ACS Liquid Cooling Cold Plate Requirements Document

Revision 1.0

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Introduction

This document outlines the requirements related to Liquid Cooling Cold Plate technology, which may be used in the Open Compute Project (OCP) environment. Liquid cooling technology is not a new technology, but until now most solutions have generally been proprietary. The OCP focuses on standardization and definition of critical interfaces, operational parameters, and environmental conditions that enable non-proprietary, multi-vendor supply chain of liquid cooled solutions.

This document is a requirement's document and not a specification. This document defines common terminology, identifies liquid cooling component selection with parameters of importance, and contains requirements that future liquid cooling design specifications need to adhere to. From this document, a checklist has been generated that any OCP liquid cooling specification need to comply with (see the Cold Plate Qualification Requirement [1]). For contributions, this checklist needs to be filled out, and peer-reviewed by subject matter experts to ensure compliance with the requirements before the contribution is proposed for approval in the Incubation Committee meeting.

This requirement document is applicable to rack manifold distributed liquid cooling with a Technology Cooling System (TCS) fluid loop [2]. This is the fluid loop from the Coolant Distribution Unit (CDU) to the rack, through the manifold and the IT equipment, and then back through the manifold back to the CDU. The document assumes that the heat from the TCS cooling loop is transferred to the facility cooling loop, which is called the Facility Water System (FWS). FWS is not covered in this document. This requirement document does not apply to the IT equipment being cooled or fully air cooled specifications, but solely to the TCS cooling loop and its ingredients.

More efficient cooling technologies are required as power and power density increase of the IT equipment to meet the continuous demand of increased compute performance. Liquid cooling provides more efficient cooling compared to traditionally used air cooling. When to switch to liquid cooling depends on many different parameters, such as targets of performance, power delivery, energy efficiency requirements, IT equipment density, compute density, cooling costs, future IT equipment needs, and strategy. All these parameters together with considerations of the potential need of retro-fitting the facility to pull in liquid to the racks/IT equipment or building a new facility to optimize the infrastructure feed into the total cost of ownership (TCO) model for the installation. From the TCO investigation, it can be determined when it is cost efficient to change to liquid cooling. Another reason for going to liquid cooling is that the IT equipment simply cannot be cooled to its temperature requirements any longer with air and therefore increased cooling is required. There is no general guideline on when or at what power levels liquid cooling will be required for the compute components, such as CPU and GPU. It should also be noted that in addition to the cost analysis, there are some new design considerations for liquid cooled solutions that need to be understood. One of those is to ensure that all the wetted materials in the cooling loop are compatible with the cooling liquid/coolant used. This is essential for the success and operation of the liquid cooling solution. Another design consideration is to ensure that the cooling liquid used will never be mixed with any other cooling liquid, since the integrity of the cooling liquid is of uttermost importance to ensure the longevity of the cooling liquid. In this requirements document, it is assumed that material compatibility between all cooling components and the cooling liquid has been determined, and it is therefore not repeated in all the different subsections. It is also assumed that no mixing of cooling liquids occurs.

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2. Revision History

Revision	Date	Comments
1.0	*Oct 9, 2019*	*First publication*

3. Terminology

The terminology used here is the same as used by ASHRAE [2] when discussing cooling solutions. The terminologies are:

- TCS, Technology Cooling System, is the cooling system from the Coolant Distribution Unit (CDU) to the rack, through the manifold and IT equipment, and back to the manifold and to the CDU.
- FWS, Facilities Water System, is the facility cooling system. The definition of FWS is extended in this document to also include other cooling liquids in addition to water.

4. Liquid Cooling Technology Definitions

4.1 Liquid Cooling Cold Plates

Liquid cooling cold plates refers to the technology of closed loop liquid cooling, where liquid or liquid/gas phase change is used as the heat transfer medium. Conduction of the heat occurs through cold plates, which are attached to the electronics power components in need of cooling. This is also sometimes called direct liquid cooling, since the cooling liquid is delivered directly to the components via a cold plate, thereby directly transferring the heat to the liquid. This should not be confused with indirect liquid cooling and immersion. Indirect liquid cooling is when air is the heat transfer medium to the liquid (f.ex. door heat exchanger). Immersion cooling is when the electronic components are in direct contact with a dielectric cooling liquid.

4.2 Cold Plates

Cold plates are heat exchangers or heat sinks with internal tubing or channels to allow cooling liquid to flow through. Cold plates are placed on the electronic components in need of cooling and provide a conductive heat transfer path to the cooling liquid. There are different types of cold plates, where the design can be optimized to enhance heat removal from the electronic components. A simple example of a cold plate is a metal block with integrated fluid piping, while a more complex and commonly used cold plate design apply micro-channels to enhance the thermal performance. This is often used for high power and high power density components.

