25°C
-20°C
-15°C
-10°C
-5°C
0°C
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C
45°C
AMBIENT TEMPERATURE


WATER COOLED CHILLER EER
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
EER)
-30°C
-25°C
-20°C
-15°C
-10°C
-5°C
0°C
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C
45°C
AMBIENT TEMPERATURE
100% Load
80% Load
60% Load
40% Load

Validation of Results

The section of the report investigates the energy and water consumption results calculated for a range of locations as shown in this report and compares them against the figures obtained from the Munters selection tool. All figures shown in the report thus far are based on Cundall's analysis and calculations, without influence from Munters as to the accuracy of these results.

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 Munters'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. 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.

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

The following table details the total energy and water calculated by Munters and Cundall independently. The major discrepancies noted are relate to the occurrence of hot and dry conditions where the measured performance of the units exceeds the simplified operation within this calculation. It is expected that the necessarily simplified assumption of the heat exchanger efficiency has resulted in the underestimation of the units performance where high differential between the ambient and saturated condition exists.

The Munters results have been proven to be conservative in comparison to laboratory testing of the units operating in varying environmental conditions. Cundall have been involved in witness testing the units under different ambient conditions and can verify the results as being accurate.

Location	Munters Calculations		Cundall Calculations		Energy Difference	Water Difference
	Energy [kWh]	Water [m³]	Energy [kWh]	Water [m³]		
Tokyo	513,815	8,254	535,969	3,644	4%	-56%
Sydney	452,570	8,487	471,050	6,255	4%	-26%
Melbourne	410,062	8,331	430,598	4,255	5%	-49%
Perth	433,602	8,678	453,410	8,592	5%	-1%
Singapore	1,254,857	8,575	1,335,210	12,335	6%	44%
Hong Kong	809,187	9,061	895,280	9,483	11%	5%
Hohhot	475,202	5,236	433,954	5,050	-9%	-4%
Shanghai	647,873	7,965	646,924	6,252	0%	-22%
Beijing	475,149	6,707	546,352	8,067	15%	20%
Shijazhuang	492,403	7,131	546,743	8,619	11%	21%
Chongqing	599,663	8,864	664,047	7,538	11%	-15%
Urumqi	464,112	5,175	425,081	5,979	-8%	16%
Hangzhou	600,083	7,863	648,790	7,280	8%	-7%
Nanjing	602,648	7,081	644,279	7,073	7%	0%
Wuhan	642,730	7,871	691,643	8,650	8%	10%
Guangzhou	812,553	9,336	857,094	9,735	5%	4%
Zhengzhou	512,956	7,294	579,150	8,056	13%	10%
Harbin	430,279	4,645	452,678	4,297	5%	-7%

Note: Due to the late inclusion of Manila and Kuala Lumpur comparison results are not available at this point in time.

Appendix B: - Unit Selection and Application

Oasis™ Indirect Evaporative Cooler Configurations

In order to assess the Oasis™ Indirect Evaporative Cooler performance, a typical unit selection is presented in Figure 12; details of which are tabulated in Appendix A: - Basis of Calculations. The selection is based on a hypothetical scenario for a data hall IT load of 720kW, which is to be supported by six Oasis™ Indirect Evaporative Coolers at (N+1). Four unit sizes are available rated at 100kW, 200kW and 300kW and 400 as well as a container based unit for international shipping to APAC region, All units can be configured for top, bottom or front supply and return.

The selection presents a typical unit for the most efficient deployment in this test case, with efficient air flow management systems such as hot 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 modulate to suit the ambient conditions.

The unit is designed to supply a constant volume of air into the data hall if IT load remains constant. 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.

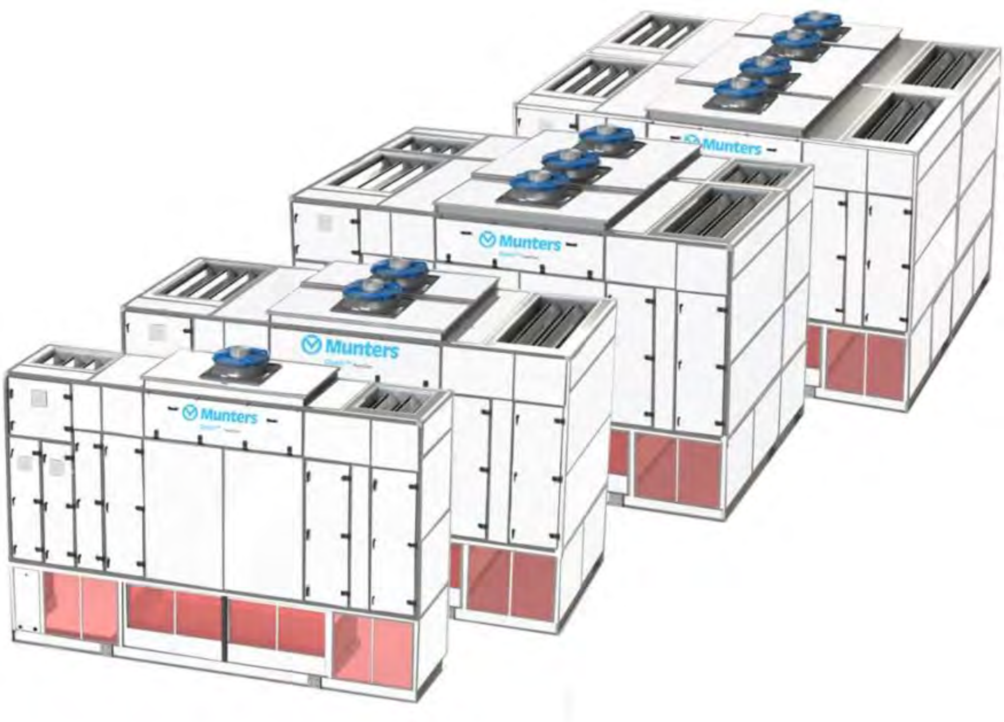


Figure 12: 3D representation of a floor mounted Oasis™ Indirect Evaporative Cooler (100kW to 300kW range).

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.

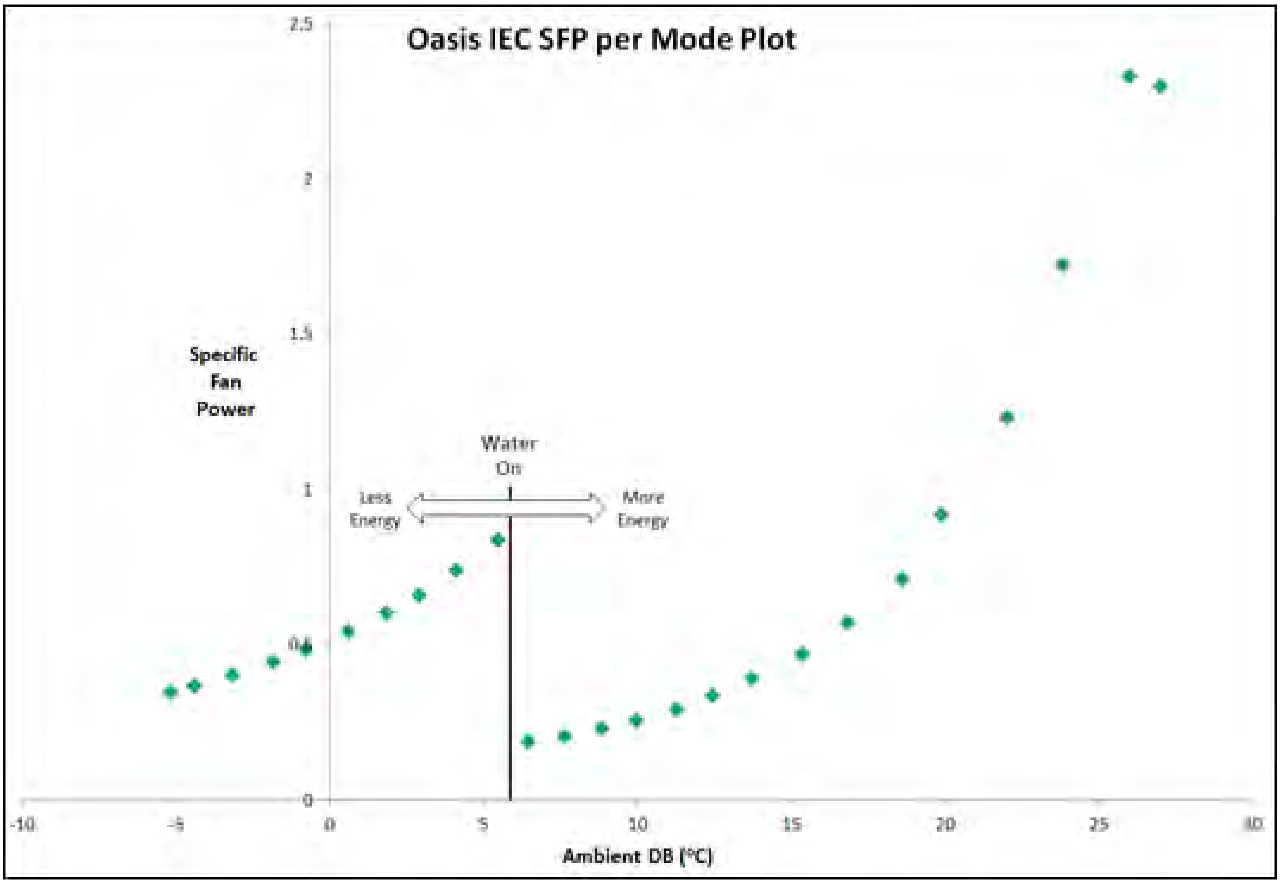


Figure 13: Specific Fan Power (SPF) vs Temperature (DB) using Oasis IEC

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 shown in Figure 12 has its supply 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.

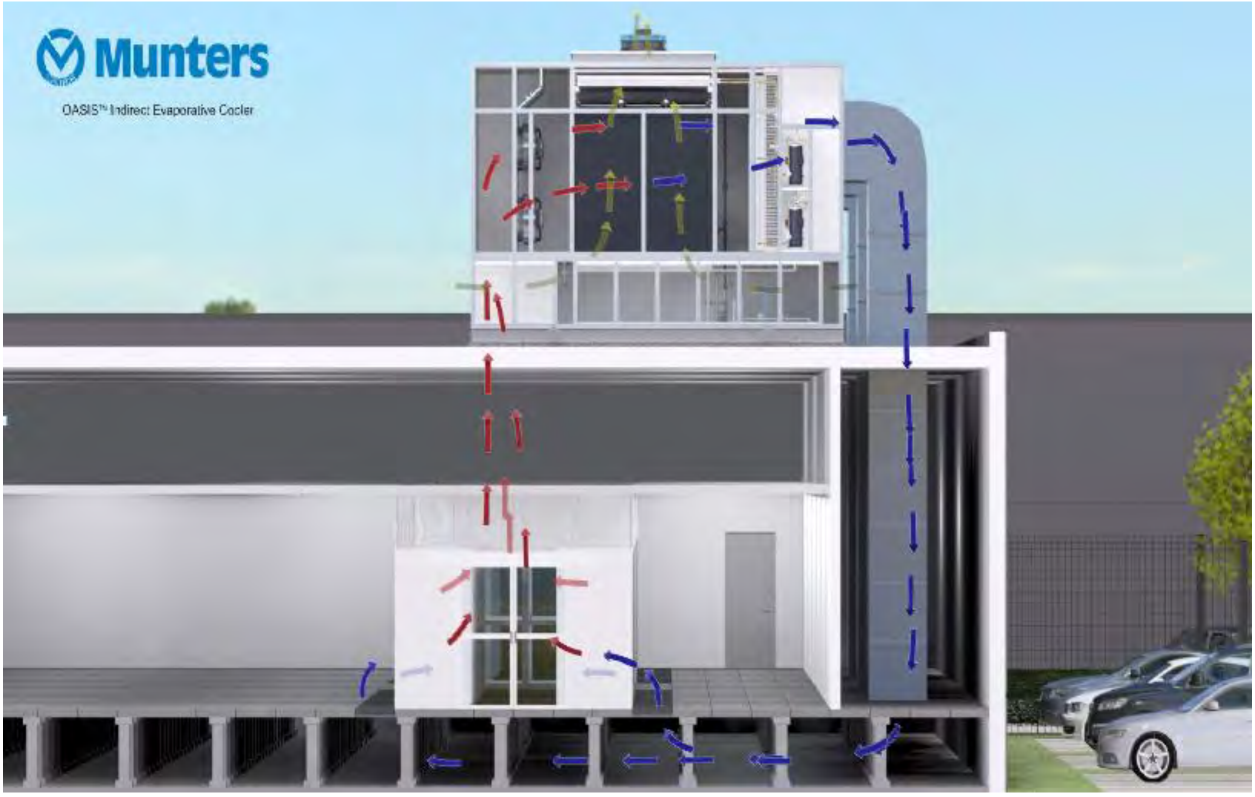


Figure 14: Example Oasis™ IEC arrangement; roof mounted unit.

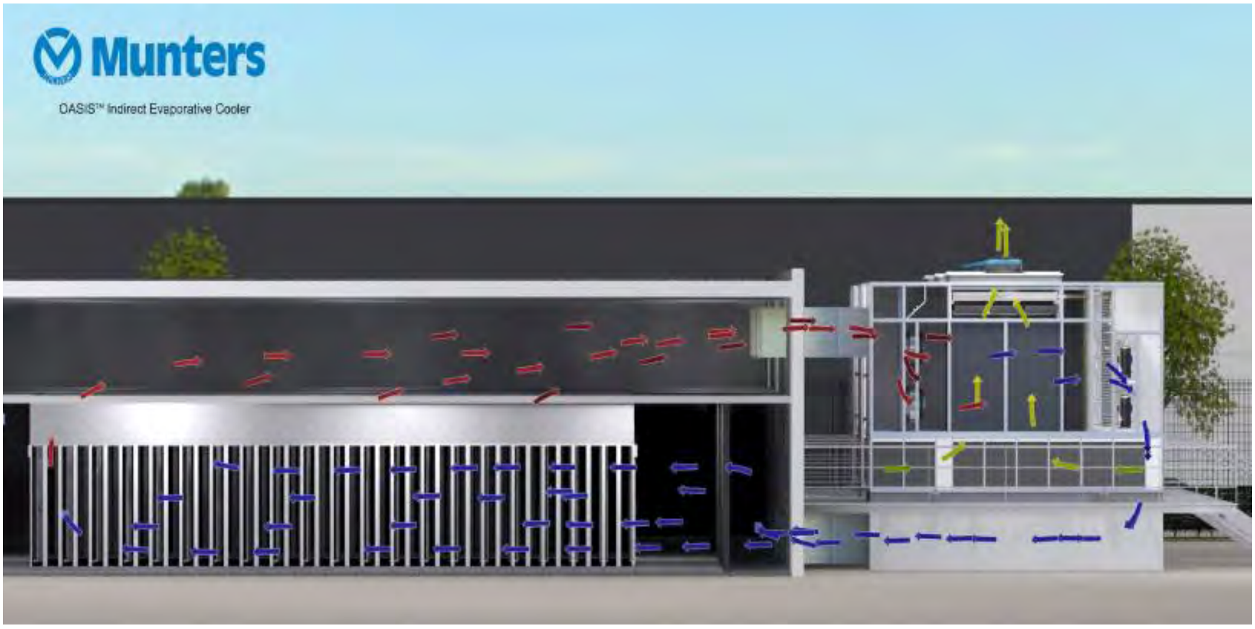


Figure 15: Example Oasis™ IEC arrangement; side mounted unit with direct wall ducting.

The Oasis™ Indirect Evaporative Cooler uses a patented evaporative polymer tube heat exchanger module (Figure 16) 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 and leads to inherent increases in static pressure. 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.

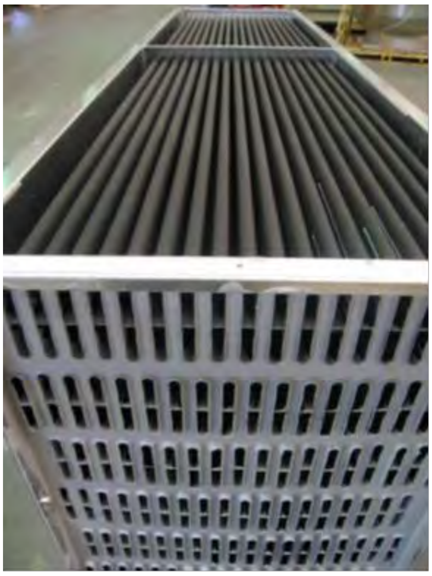


Figure 16: Polymer tube heat exchanger, detailed view.

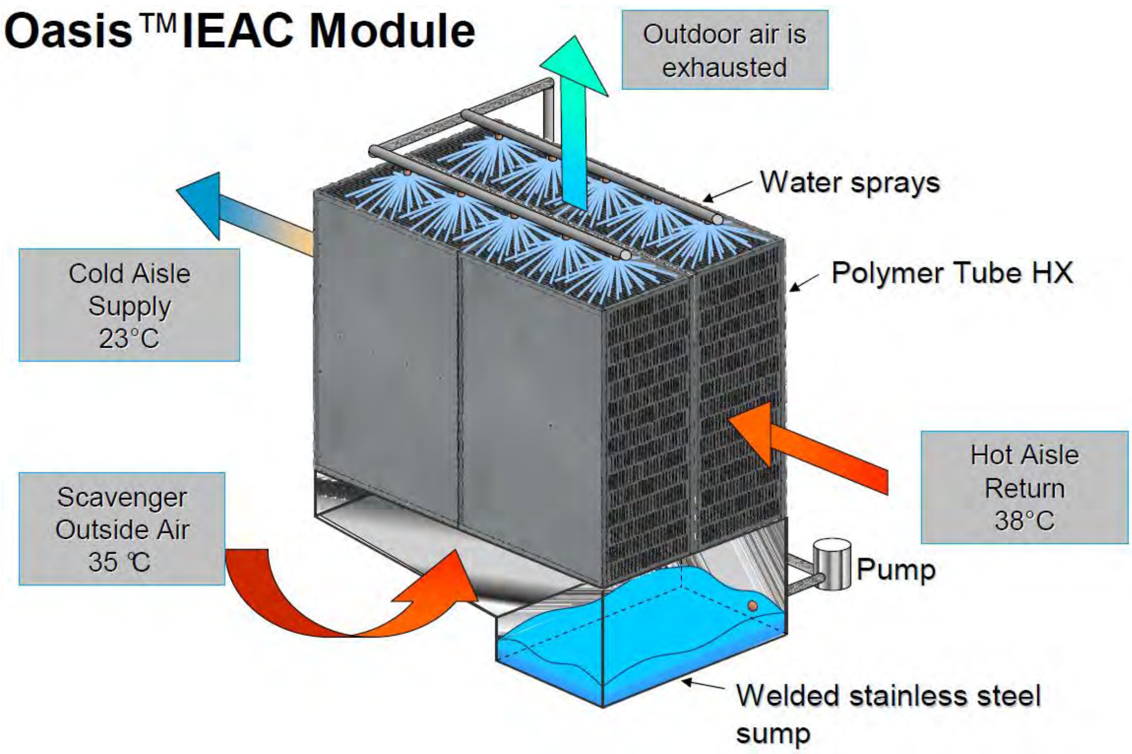
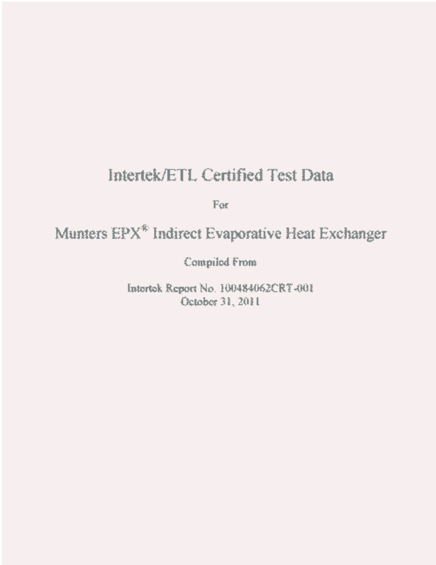


Figure 17: Oasis™ Indirect Evaporative Cooler polymer heat exchanger function diagram

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.

