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Iceotope Engineering Review

Desktop Study Report- Liquid and Air-Cooling Compared

Iceotope Technologies Limited

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Executive Summary

SECTION 1: Introduction

The purpose of this report is to introduce liquid cooling for data-processing equipment, with a focus on the chassis-level precision immersion and Direct-to-Chip solutions produced by Iceotope Ltd. Different forms of liquid cooling are described and compared, as are other hybrid forms of liquid to air cooling.

The performance and energy efficiency advantages that liquid cooling can offer over conventional air-cooling are assessed, based around four imaginary Data Centres, all of which are based upon real world scenarios. Calculated PUE and WUE performance figures and predicted OPEX savings are presented, along with an indication of the environmental benefits, to illustrate the advantages that an operator would achieve through the adoption of liquid cooling.

The report predicts a strong, growing need for data centre capacity and highlights the challenge of providing cooling to these facilities in ways that minimise their carbon footprint. Several factors driving the adoption of liquid cooling are highlighted, including:

- Increasing CPU power and associated increases in power densities, both at a rack level and within the overall white space.
- Emergence of Artificial Intelligence (AI) and other power-hungry applications.
- Legislation, at local, national, and international levels.
- Increased adoption of Waste Heat Recovery (WHR), which is greatly facilitated by the use of liquid cooling.
- The need to reduce carbon footprint, particularly through a reduction in power and water consumption.
- Limited availability of large plots of development land for low-density, single storey data centres – recognising that the higher power density achievable with liquid cooling can reduce the overall footprint of the facility, especially if constructed in multi-storey. Heat rejection may also simplify, by virtue of the operating temperatures of the FWS, which for Classes W4 and W5, would be higher than those of the air and chilled water system typically deployed within an air-cooled facility.

The report describes the 5 classes of liquid cooling defined by ASHRAE, ranging from W1, (with an FWS temperature range of 2°C - 17°C), to W5 (with temperatures >45°C).

Section 1.5.1 of the report introduces the following generic forms of liquid cooling:

- Direct-to-Chip (Single-phase and Two-phase)
- Full Immersion – otherwise known as "Tub" or "Open-Bath" (Single-phase and Two-phase)
- IT Chassis-Level Precision Immersion

Reference is also made to hybrid air-cooled solutions, such as In-Row and Rear-Door Units, noting that these can be useful to support clusters of high-density racks, but recognising that the cooling medium is still air, so the capacity of High Density (H-D) racks that can be supported is limited by the amount of airflow that can be delivered to them.

In section 1.6.1 the report assesses the diverse variety of mainstream applications into which liquid cooling is now being applied:

- Cloud & Hyperscale
- Enterprise & CoLocation
- Edge Computing & IoT

The report highlights the following generic advantages of liquid cooling compared to air-cooling:

- Ability to accommodate rising power densities – most air-cooled racks typically operate in the range of 7-10kW/rack. Higher power densities can be supported by adoption of supplementary cooling such as in-row and rear door coolers. However, Iceotope's KU:L Box System can comfortably accommodates power densities of up to 60kW/rack.
- Significantly reduced building footprints – The report highlights that by increasing the Power Density from 8kW/rack to 60kW/Rack, it is possible to significantly reduce the number of racks required to support the load. This would equate to a reduction in data hall footprint of 86%. Even for application where mixed high- and low-density loads are anticipated, where power is available, groups of high-density loads can be introduced into a low-density hall and greatly increase its capacity without the need for additional space.
- Simplified Heat Rejection - the higher FWS operating temperatures typically associated with liquid cooling provides for simplified and smaller heat rejection plant. The need for mechanical compressor-based cooling plant may be avoided and the need for evaporative cooling may only arise in specific localities, or under peak summertime conditions. The requirement to design the data hall to accommodate large air-handling cooling plant, or large numbers of CRAHs is avoided. This reduces the overall complexity of the building and would simplify multi-storey construction.
- Reduced CAPEX - due to the elimination of aisle containment systems, the reduction in cooling plant complexity and the potential to reduce the size and cost of both the building and the plot on which it sits.
- Energy Efficiency – water has a volumetric heat transfer capacity that is over 3,000 times greater than that of air, so cooling can be delivered far more efficiently through this medium. Furthermore, liquid cooling systems typically operate with a supply temperature in the range 40-48°C, compared to a typical range for air-cooling of 16-25°C, which will enable far greater use of free cooling.
- WHR is far more effective and easier to achieve, thanks to the higher operating temperatures cited above.
- Reduced water consumption - the higher operating temperatures noted above, means that the use of evaporative cooling is greatly reduced or even eliminated, resulting in greatly reduced water consumption.
- Reliability and life-expectancy of components is greatly enhanced with liquid cooling, due to the uniformity of cooling and the elimination of hot-spots.

Section 1.7.5 of the report provides definitions of '*Power Utilisation Effectiveness' (PUE)* and *'Water Utilization Effectiveness' (WUE)*, before highlighting in the following section the shortcomings of these measures – most notably the failure of the *PUE* metric to recognise the proportion of server power that is consumed by parasitic loads, such as the dielectric fluid pumps within an liquid-cooled server, or the PSU cooling fans within an air-cooled server. Whilst the latter will typically consume around 10% of the total rack power, the former only consumes around 3%, thus providing a 'hidden energy saving' of around 7% of total rack ITE power.

To provide a more comprehensive, transparent, and accurate measure of efficiency, the report therefore recommends the use of '*IT Power Usage Effectiveness' (ITUE)* as a useful measure of server specific efficiency. Furthermore, it suggests that *'Total-Power Usage Effectiveness' (TUE)*, calculated as *ITUE x PUE*, provides a more precise indication of the data centre overall energy performance.

Section 1.7.9 considers local environmental considerations, such as the reduced noise propagation of liquid-cooled systems (both internal and external) and the ambivalence of liquid cooled systems to poor air quality and variations in humidity, that can both be so damaging for air-cooled systems.

The report then describes the 3 Classes of "Continuous Cooling" defined by the Uptime Institute (UTI), highlighting how the increased thermal storage in chassis and full immersion liquid-cooled systems compared to those using air, combined with the faster start-up capability of dry/hybrid coolers compared to chillers, makes liquid-cooled systems far less vulnerable to temporary disruptions in the power supply.

SECTION 2: Iceotope Liquid Cooling Technology

The report provides a summary of key facts regarding Iceotope, along with an overview of its various Liquid Enable Architecture and Technology Platforms, including:

- KU:L Heat Sink - part of the 'Precision Delivery' architecture, providing localized 'bathtub' containment of dielectric fluid over the centre of the chip.
- KU:L Cold Plate - maximum cooling for HPC applications.

- KU:L System - core reference platform, targeting users and applications where high volume reference form factors are used at scale.
- KU:L Hybrid System - using the core components of the KU:L system, but replacing the KU:L heat sink with a KU:L cold plate.
- Hyperscale Cloud KU:L Box - chassis-type server enclosures in an insulated, rigid plastic structure, partially filled with dielectric fluid, that is cycled through plate heat exchangers at the rear of the box.
- Rack - developed in collaboration with Schneider Electric, that houses up to eight KU:L Box 'Cubbies' plus an optional liquid-cooled power supply unit. Provides easy access, allowing an individual chassis to be partially withdrawn from the rack, whilst maintaining the power supply and without disrupting the flow of cooling water to the adjacent racks.
- KU:L 2 - a flexible and server adaptable solution, where current 1U and 2U air-cooled servers can be converted to liquid cooling by a simple swap of air cooling infrastructure with Iceotope's liquid cooling technology.

The report then considers the relative merits of Iceotope's chassis-level approach to liquid cooling compared to the more traditional 'Full Immersion' alternative, highlighting the following advantages:

- Far less dielectric fluid is required for a given cooling capacity. This has cost and environmental benefits.
- The reduction in fluid volume equates to a significant weight reduction, which for a large deployment would equate to an advantageous reduction in structural load.
- The KU:L Box cubbies each form a self-contained unit that is interchangeable with other cubbies within the rack, providing 'Plug and Play' functionality. In the event of a server failure, a replacement Cubby can be shipped to site, pre-built, tested and already filled with dielectric fluid, where it can be quickly exchanged for the failed unit. At all times, the replacement server would remain secure within its sealed Cubby, protected from any airborne contamination.
- Individual servers can be accessed and serviced without affecting adjacent equipment within the rack.
- With the depth of dielectric fluid being much shallower than with full immersion systems, it is far easier to access, inspect and if necessary replace individual components in a liver server tray, without creating the drips and spillages often associated with full immersion systems.
- The 'Plug and Play functionality of KU:L Box is also advantageous for provisioning new installations. The racks can be delivered to site pre-populated with Cubbies, which would be tested at the factory and arrive fully charged with dielectric fluid.