The unit and its various functions can be viewed in operation at https://www.Munters.com/oasismovie or directly on You Tube https://youtu.be/Sp7Aru39CsE

For all Munters data center related information visit www.Munters.com/datacenters or email datacenters@Munters.com

Some images showing the internal cooling mechanism of the unit are given in Figure 18

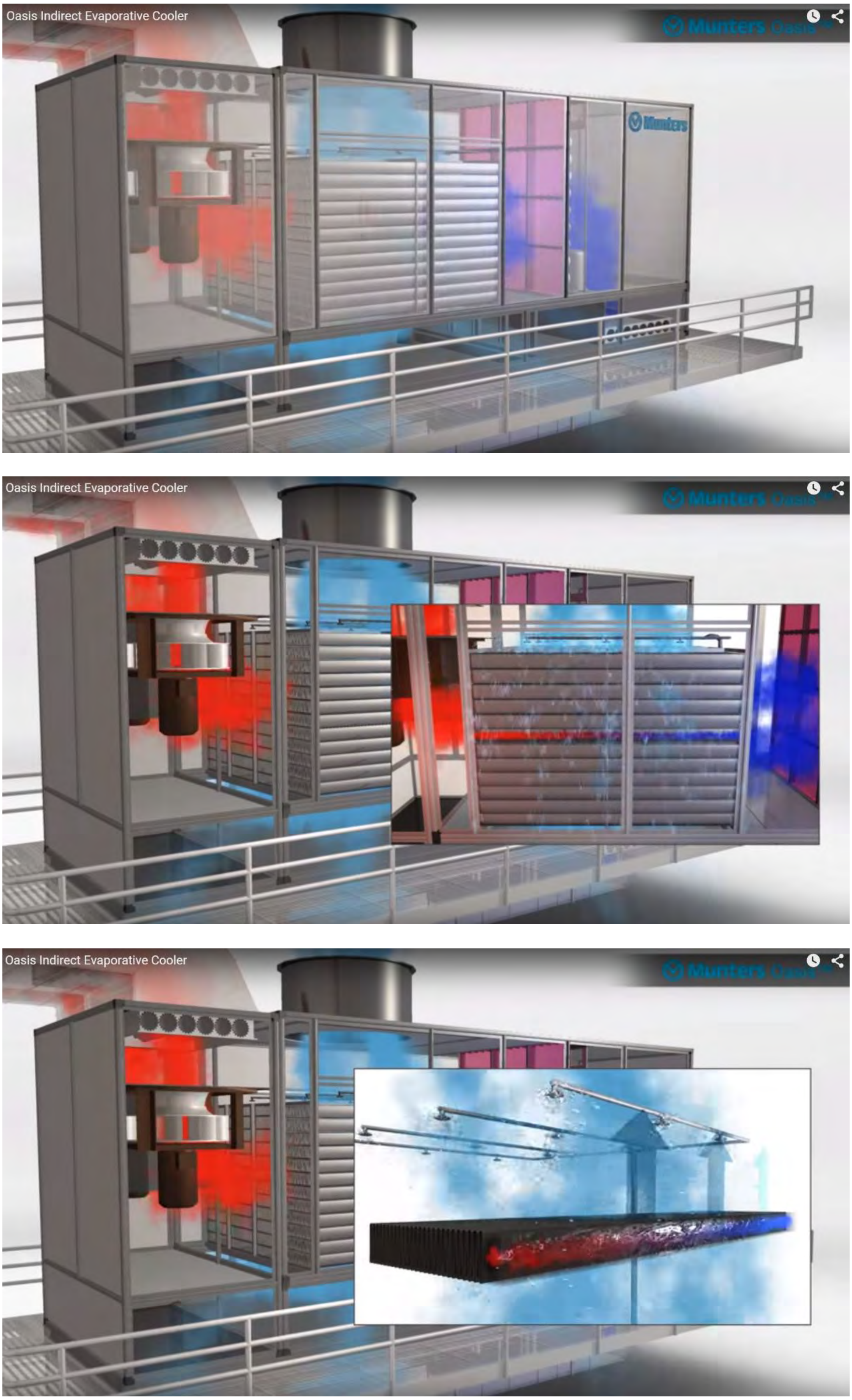


Figure 18: Munters Oasis™ detailed operational views.

Electrical Infrastructure Requirements

A chilled water data centre has a higher PUE than an IAO solution, as previously described. With IT demand being a relatively 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 some DX cooling top up depending on location. This has several knock on cost saving effects.

Reducing the required power (per m²) means that more IT space can be allocated for a given supply of power to site.

Alternatively, 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[viii]. 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.

Part Load Application

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. Simulated results in Singapore are shown below, the pPUE increases from 1.21 to a maximum of 1.38 at 25% loading.

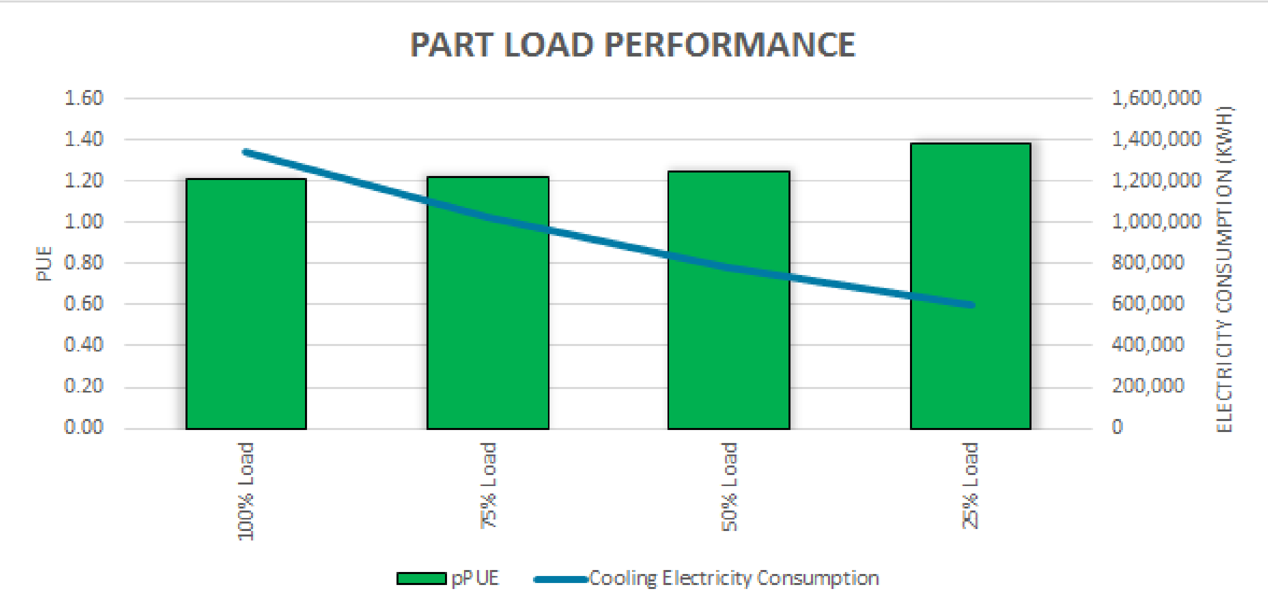
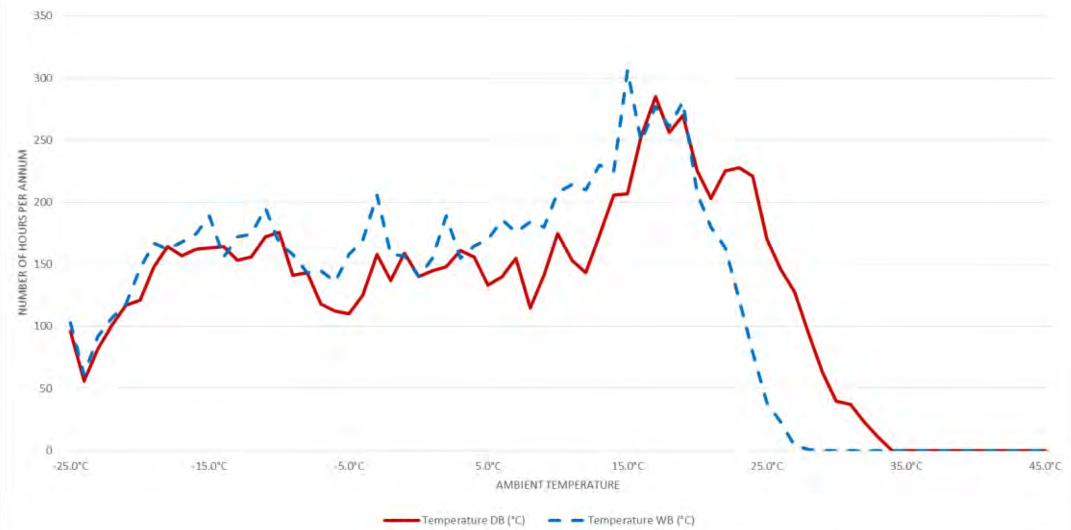
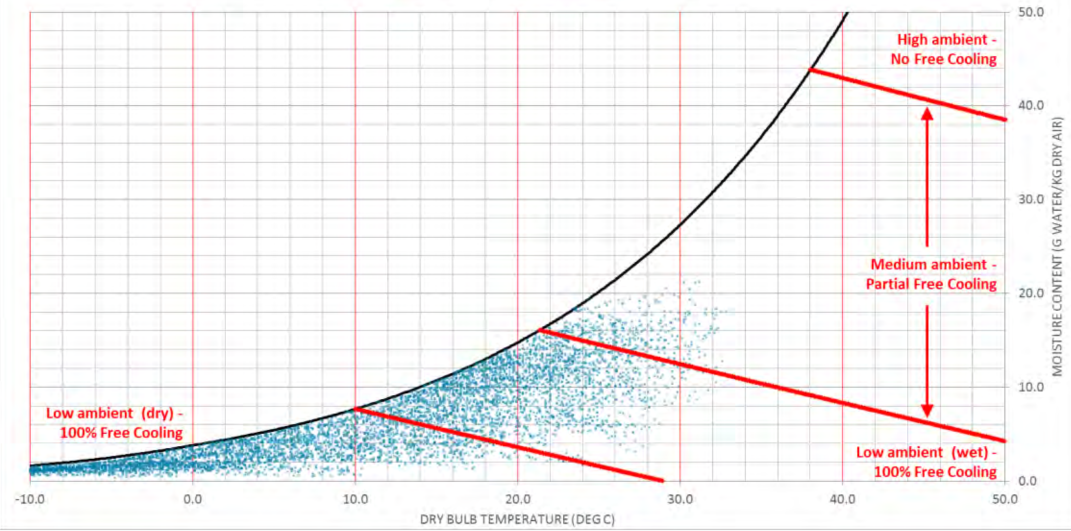


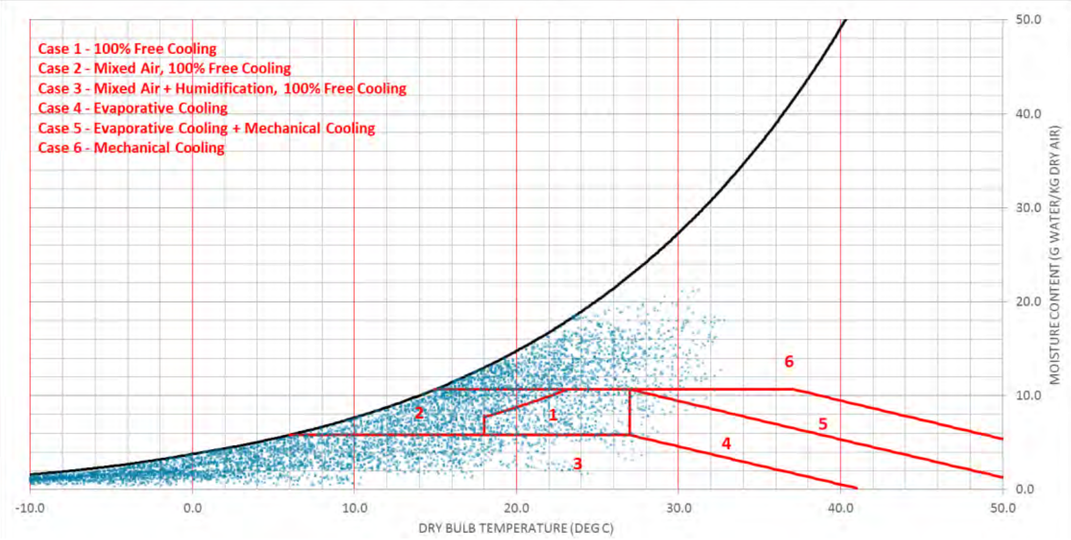
Figure 19: Performance of a IAC system are part loads, 25% to 100% hall loading.

Appendix C: - Weather Profiles[ix]

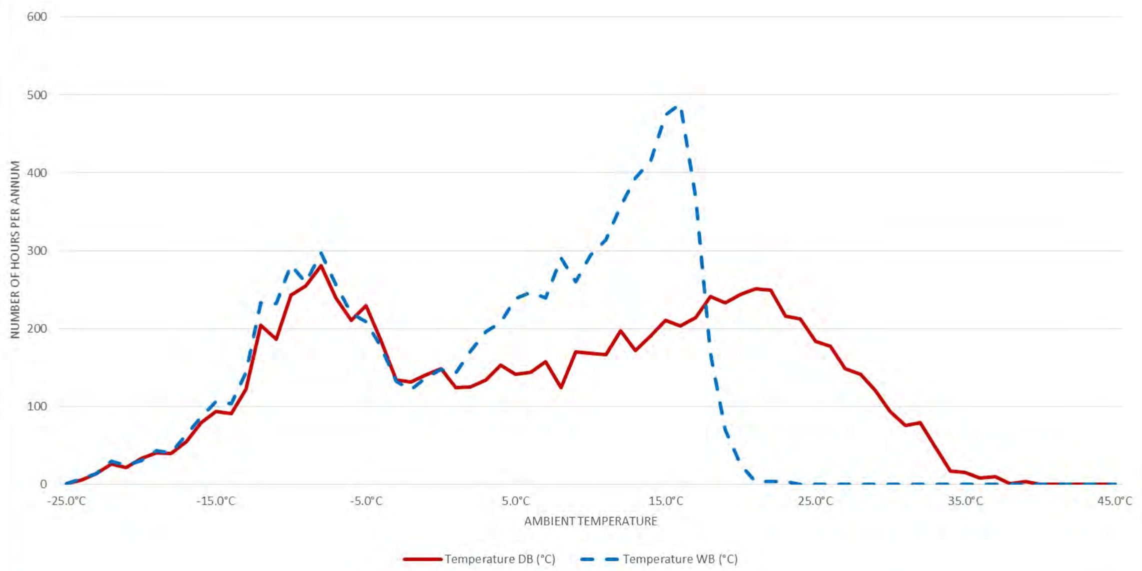
Harbin (HeiLongJiang), China

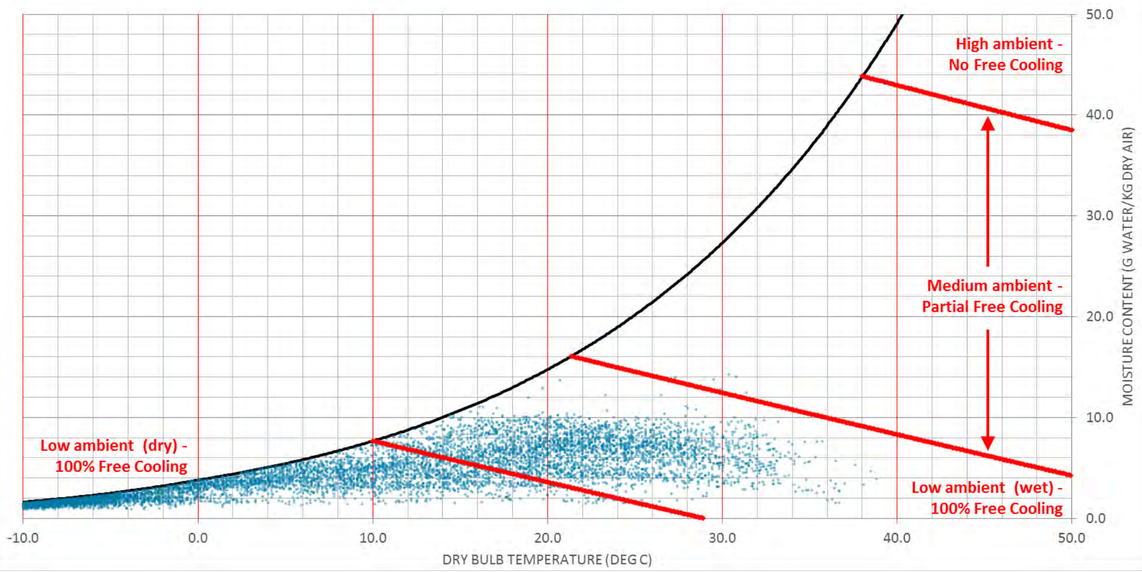


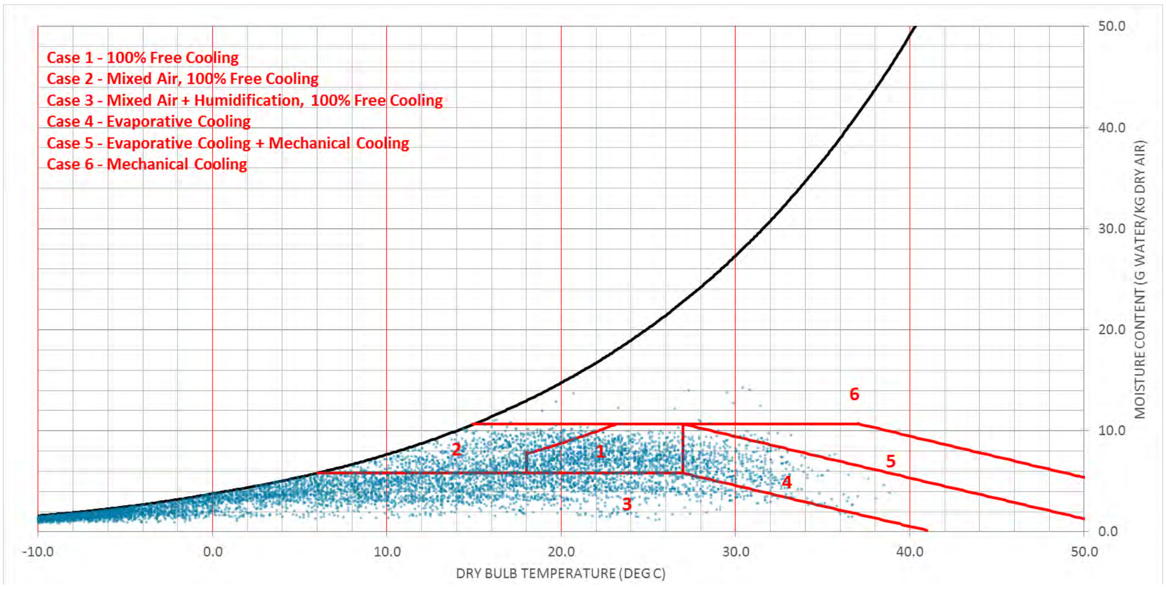




Urumqi (Xinjiang), China







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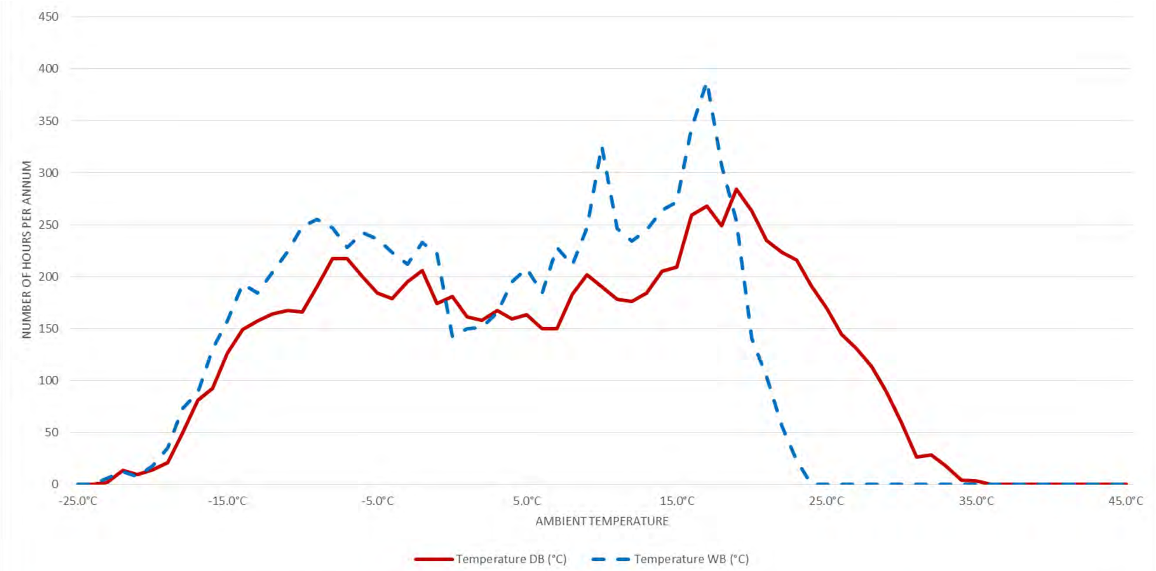
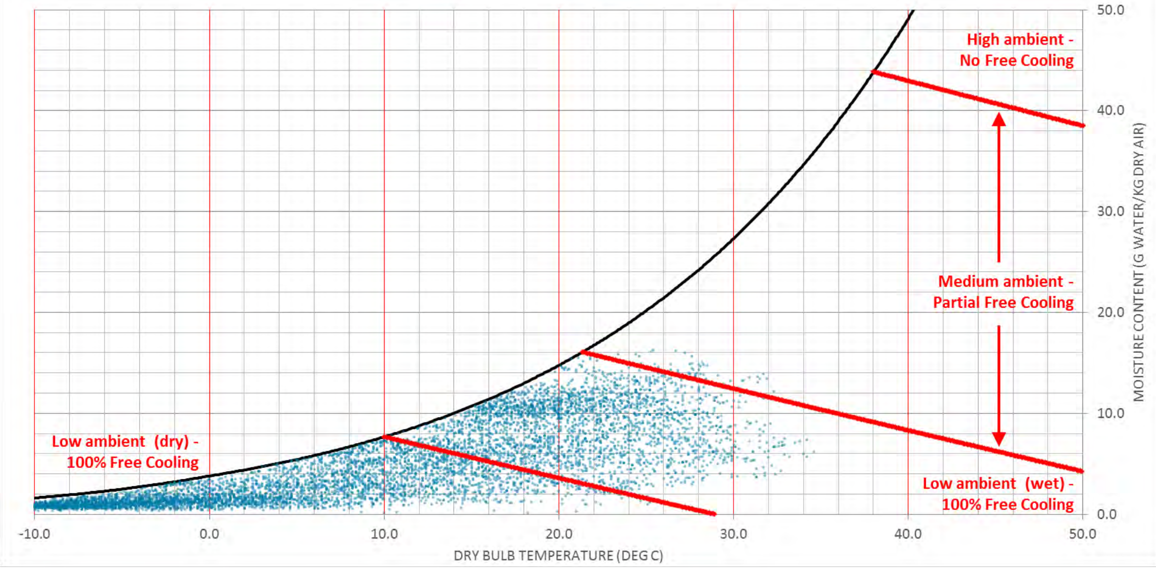
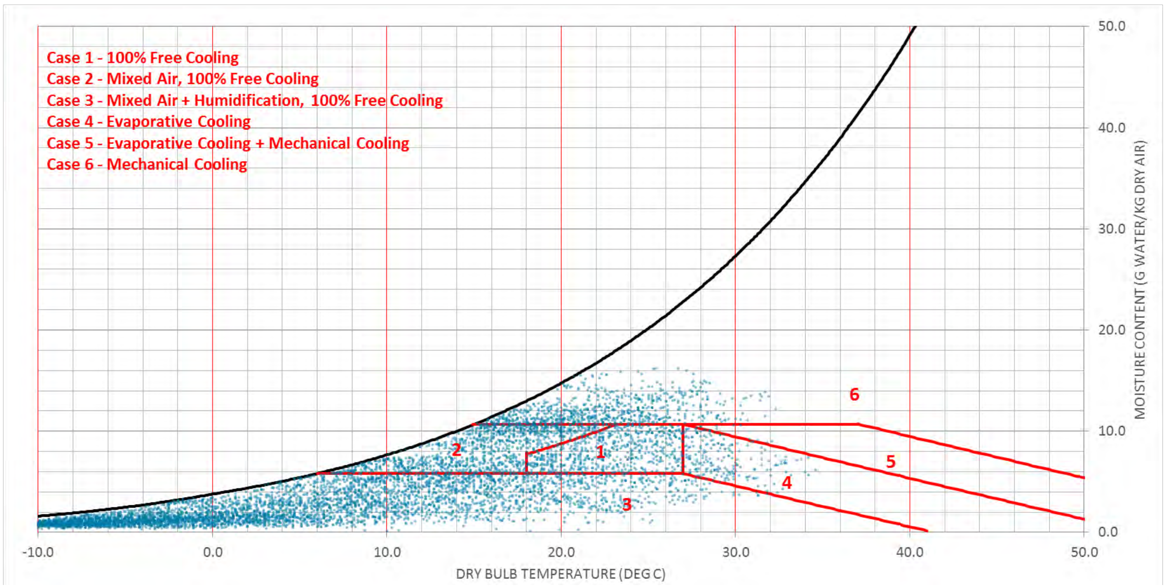
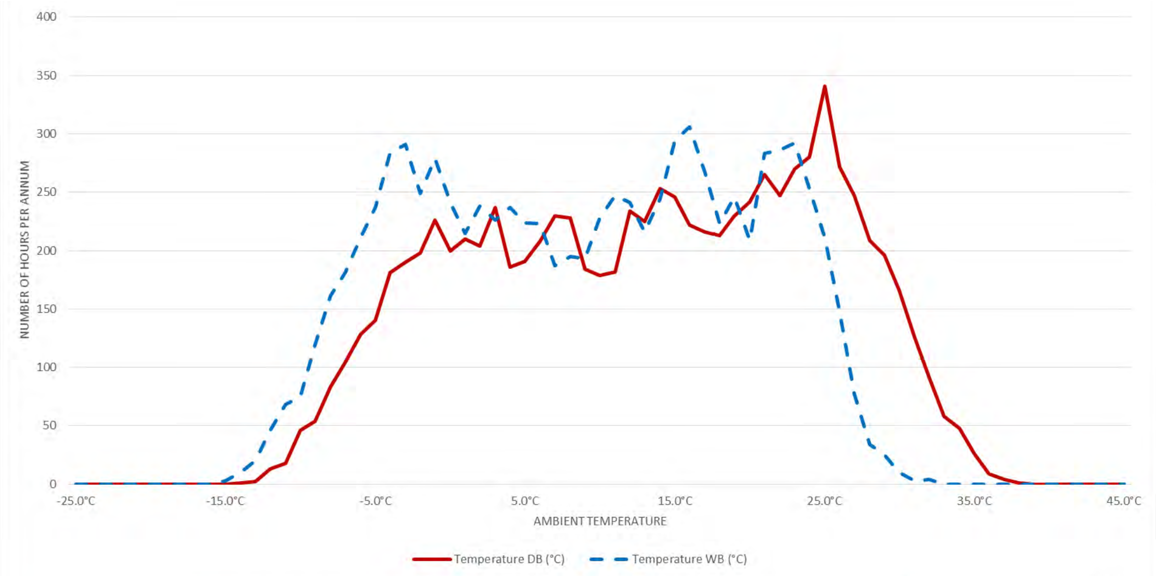
Hohhot, Inner Mongolia