Section 2.4 then describes the interface of these systems with the Facility Water System (FWS) and provides recommendations to optimise the FWS for efficient, reliable operation.

SECTION 3.0: The Liquid Cooled Data Centre

Here the report summarises the characteristics of the Liquid-Cooled Data Centre, including building form and layout, heat rejection plant and implications regarding footprint.

The ASHRAE Thermal Guidelines are explored in more detail, including a review of the heat rejection systems typically used and the potential utilisation of WHR. Diagrams are provided, showing the typical infrastructure arrangements that would be recommended in order to achieve different levels of supply temperature to the CDU.

Section 3.2 describes the issues to be considered when designing a Liquid-Cooled Data Centre, including the recommended temperatures and pressures in the Technology Cooling System (TCS) and Facility Cooling System (FCS). Consideration is then given to the relative merits of Low-Level versus High-Level Services Strategies.

The section concludes with a detailed review of the dielectric fluids typically used for ITE cooling applications, which fall into two broad categories:

Oils – both mineral and synthetic.

Fluorocarbons – for both single and two-phase applications.

When comparing the relative merits of the two basic forms of dielectric fluids, the report highlights the following key points for each generic type:

Oils:

- Lower CAPEX
- Lower OPEX
- Zero GWP & ODP (but are polluting in the environment if released)
- No evaporation (but can therefore be messy if spilt)
- Typically, 10-20 year service life
- Typically classified as 'Combustible Liquids', rather than 'Flammable'
- Flash point is well above normal system operating temperatures

Fluorocarbons:

- Higher cost
- Prone to evaporation if not fully enclosed, thus a higher GWP
- Zero ODP
- Non-polluting in the environment
- Typically, 30-year service life
- Non-flammable, non-combustible

SECTION 4.0: Performance Comparison

Here the report describes three scenarios that Data Centre Operators may face, each with differing objectives, priorities, and constraints. In each case, the scenarios reflect real-world situations, as far as possible, based upon the needs of three fictitious Clients.

For each scenario, a design that includes the complete or partial adoption of Liquid Cooling, is compared against a benchmark that uses the best available form of air-cooling technology, taking account of the location and specific application.

In each case, the operating envelope reflects those most often requested in real-world projects by the relevant type of data centre operator:

Hyperscale Operator (Air-Cooled) – Assumed supply air condition at the server inlet of 18°C to 29°C Dry Bulb and 25% to 80% relative humidity. Supply air volume generally equates to a 12K rise across the racks.

CoLo Operator (Air Cooled) – Assumed supply condition following TC9.9 Recommended Range. Supply air condition at the server inlet of 18°C to 27°C dry bulb and relative humidity range equating to -9°C dew point at the lower limit and 15°C dew point and 60% relative humidity at the upper limit.

Liquid Cooled or Mixed Air and Liquid Cooled Environments – Taken as being the same as those specified for corresponding air-cooled environments.

Detailed weather data for each scenario is taken from the 2017 ASHRAE bin file.

Wherever possible, annualised energy and water consumption figure for the main mechanical plant has been based upon actual plant selections obtained from vendors. Where this has not been possible, performance has been estimated based upon pro-rata the water and power consumption of different sized plant, performing under identical operating conditions to those described in each scenario.

In all cases, the same approach to calculating energy and water consumption has been adopted for both air and liquid-cooled options.

The report includes a detailed analysis of the results, which in terms of impact on the operating costs can be best summarised in the following tables:

Base Case	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Application	5MW Hyperscale		2.4MW Co-Lo	1MW Edge DC
Location	Richmond VA	San Jose CA	London UK	Singapore
Tech Comparison	Fan Wall with Hybrid Cooler		IEC	Chiller + CRAH
Cost of Power for Cooling	£1,106,742	£1,098,586	£550,785	£755,899
Cost of Water for Cooling	£23,049	£11,077	£ 3,119	£ 15,993
Total Cost of Cooling	**£1,129,791**	**£1,109,663**	**£553,904**	**£771,893**
Cost of Power for Computing	£4,194,288	£4,194,288	£1,342,172	£838,858
Total Cost of Power	£5,301,030	£5,292,874	£1,892,957	£1,594,757
Total OPEX Cost	**£ 5,324,079**	**£ 5,303,951**	**£ 1,896,076**	**£ 1,610,750**
Total ITE Rack Power [kW]	5,000	5,000	1,600	1,000
Total ITE Power [kW]	4,500	4,500	1,440	900
Total Cost per KW of ITE Rack Power	£ 1,065	£ 1,061	£ 1,185	£ 1,611
Total Cost per KW of ITE Power	£ 1,183	£ 1,179	£ 1,317	£ 1,790
Total Cost of Cooling per KW of ITE Power	**£ 251**	**£ 247**	**£ 385**	**£ 858**