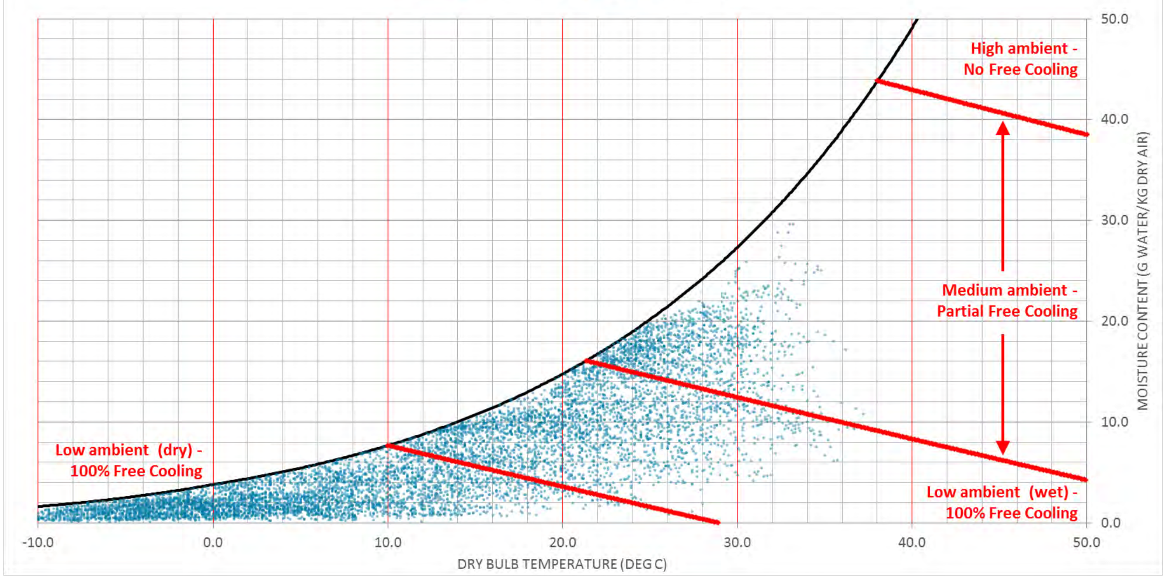


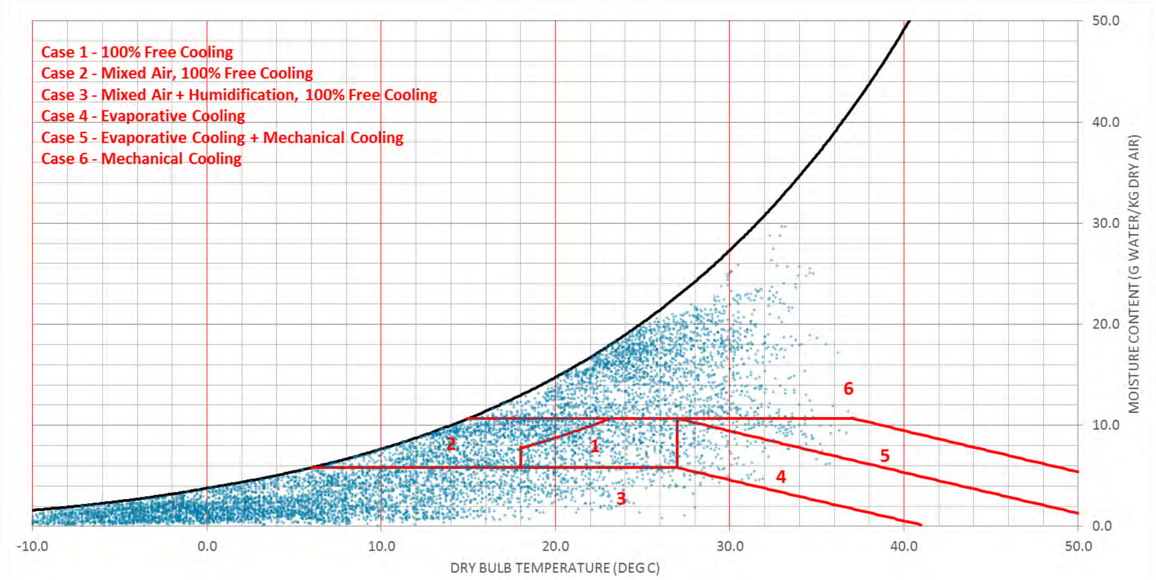




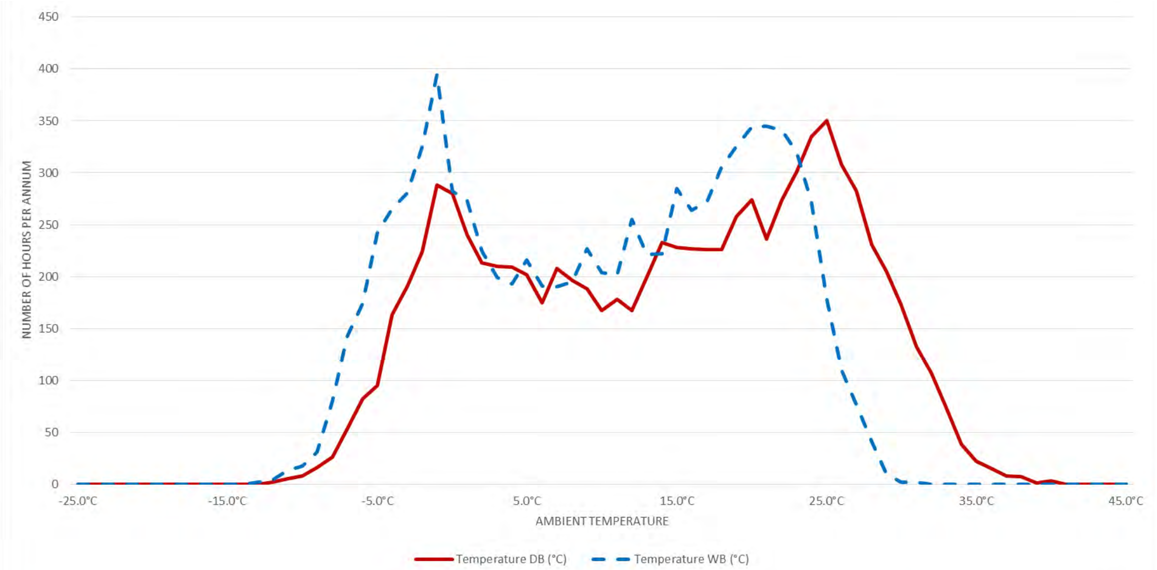
Beijing, China

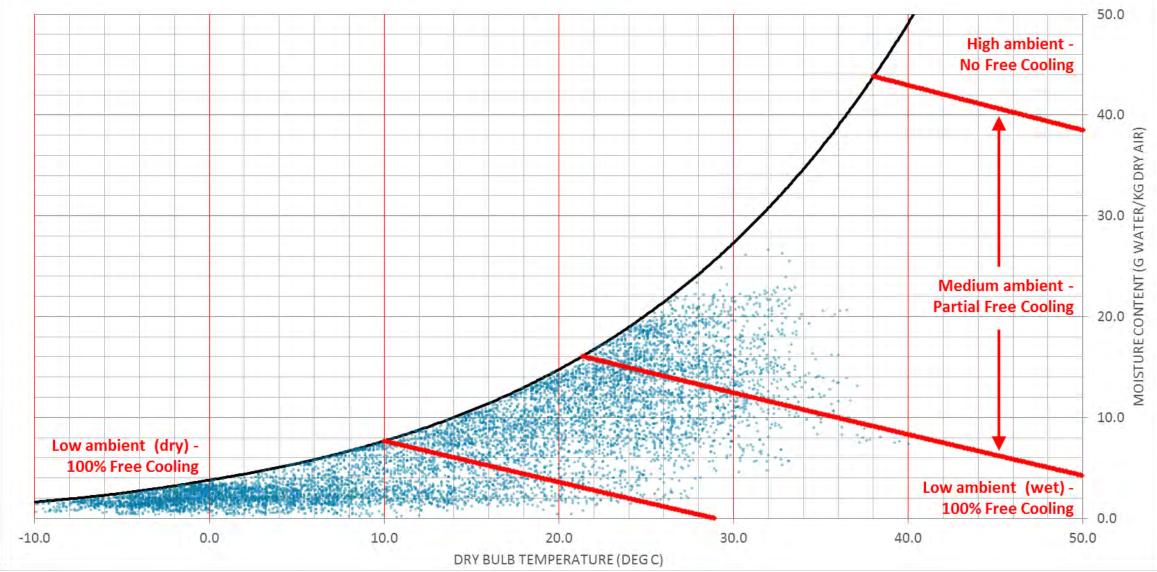


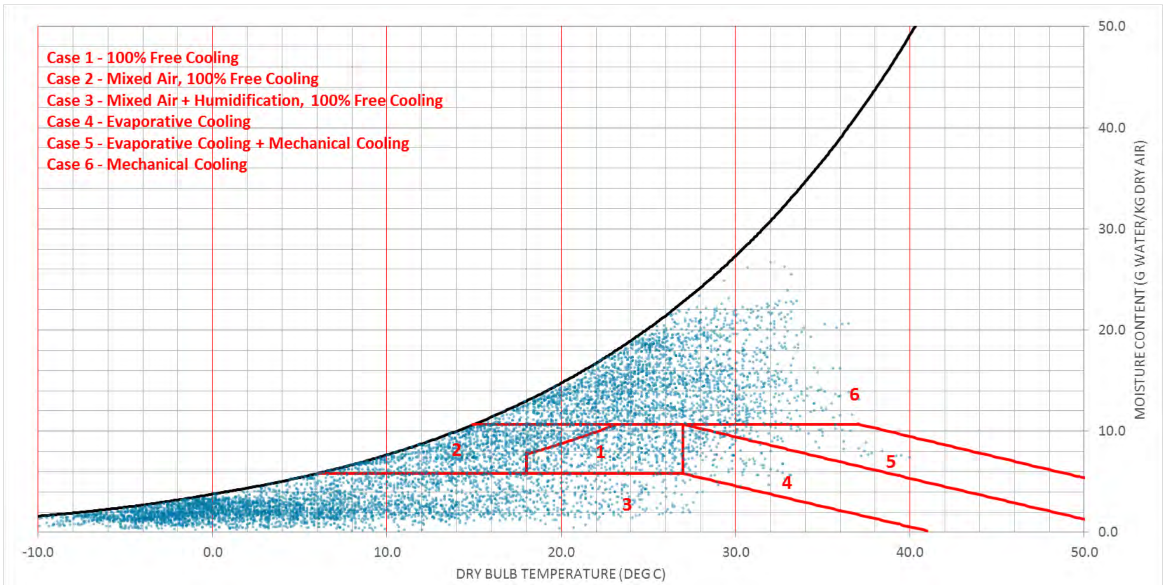




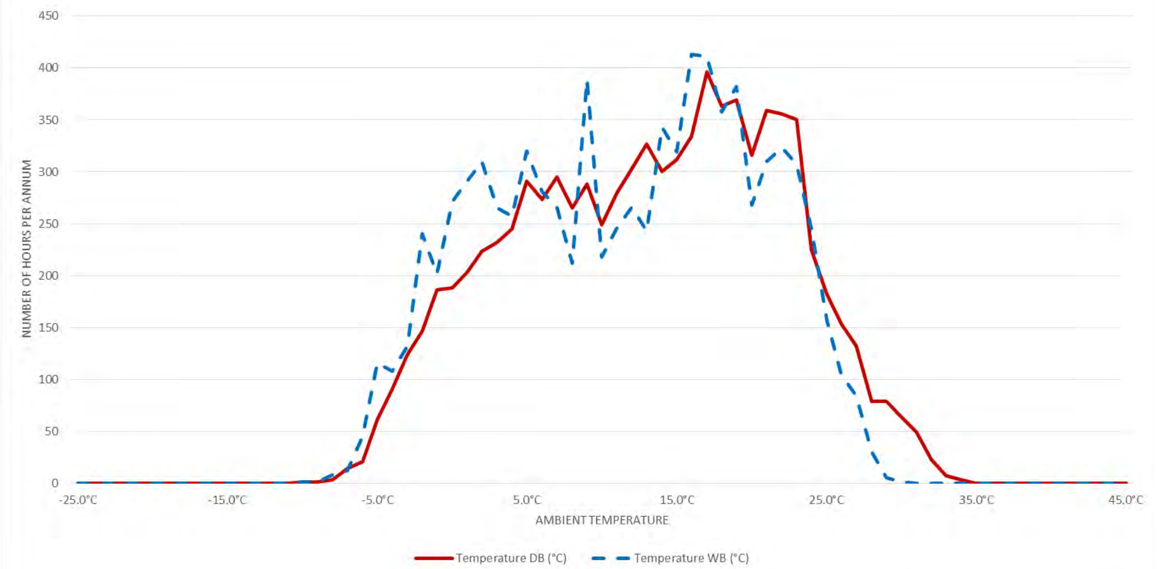
Shijiazhuang (HeBei), China



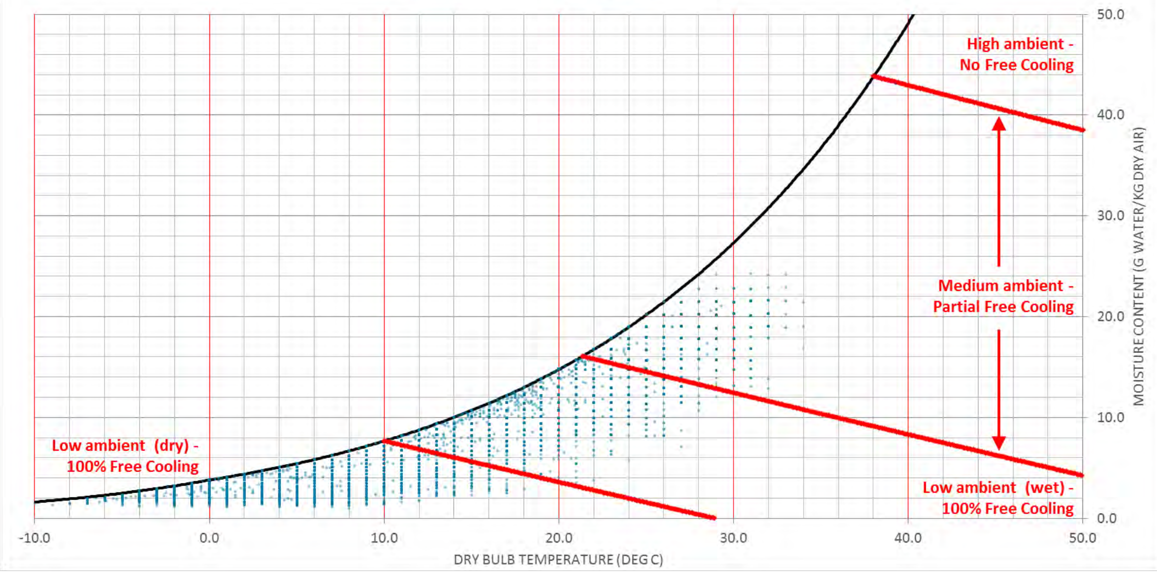




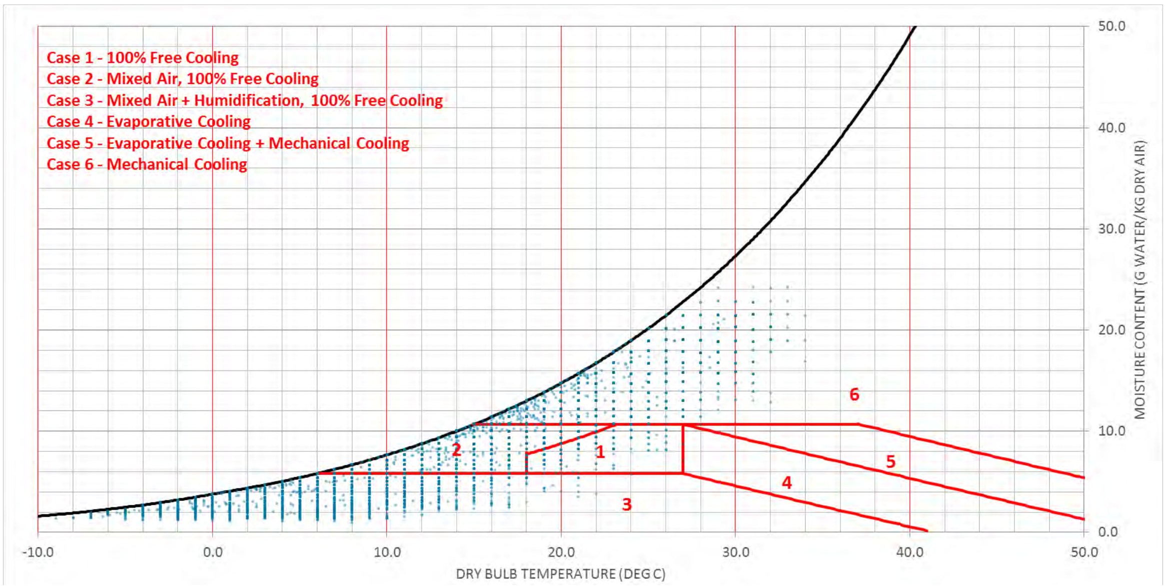
Tokyo, Japan



NUMBER OF HOURS PER ANNUM
AMBIENT TEMPERATURE
Temperature DB (°C)
Temperature WB (°C)

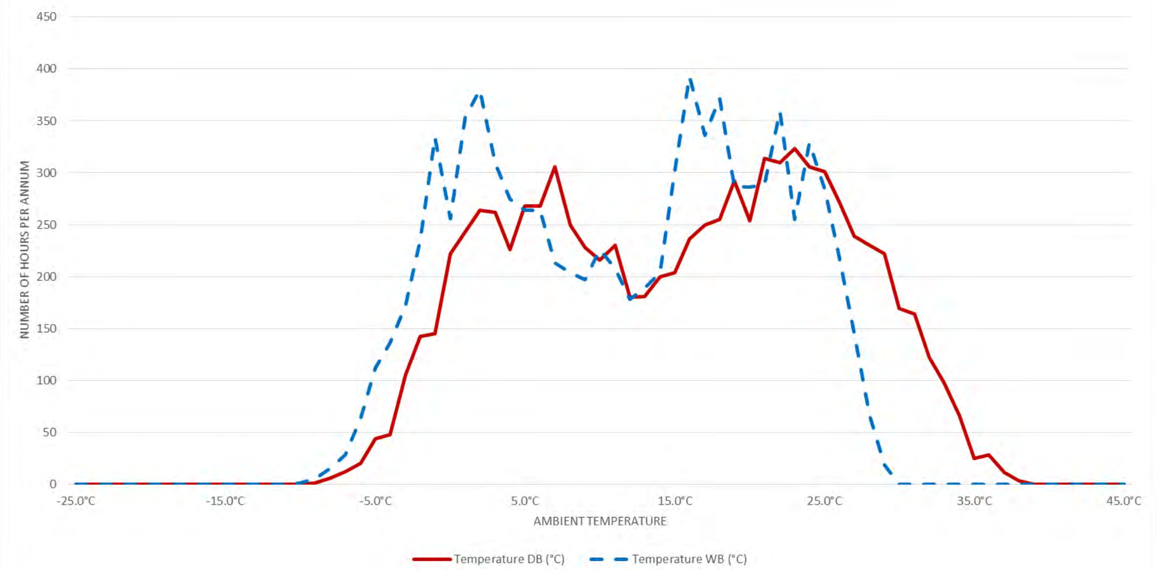


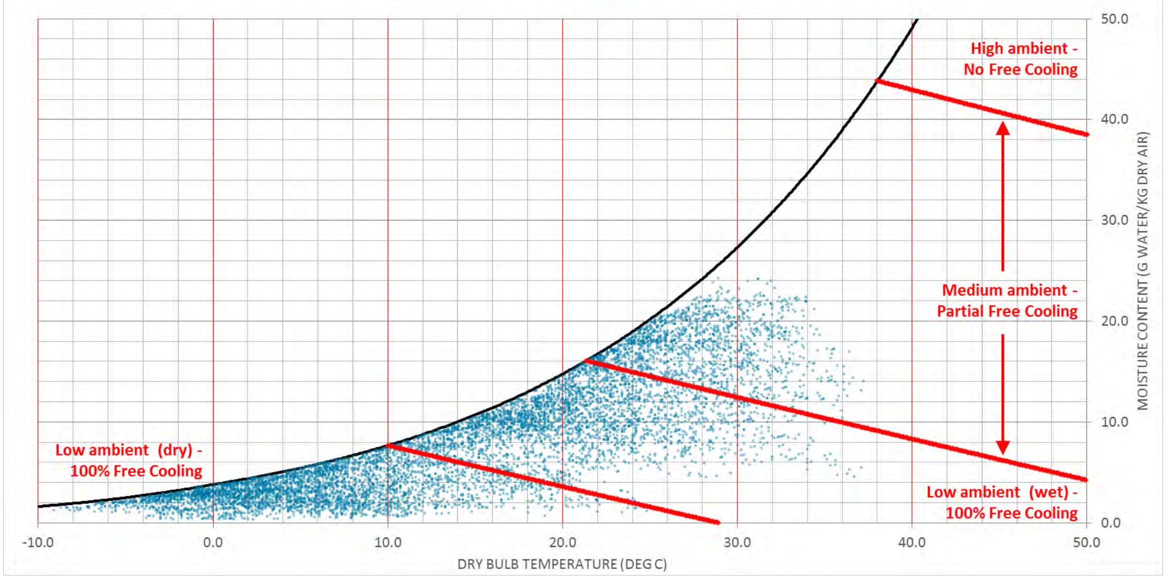
High ambient -
No Free Cooling
Medium ambient -
Partial Free Cooling
Low ambient (dry) -
100% Free Cooling
Low ambient (wet) -
100% Free Cooling
DRY BULB TEMPERATURE (DEG C)
MOISTURE CONTENT (G WATER/KG DRY AIR)

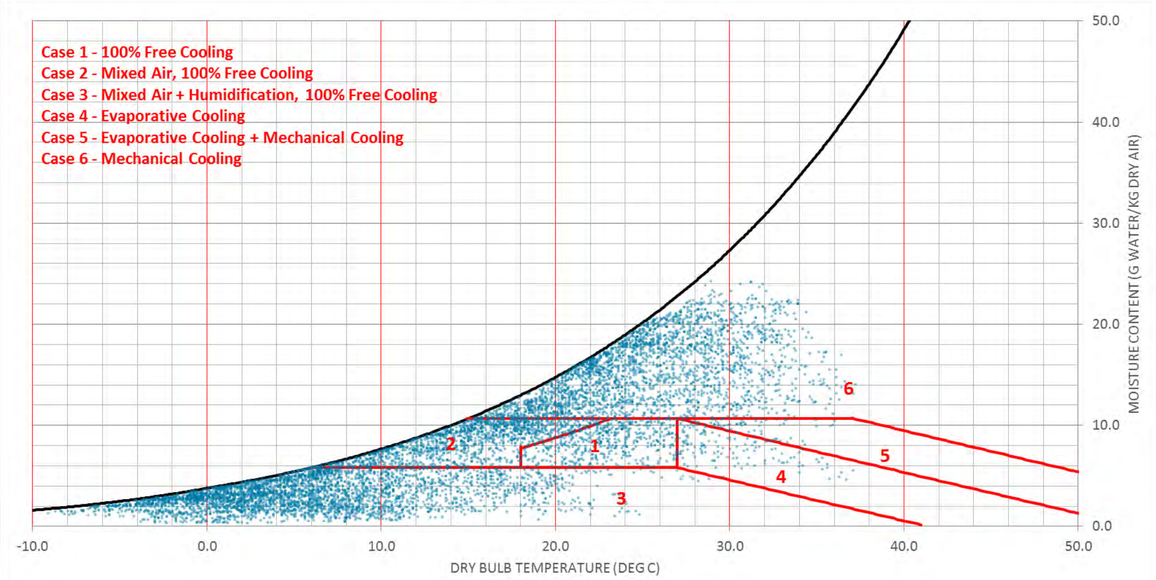


Case 1 - 100% Free Cooling
Case 2 - Mixed Air, 100% Free Cooling
Case 3 - Mixed Air + Humidification, 100% Free Cooling
Case 4 - Evaporative Cooling
Case 5 - Evaporative Cooling + Mechanical Cooling
Case 6 - Mechanical Cooling
DRY BULB TEMPERATURE (DEG C)
MOISTURE CONTENT (G WATER/KG DRY AIR)

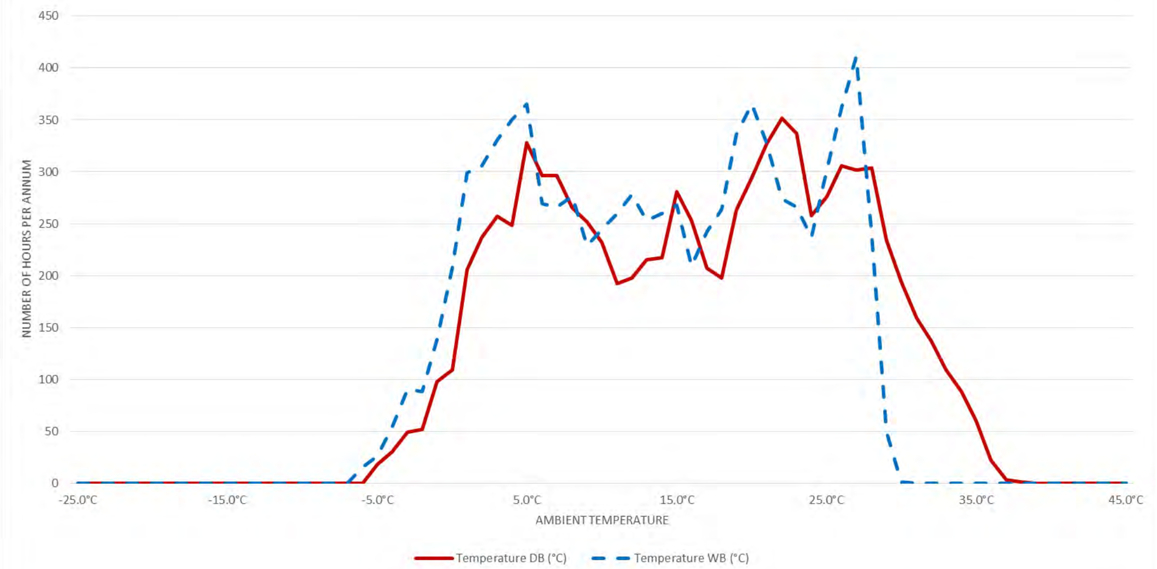
Zhengzhou (Henan), China

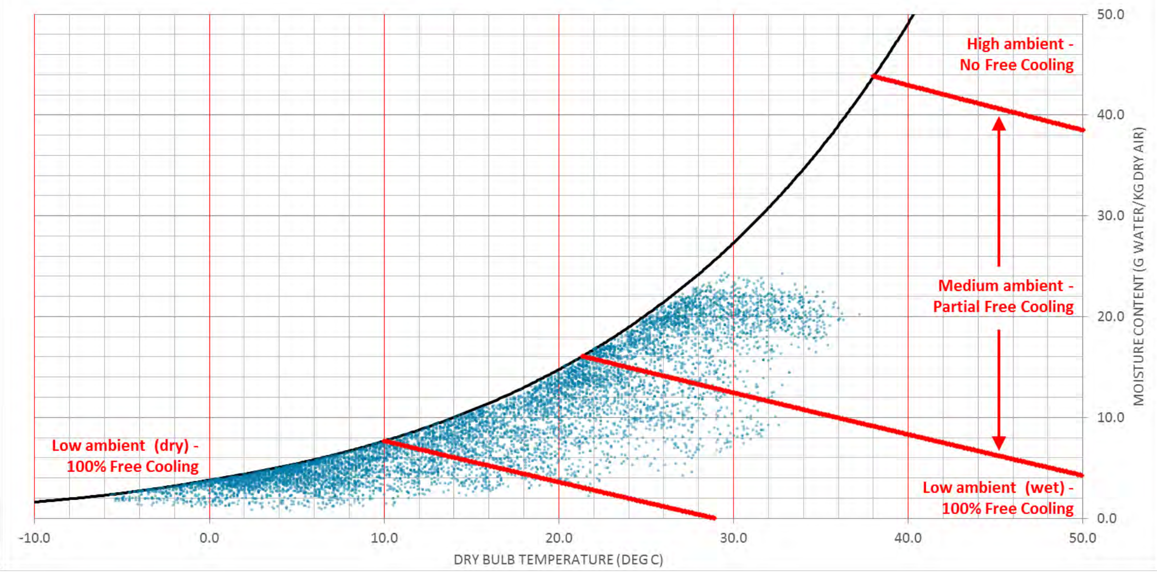


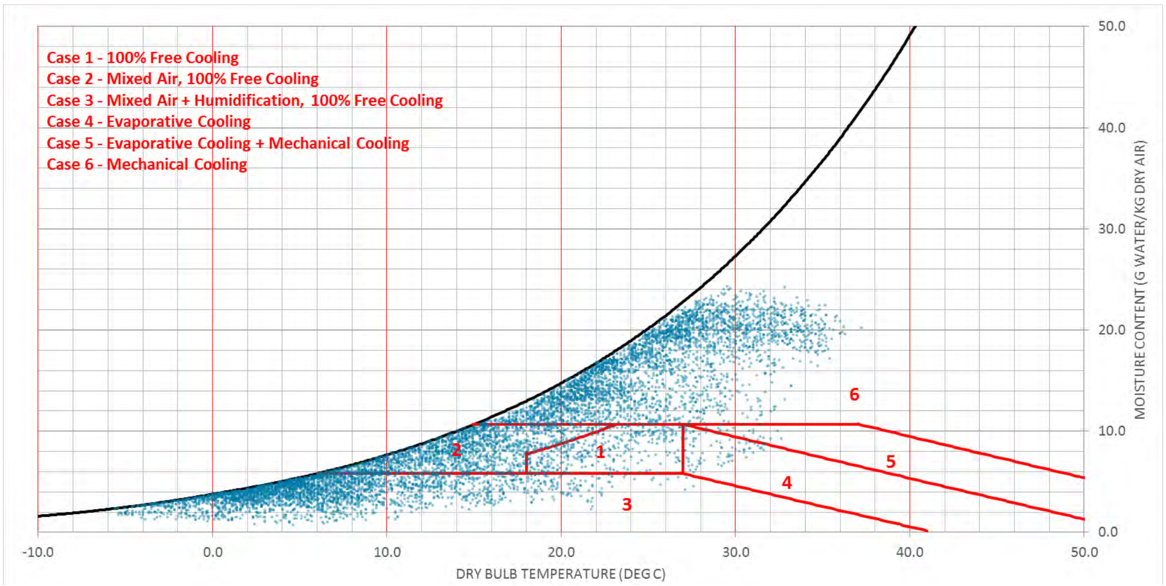




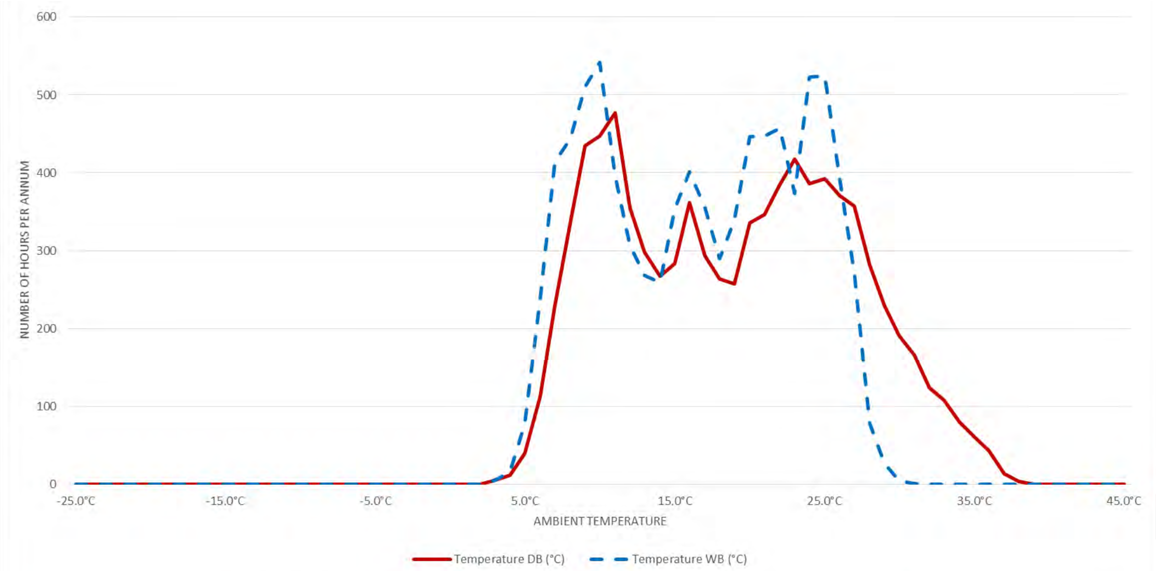
Nanjing (Jiangsu), China

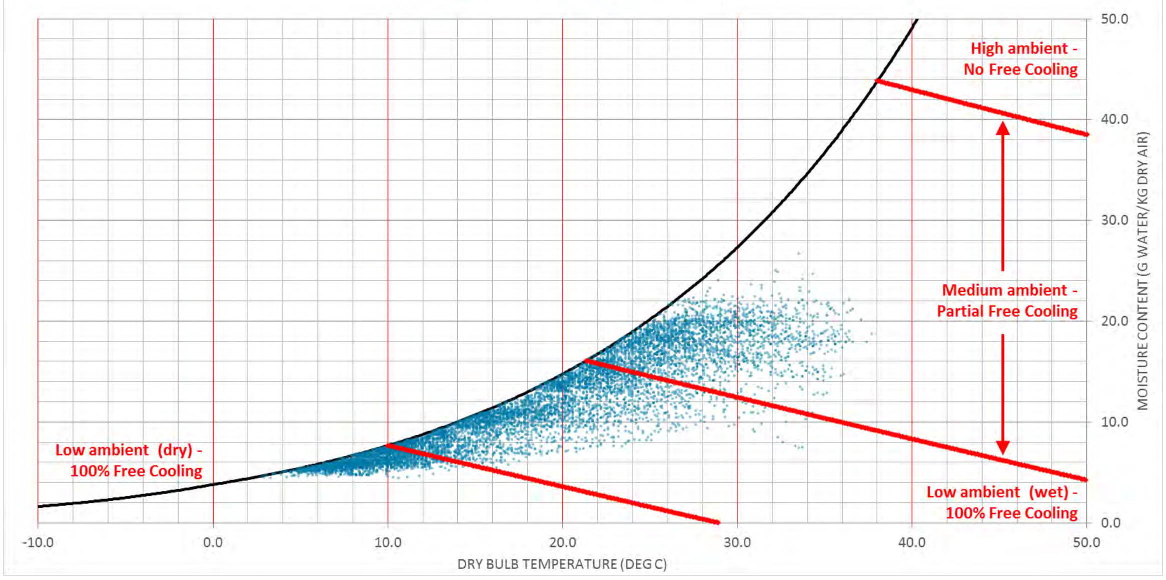


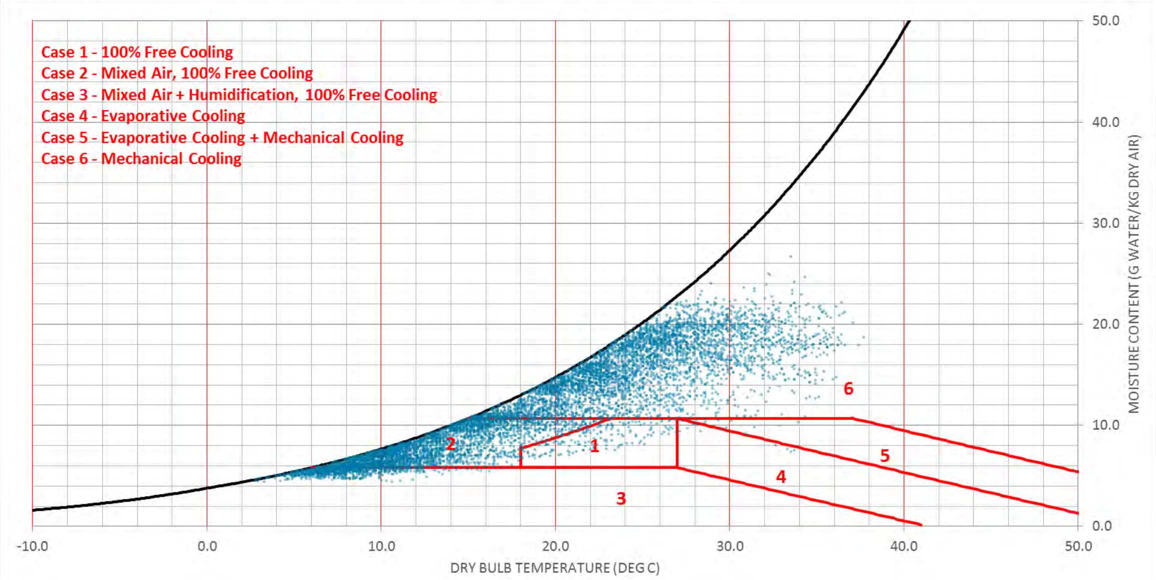




Chongqing, China







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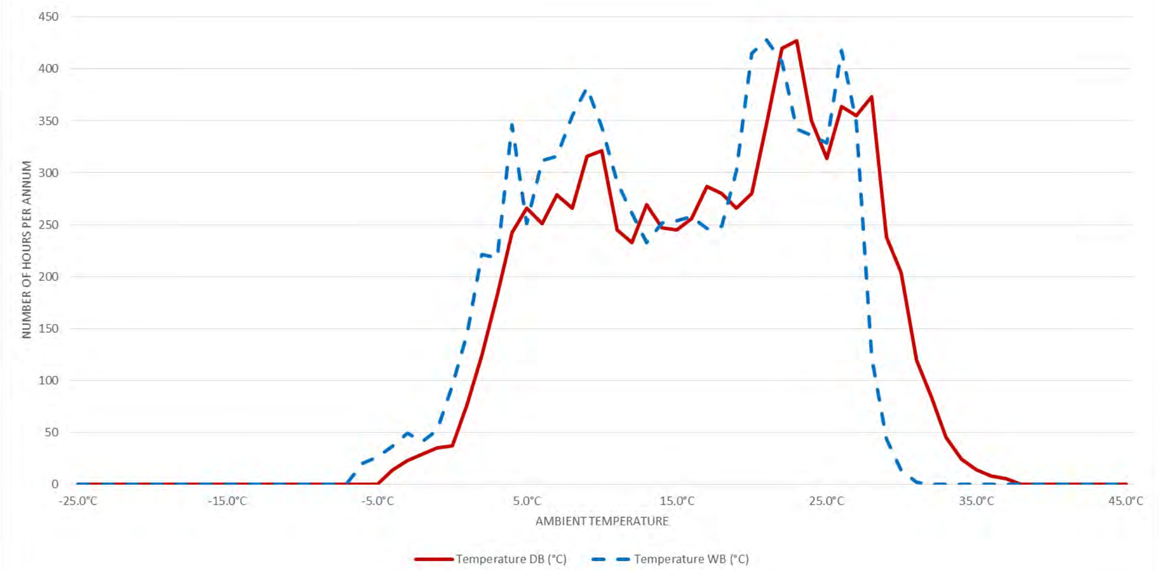
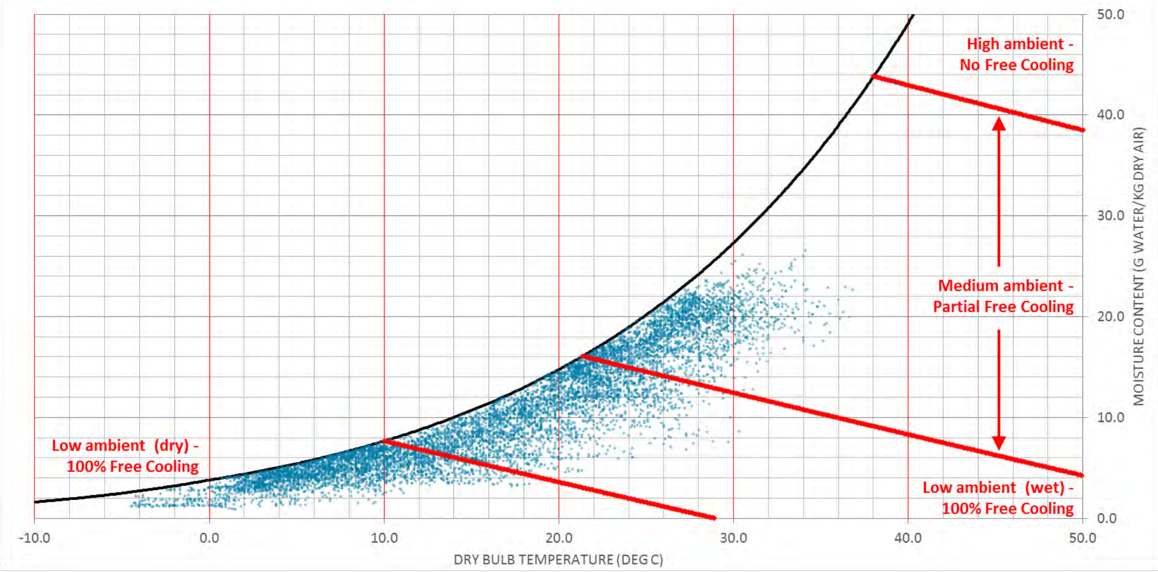
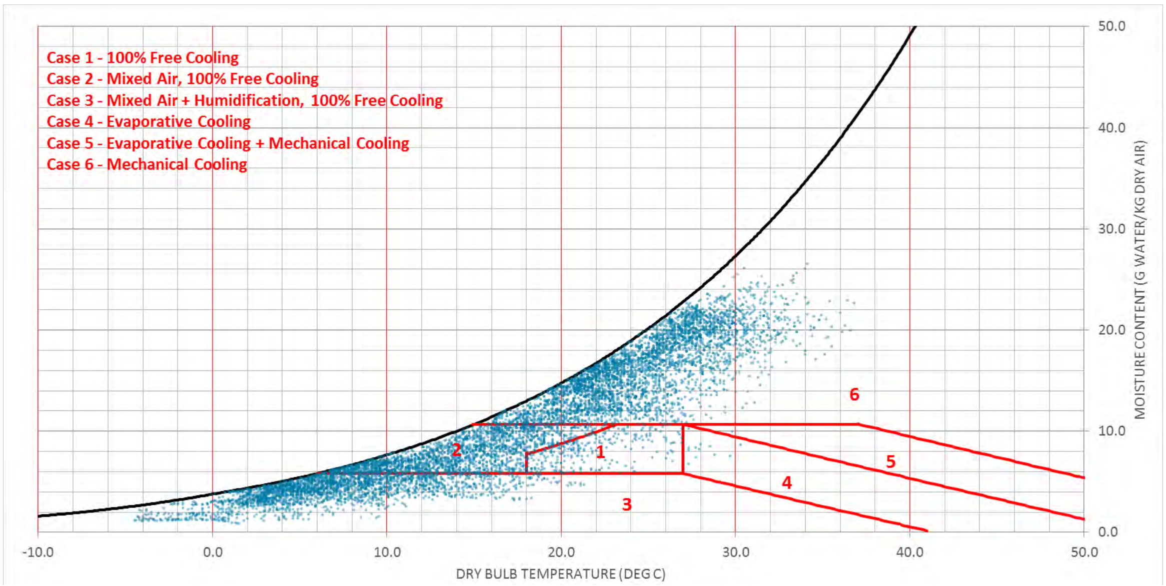
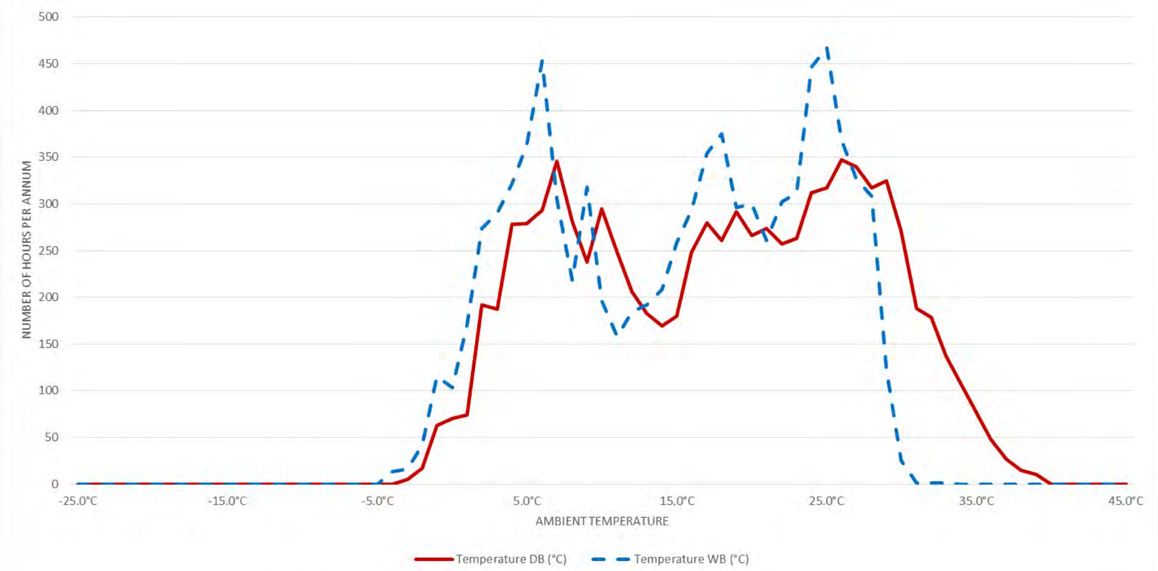
Shanghai, China