Liquid Cooling	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Cost of Power for Cooling	£562,263	£562,263	£663,514	£136,368
Cost of Water for Cooling	£ 3,557	£ 1,256	£ 343	£ 676
Total Cost of Cooling	**£565,820**	**£563,519**	**£663,858**	**£137,044**
Cost of Power for Computing	£4,520,510	£4,520,510	£2,091,552	£904,102
Total Cost of Power	£ 5,082,773	£5,082,773	£ 2,755,066	£ 1,040,470
Total OPEX Cost	**£ 5,086,330**	**£ 5,084,029**	**£ 2,755,409**	**£ 1,041,146**
Total ITE Rack Power [kW]	5,000	5,000	2,400	1,000
Total ITE Power [kW]	4,850	4,850	2,244	970
Total Cost per KW of ITE Rack Power	£ 1,017	£ 1,017	£ 1,148	£ 1,041
Total Cost per KW of ITE Power	£ 1,049	£ 1,048	£ 1,228	£ 1,073
Total Cost of Cooling per KW of ITE Power	**£ 117**	**£ 116**	**£ 296**	**£ 141**

Impact	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Water useage per KW of ITE Power	-85.7%	-89.5%	-92.9%	-96.1%
Power useage per KW of ITE Power	-11.0%	-10.9%	-6.6%	-39.5%
Total Cost per KW of Rack Power	-4.5%	-4.1%	-3.1%	-35.4%
Total Cost per KW of ITE Power	**-11.4%**	**-11.1%**	**-6.7%**	**-40.0%**
Total Cost of Cooling per KW of ITE Power	**-53.5%**	**-52.9%**	**-23.1%**	**-83.5%**
Increased ITE Capacity per Hall	*7.8%	*7.8%	55.8%	*7.8%
Footprint Required for additional Hall	n/a	n/a	n/a	-74.1%

*Note: The 7.8% increase in ITE Capacity per Hall in Scenarios 1a, 1b & 3 derives entirely from the reduced power draw of the on-board pumps in the liquid cooled design, compared to that of the server fans in the air-cooled base case. Substantial further increases could have been achieved by increasing the rack density and number of racks in the liquid-cooled design.

The report finally assesses the environmental impact of the alternative designs, by first estimating the carbon-footprint, then by assessing the amount of water consumed. In all cases, the report shows significant improvements:

Base Case	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Application	5MW Hyperscale		2.4MW Co-Lo	1MW Edge DC
Location	Richmond VA	San Jose CA	London UK	Singapore
Tech Comparison	Fan Wall with Hybrid Cooler		IEC	Chiller + CRAH
Total Power Demand [kWh/year]	49,821,715	49,745,054	17,790,948	14,988,326
CO2 Emissions [kg/year]	11,615,435	11,597,562	4,147,782	3,494,378
Total ITE Power [kW]	4,500	4,500	1,440	900
kg of CO2 per kW of ITE Power [kg/kW per year]	2,581	2,577	2,880	3,883

Liquid Cooling	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Total Power Demand [kWh/year]	47,770,423	47,656,116	25,893,476	9,778,856
CO2 Emissions [kg/year]	11,137,196	11,110,547	6,036,805	2,279,842
Total ITE Power [kW]	4,850	4,850	2,244	970
kg of CO2 per kW of ITE Power [kg/kW per year]	2,296	2,291	2,690	2,350

Impact	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Percentage Reduction in CO2 Emissions per kW of ITE Power [kg of CO2/kW per year]	**11.0%**	**11.1%**	**6.6%**	**39.5%**

Note: Emissions estimate based upon data published by BEIS (Dept. for Business, Energy & Industrial Strategy). For 2020, UK Grid generation represents 0.23314 kg of CO2/kWh.

Litres of water consumed per year, per kW of ITE Power	Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Air-Cooled	4,687	2,252	1,982	16,261
Liquid-Cooled	671	237	140	638
Reduction	**86%**	**89%**	**93%**	**96%**

Contents

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ONE PLANET LIVING

An initiative by Bioregional