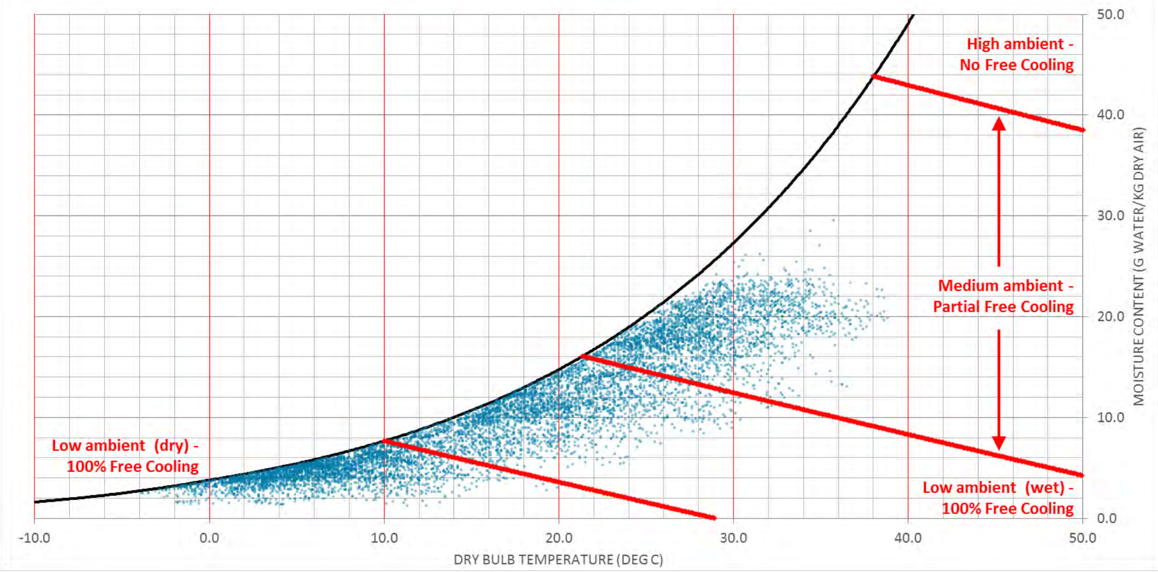


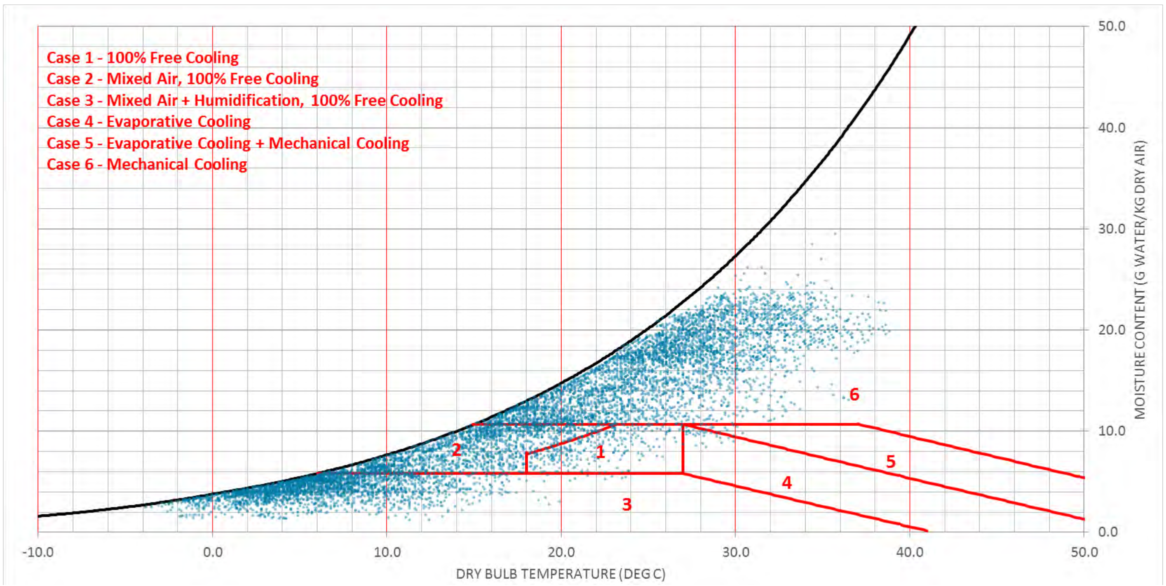




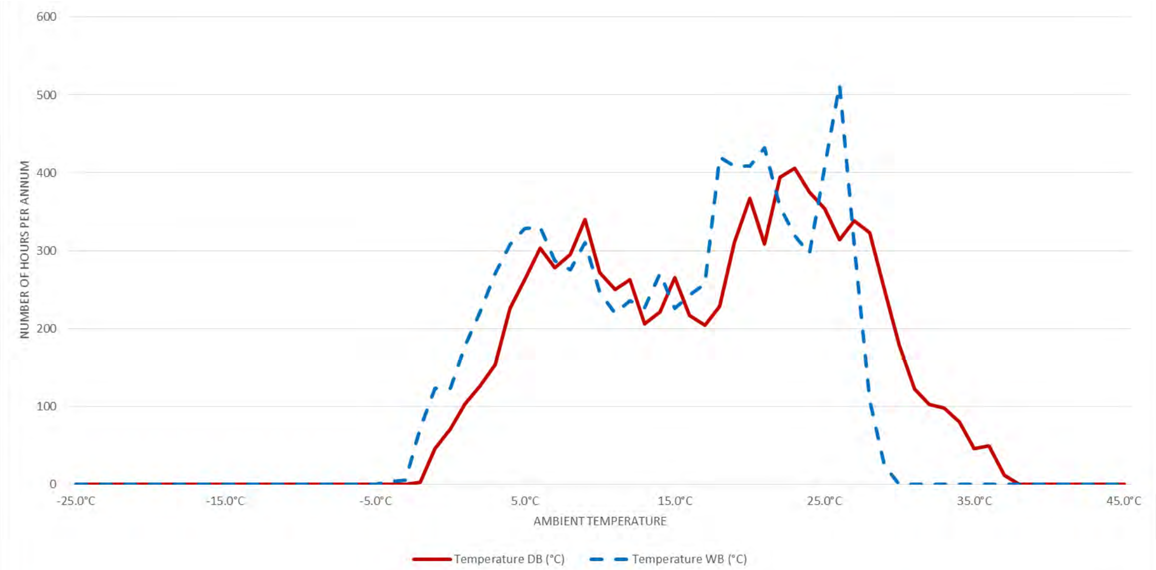
Wuhan (Hubei), China

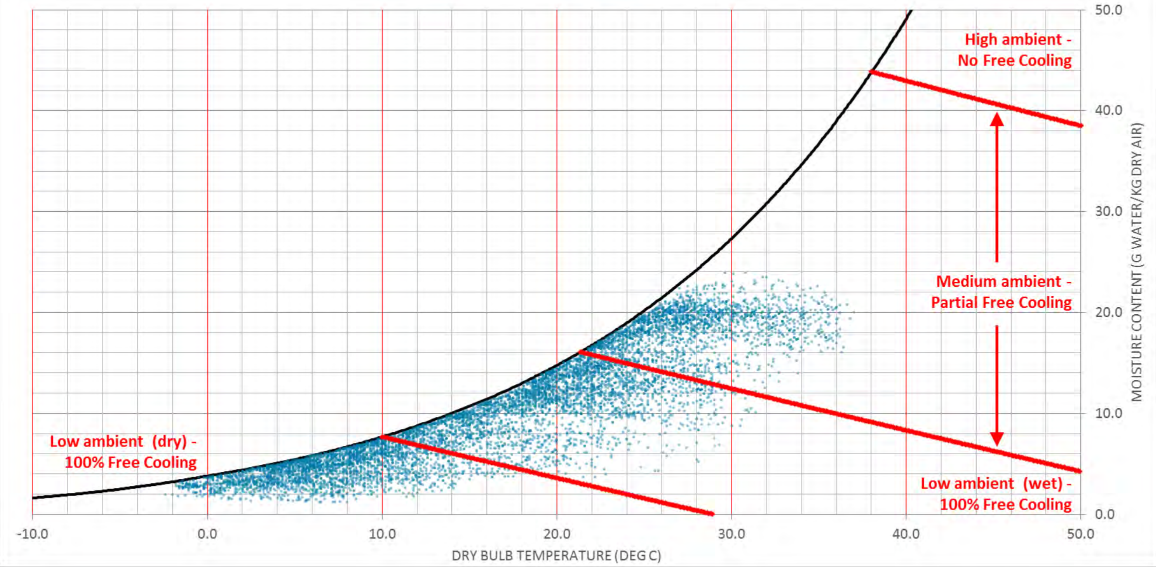


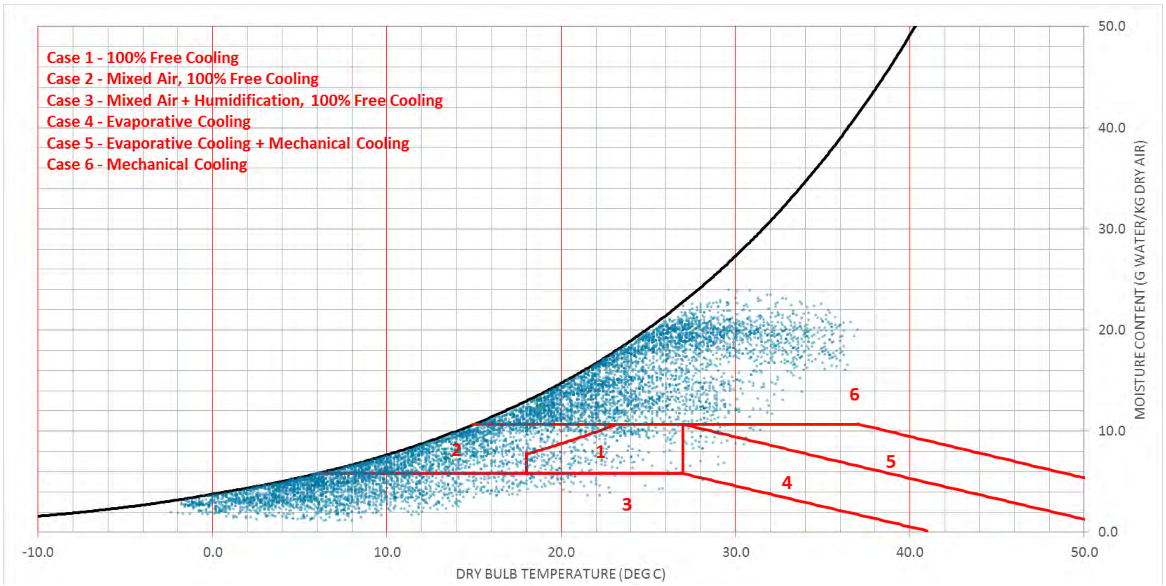




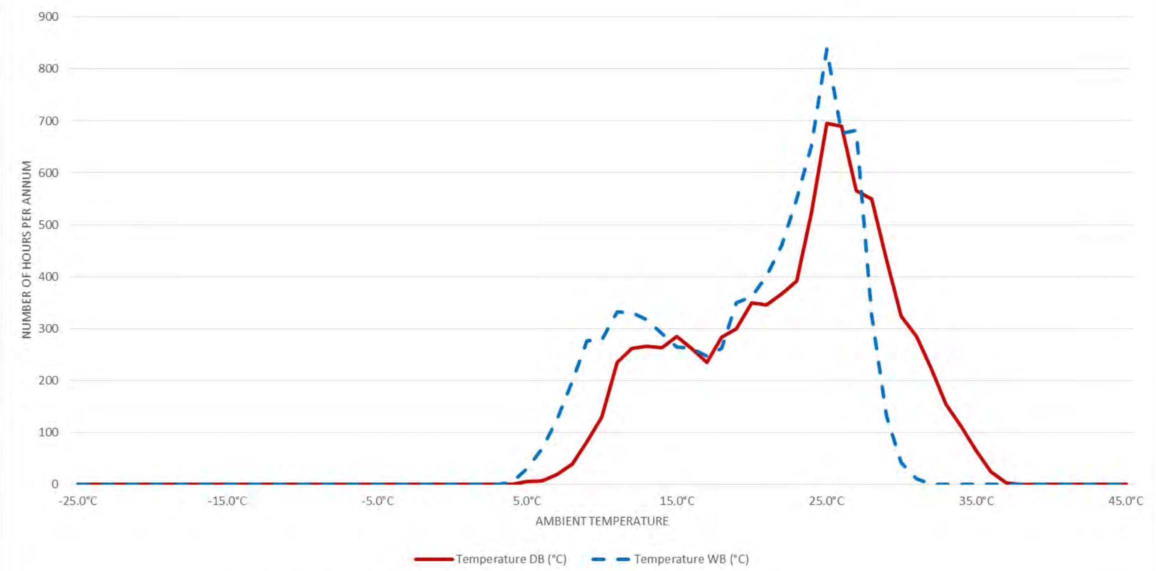
Hangzhou (ZheJiang), China

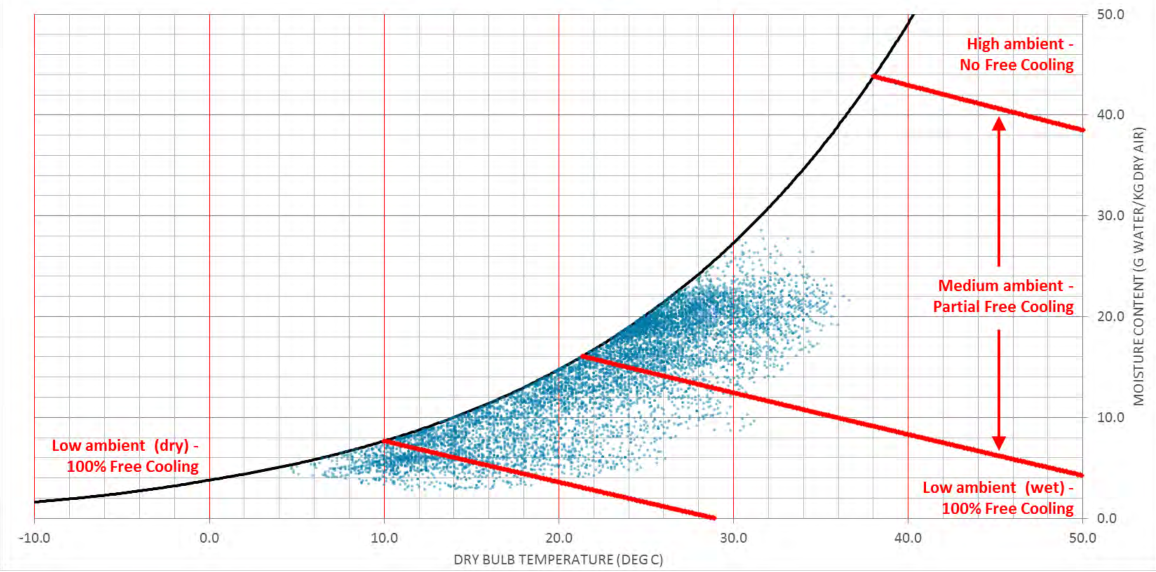


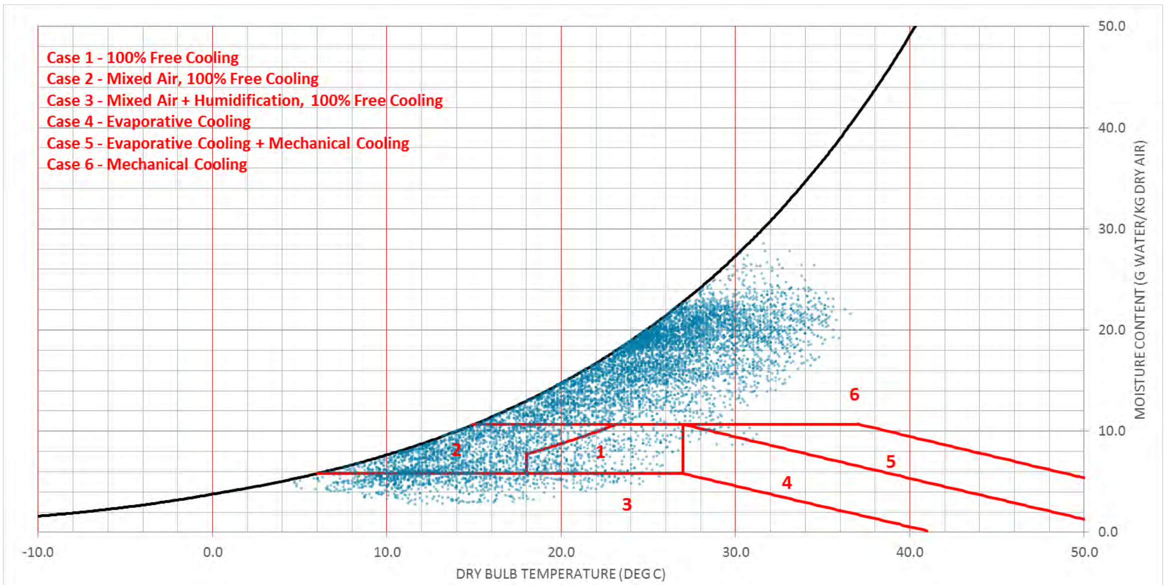




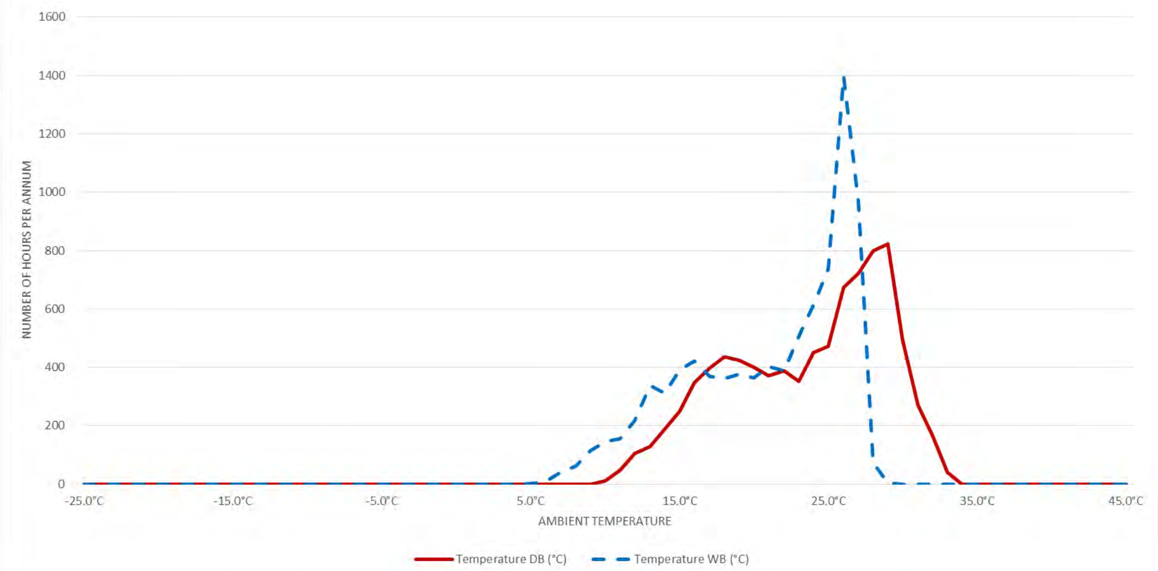
Guangzhou (Guangdong), China

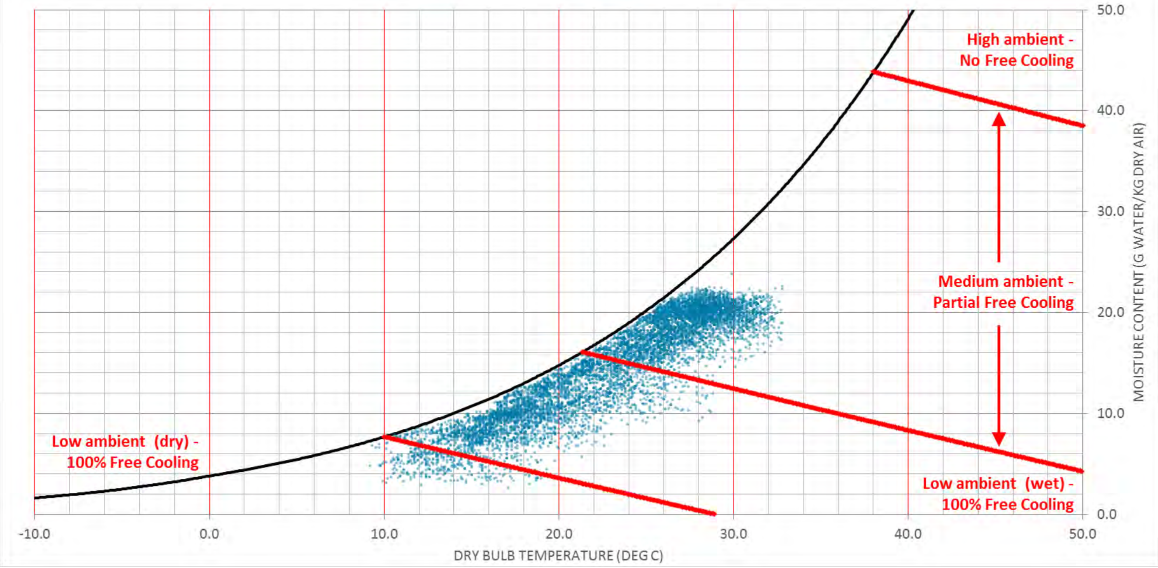


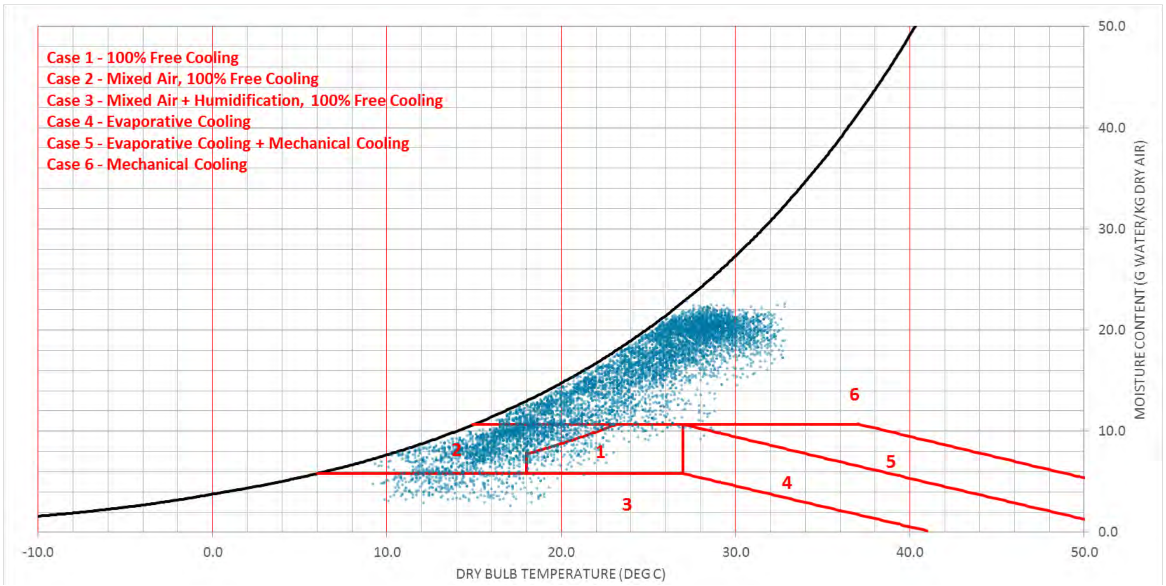




Hong Kong, Hong Kong

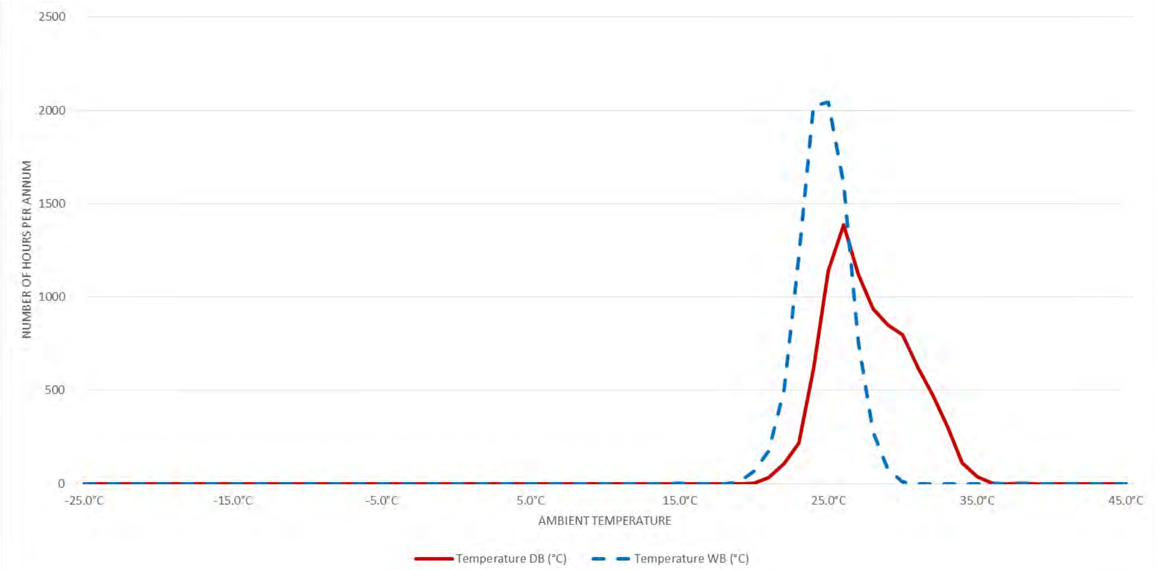


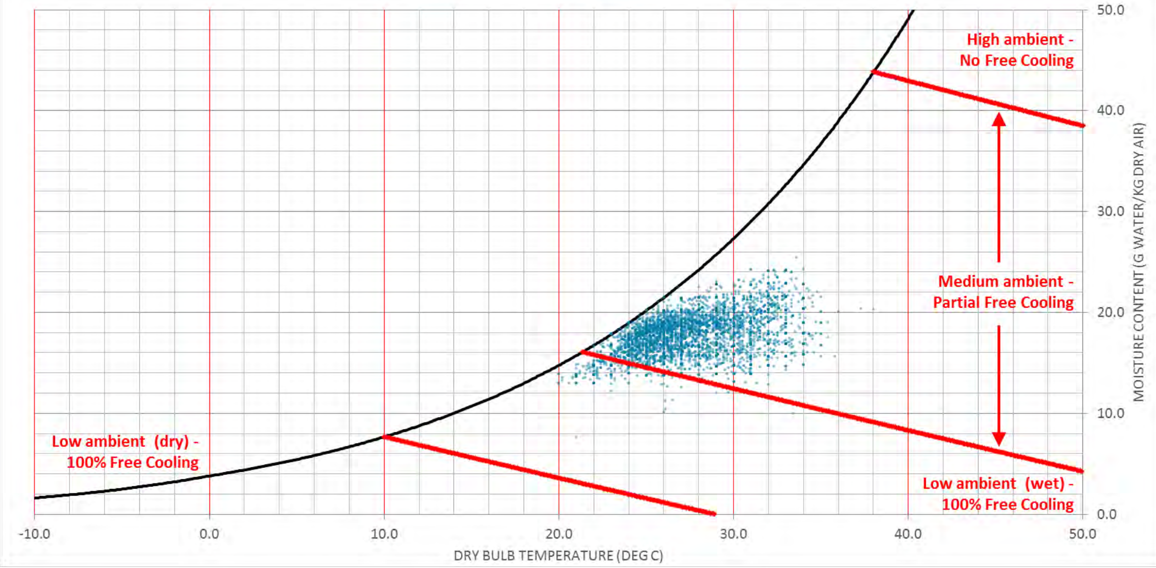


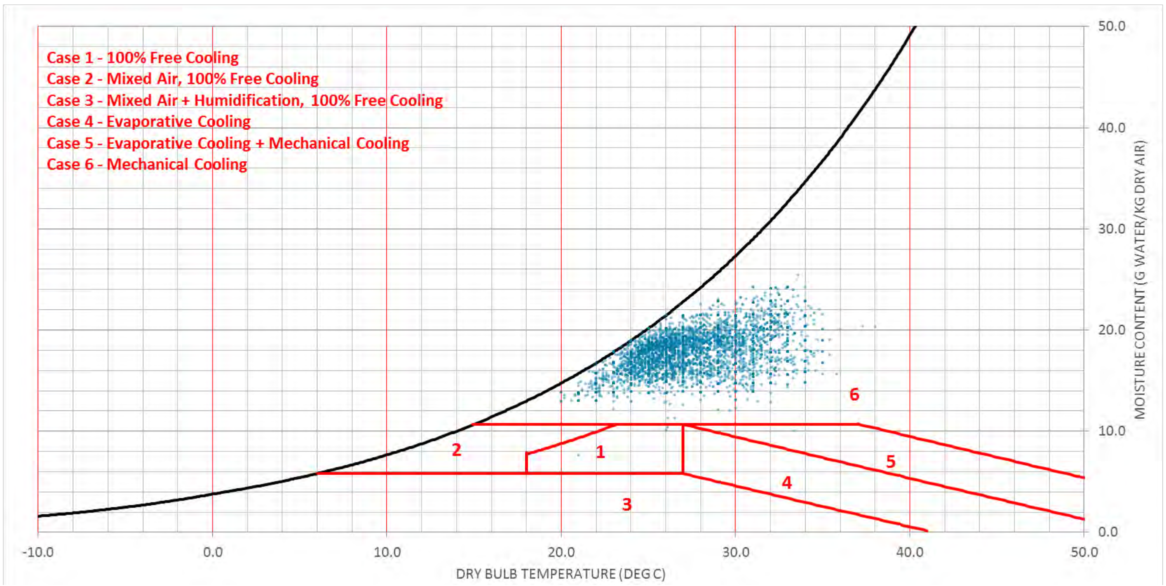


CUNDALL

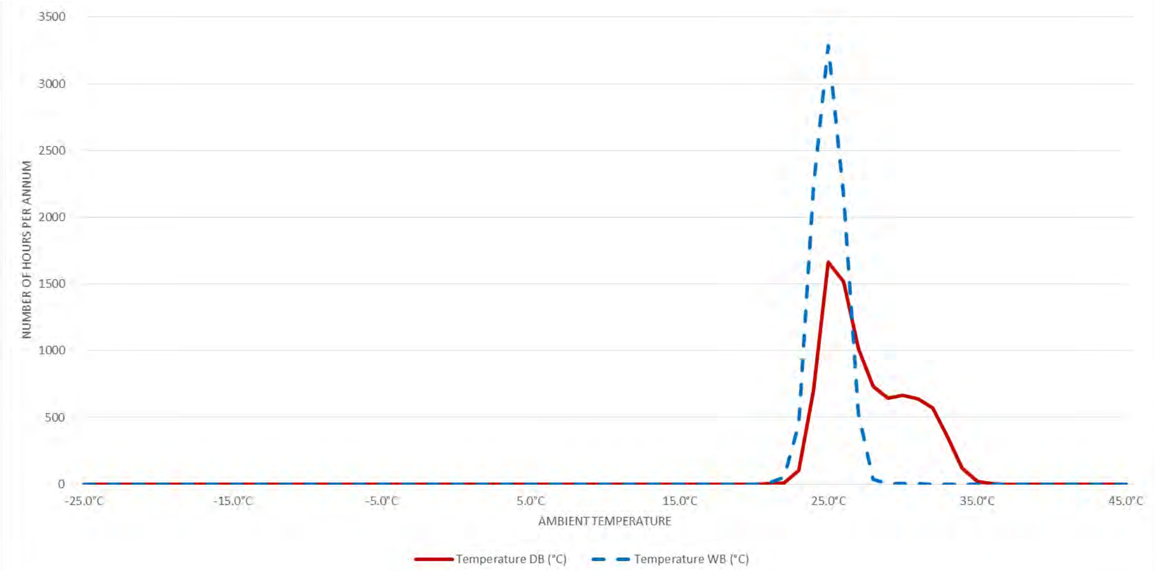
Manila, Philippines

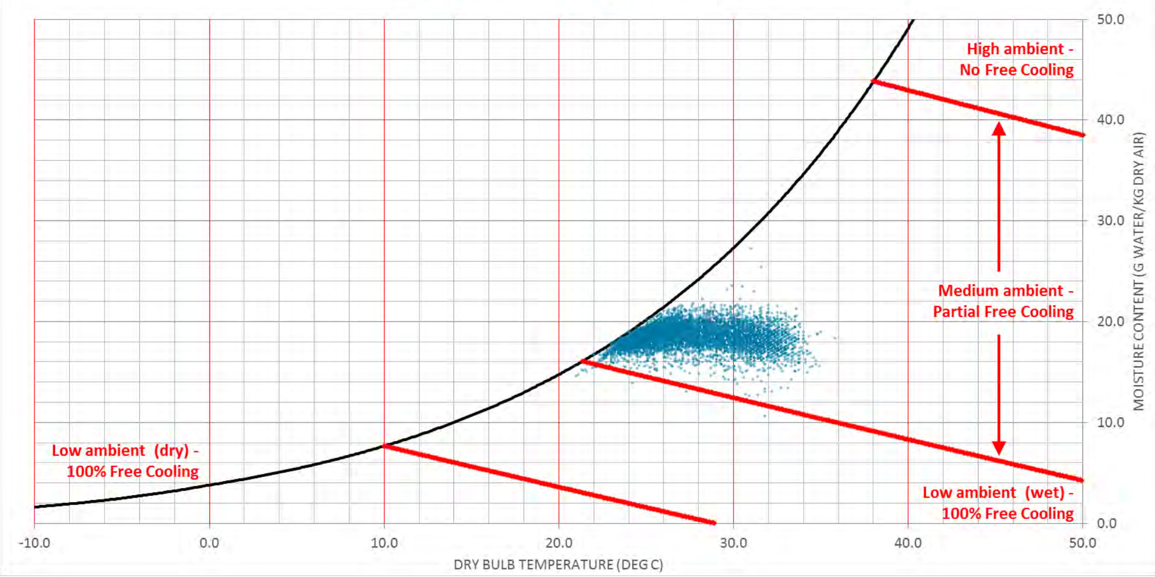


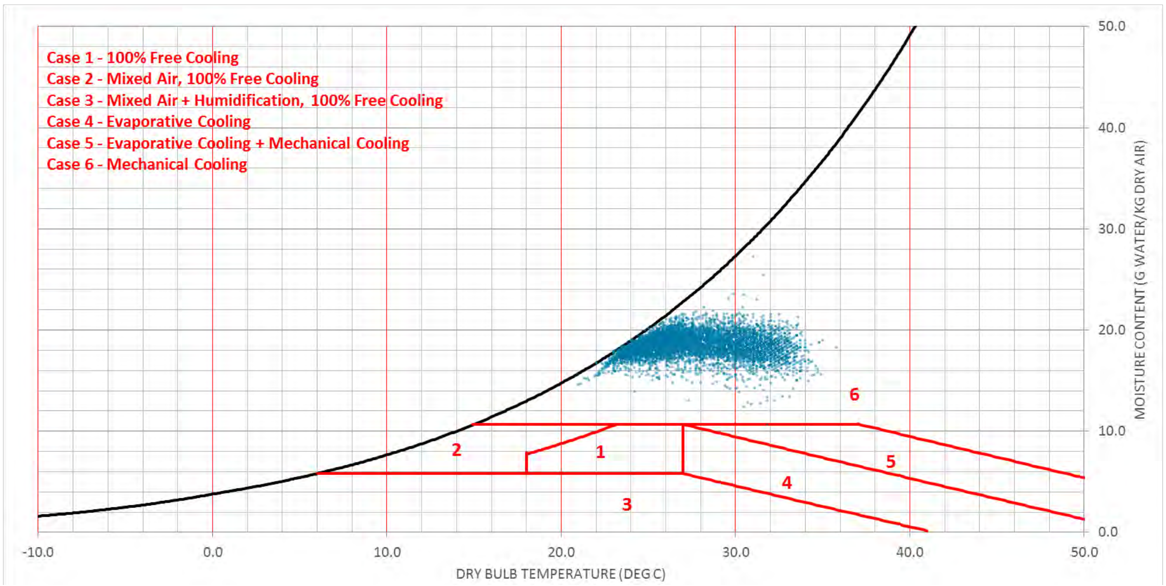




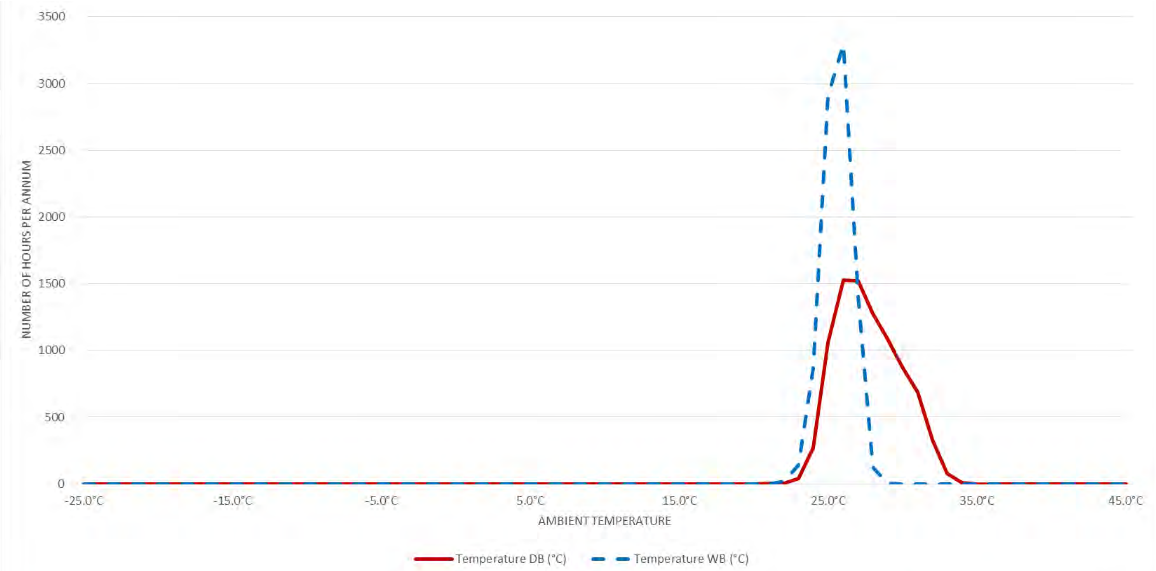
Kuala Lumpur, Malaysia

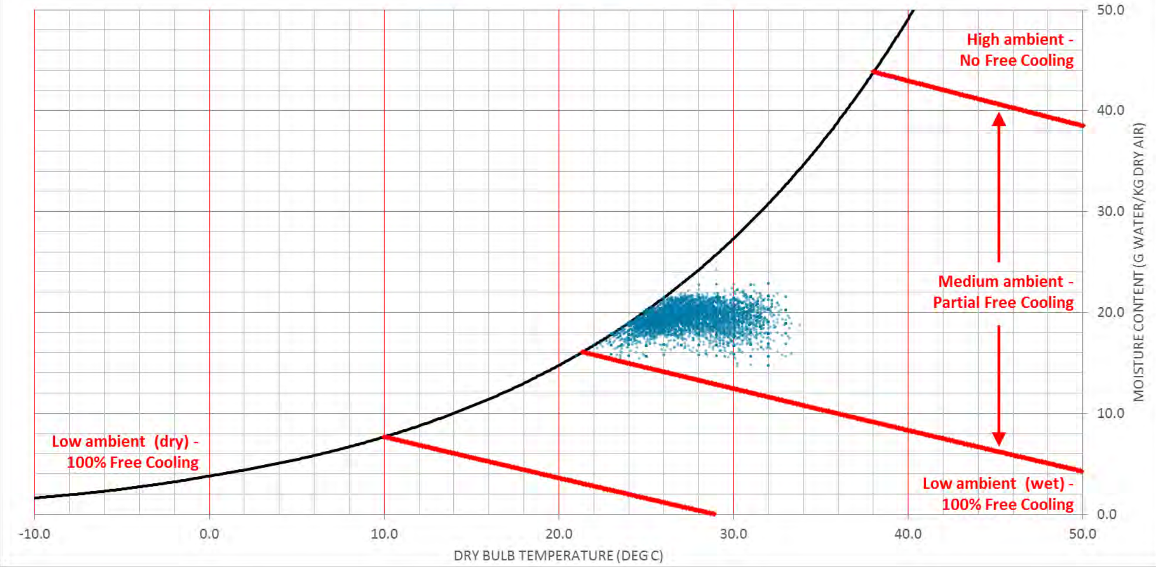


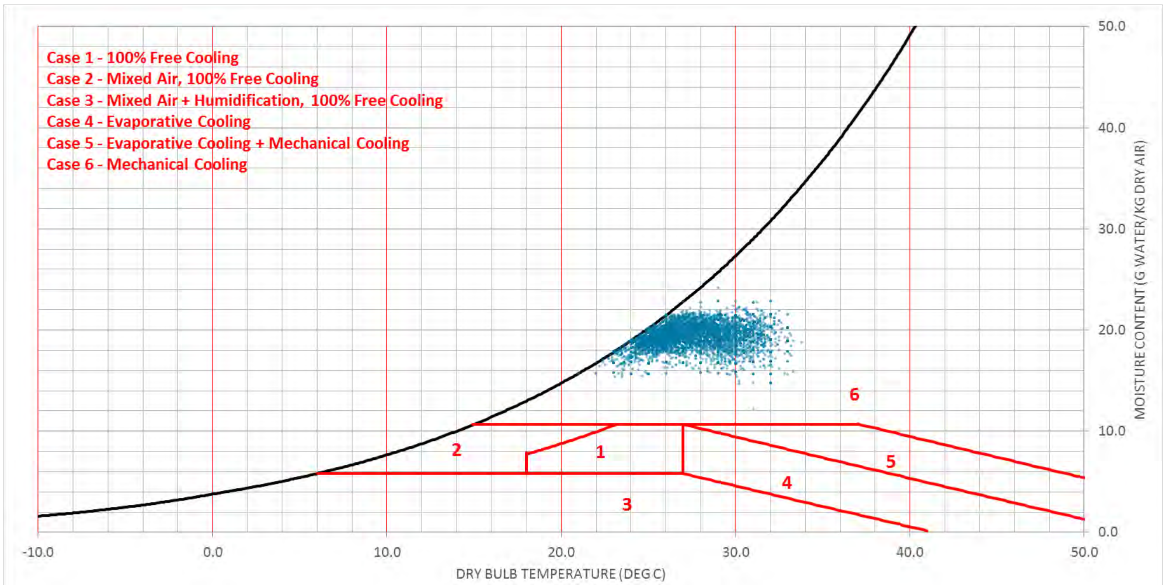




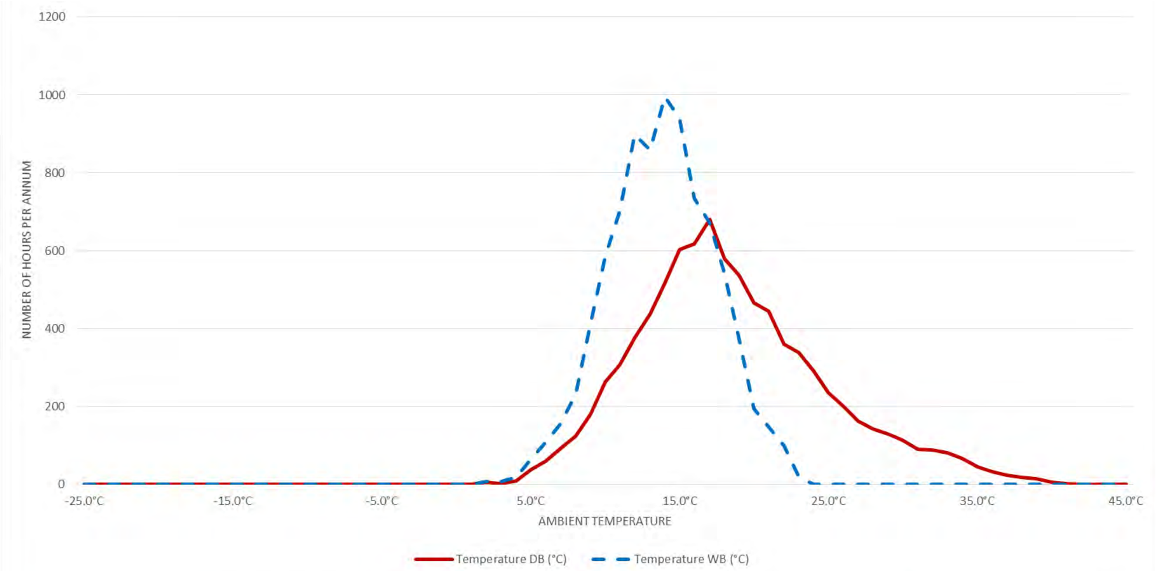
Singapore, Singapore

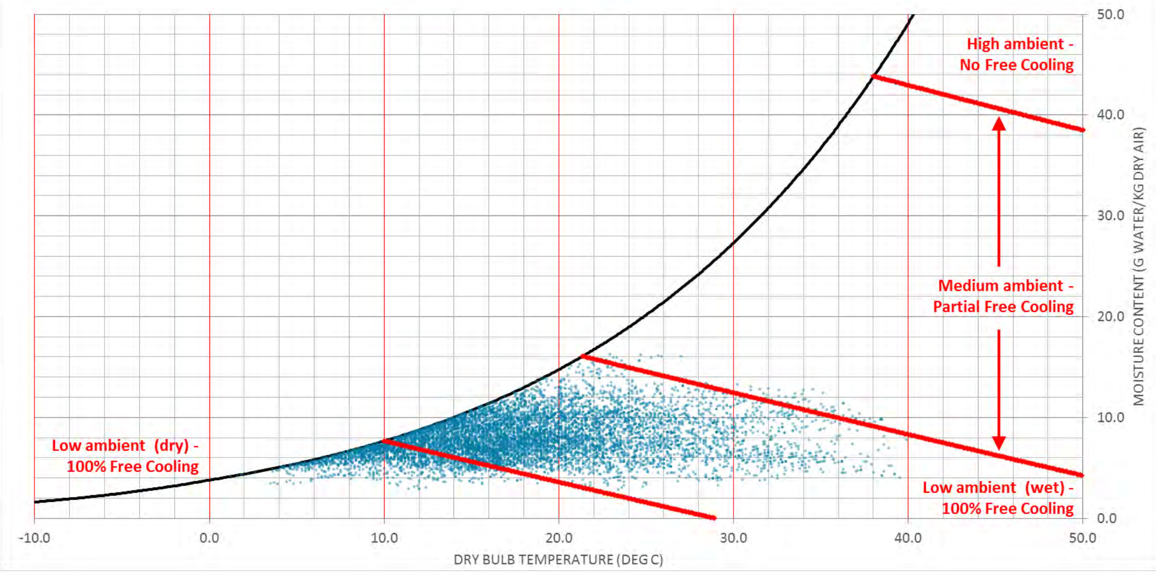


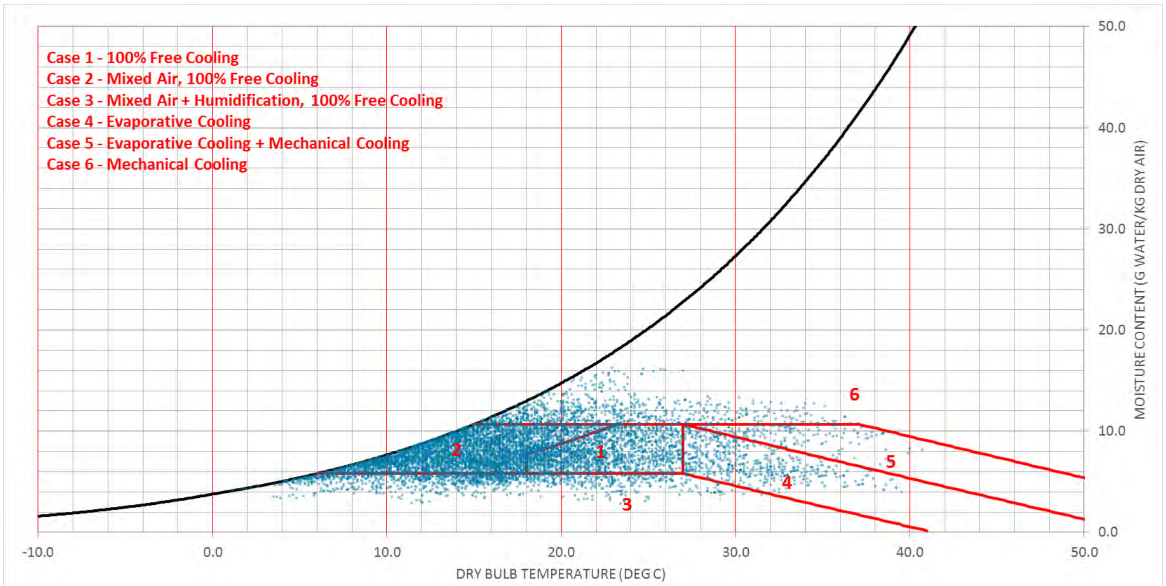




Perth, Australia







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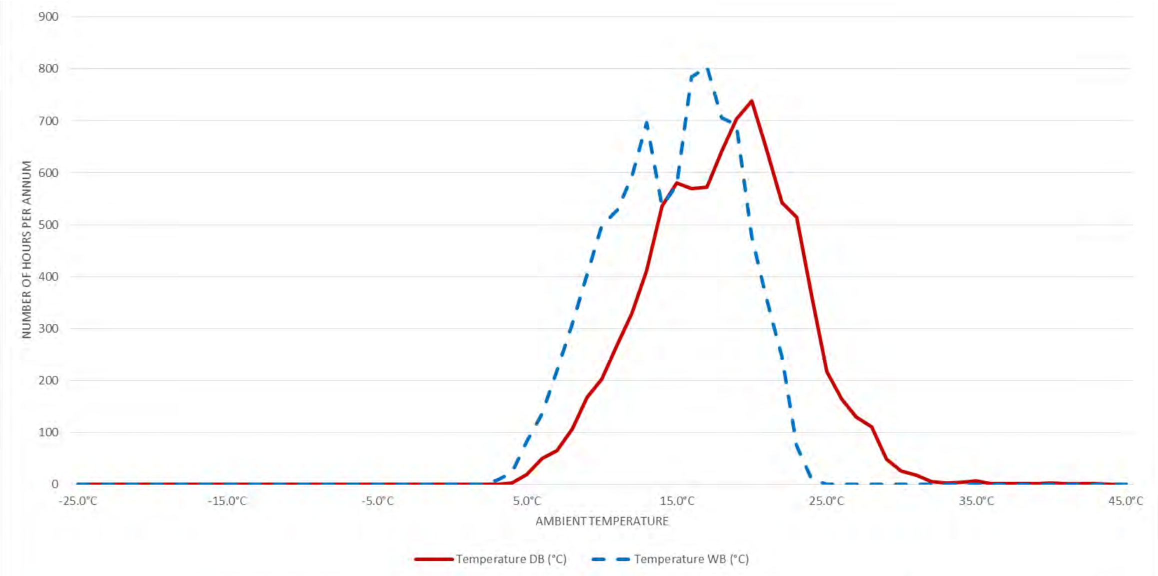

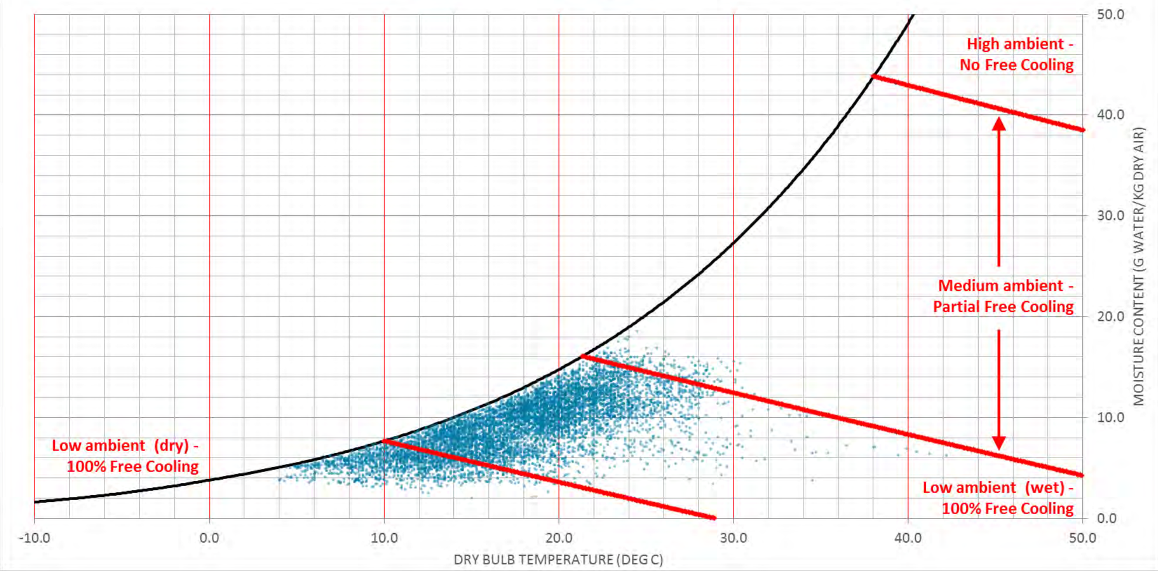

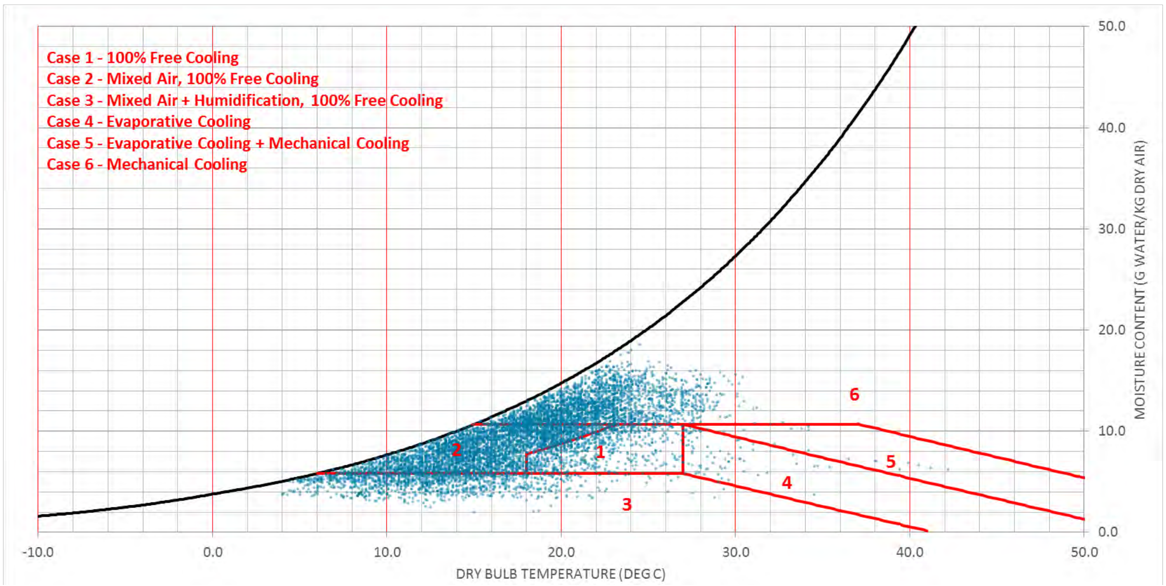

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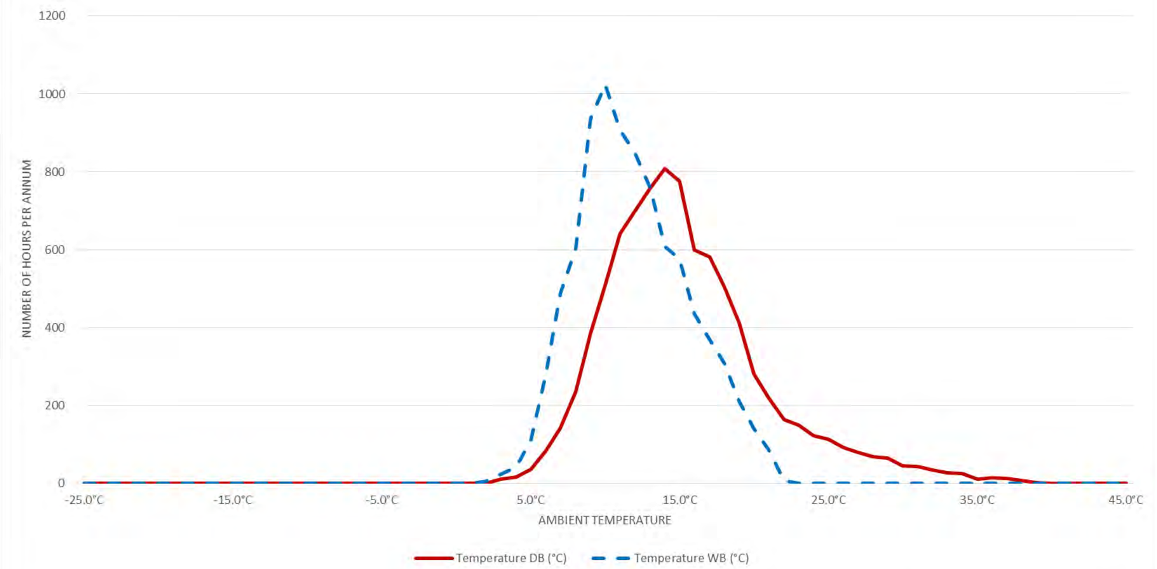

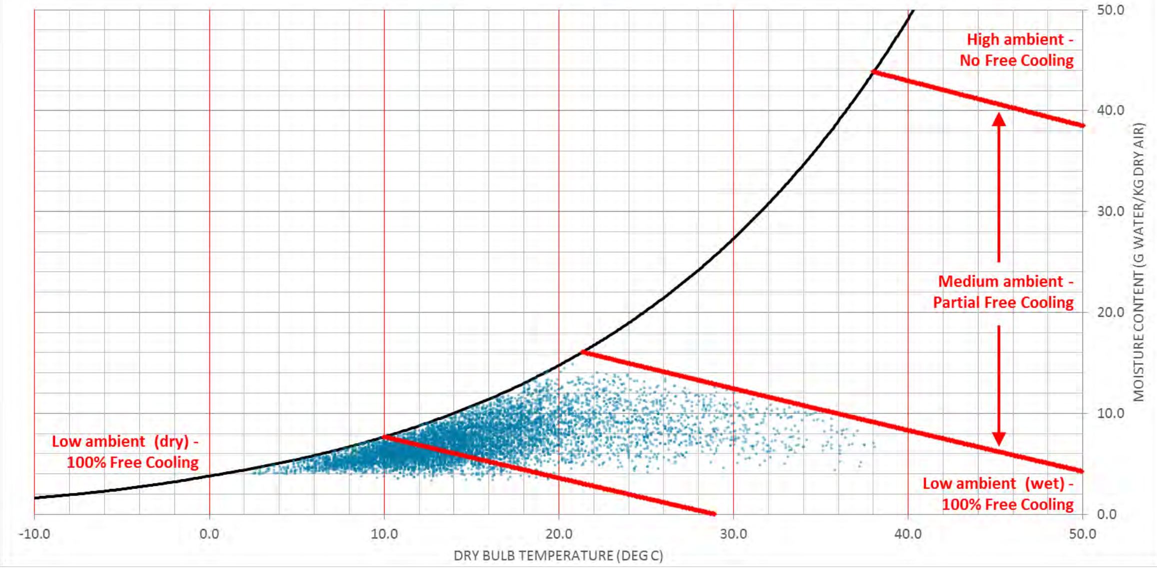

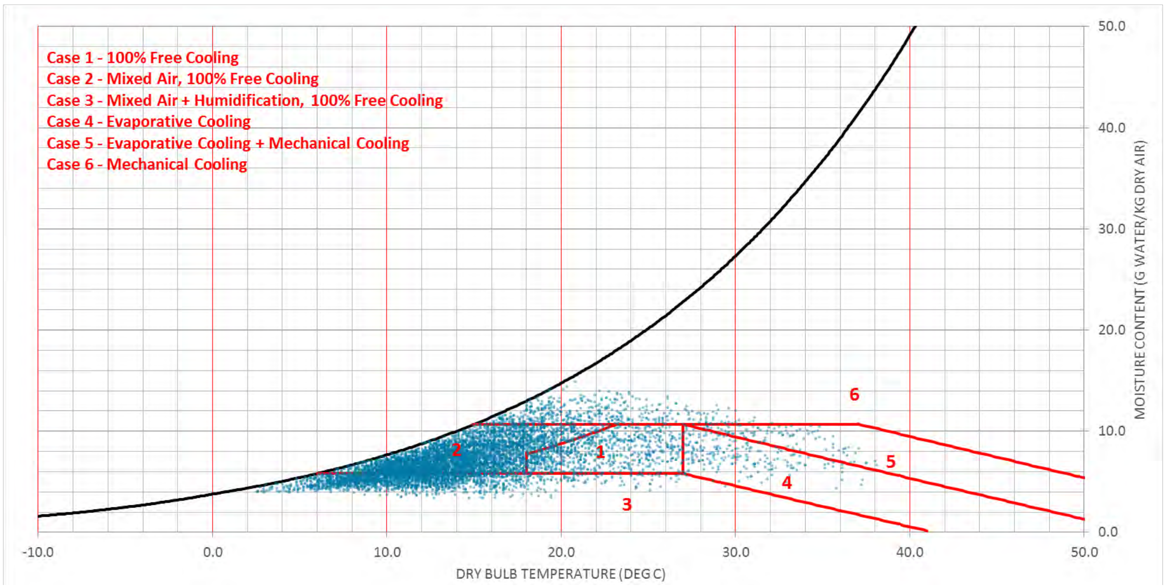

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Appendix D: - References

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

[ii] Datacenter Dynamics – Focus, Off the Grid,…. And other questions for the future. Volume 3 Issue 33 January/February 2014.

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

[iv] http://epi.yale.edu/pollution-map/

[v] http://www.datacenterknowledge.com/inside-microsofts-dublin-mega-data-center/

[vi] http://www.datacenterknowledge.com/archives/2009/07/15/googles-chiller-less-data-center/

[vii] http://www.datacenterknowledge.com/archives/2009/07/15/googles-chiller-less-data-center/

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

[ix] http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm;jsessionid=1A9A0DA1B01E74BE3D4909C0DF685C4A.eere?CFID=3916890&CFTOKEN=84e77c00c4fd7bc5-45249B84-E552-AB00-D2442F111462A77B