4.3 Hybrid Cooling

Hybrid cooled solutions referenced in this document refers to cooling using both air cooling and direct liquid cooling. A common hybrid installation is to use direct liquid cooling for high power and high power density components, while air is used to transfer heat from the low power components. An example of hybrid cooled IT equipment is servers with cold plates attached to the microprocessors, while fans are used to cool all other components. Hybrid solutions still require room air-conditioning.

4.4 Full Liquid Cooling

Full liquid cooling refers to cooling solutions where all heat is rejected to liquid. For the IT equipment, such as a server solution using full liquid cooling, a heat transfer path is required to the cooling liquid through cold plates for all components. An example of full liquid cooled server installation is to use micro-channel cold plates for the high power components, while plates with internal piping are used to cool all other low power components. A common example of a full liquid cooled rack is a hybrid IT equipment solution with a door heat exchanger that captures all the heat from the air and transfers it to the cooling liquid. Full liquid cooling requires minimal room air-conditioning to remove heat transferred to the air only through unintentional thermal losses.

4.5 Single- and Two-Phase Cooling Liquids

The heat can be transferred to cooling liquids that either operate in single-phase or two-phase. For single-phase liquids, the liquid stays in liquid phase during the whole operation, while being circulated and removing heat from the hot components. The cooling liquid is cooled in a heat exchanger approach. Examples of single-phase liquids used are water with additives, glycol based liquids, and dielectric liquids.

Two-phase liquids have a low boiling temperature and removes heat predominantly through a process of heat of vaporization and condensation via a heat exchanger. Either dielectric or refrigerant liquids can be used as the two-phase liquids, and many liquids are available with different boiling temperatures. The cold plate using two-phase technology are sometimes called evaporators. In this document, cold plate applies to both single- and two-phase cold plates, and cooling liquid refers to the coolant in both single-phase and two-phase implementations.

It is essential that there is material compatibility between the cooling liquid and all the materials exposed to the cooling liquid, which are referred to as wetted materials, to minimize any long term risks of corrosion. Even when ensuring material compatibility between cooling liquid and all wetted materials, it is still important to regularly check the quality of the cooling liquid to ensure that there are no issues.

4.6 Coolant Distribution Unit

The purpose of the Coolant Distribution Unit, CDU, is to provide an isolated cooling loop to the IT equipment. Heat transfer occurs inside the CDU, via a heat exchanger, between the heated liquid from the IT equipment loop (TCS) and the facility liquid (FWS) on the facility side. The CDU options are in-rack, row level, or facility level. One or several in-rack CDUs can be present in a rack to cool the IT equipment. The row level CDU often provides cooling to one or several racks full of IT equipment. A facility level CDU is a distribution solution with facility level pumps and heat exchangers that service the combined heat load of all the liquid cooled racks with TCS quality cooling liquid. It is common that filters are incorporated in the CDUs, while the filter size requirements are specified by the components in the cooling loop that are the most sensitive to particles, such as fluid connectors and/or micro-channel cold plate geometry. The filters ensure that potential particles in the cooling fluid do not get stuck in the fluid loop and block the flow of the cooling liquid.

4.7 Rack Manifold

The rack manifold distributes cooling liquid inside the rack from the CDU to the IT equipment and back again. The manifold must be able to deliver the flow rate required to cool the IT equipment, at targeted pressure drop, and provide a uniform flow distribution within the rack. This requires careful design considerations.

4.8 Quick Disconnect Couplings

Quick disconnect (QD) couplings are used to quickly disconnect the IT equipment or its components from the liquid cooling loop for serviceability. A liquid cooled installation should use drip-less couplings, where liquid flow is shut off at both ends when being disconnected. This limits the potential issue of liquid on the IT equipment.

There are two options of QDs between the rack manifold and the IT equipment, either hand mate or blind mate connectors. Hand mate couplings are manually connected, while blind mate connects through a sliding or snapping action.

5. Cooling Components Selection and Parameters of Importance

5.1 Cooling Liquid Selection

The cooling liquids commonly used in the TCS cooling loop are water with additives, glycol based liquids, dielectric liquids, or refrigerants. The selection of cooling liquid should not be made lightly and should take into consideration operational need, material compatibility with the wetted materials in all cooling components, IT equipment serviceability, cooling liquid maintenance need, life expectancy, and liquid cost to mention a few. There are different pros and cons with each of the cooling liquids and the high level details are discussed below and also found in Table 1, 2, 3, and 4.

Water with additives is used because of the good heat transfer properties of water and the additives are chemicals added to reduce corrosion risk and bacterial growth. These additives can reduce the heat transfer properties of the water, and potential impact to overall performance should be investigated. Another property of water is its freezing point at 0 ºC. It is therefore important to know the operating range of the liquid and temperature requirement/exposure during shipping and storage. To reduce the risk from corrosion and contamination during transit, the IT equipment and/or rack can be shipped pre-charged with a suitable cooling liquid or gas. As part of the installation procedure the pre-charged fluid should be considered to be flushed before the system is operational, when following the guidelines of the manufacturer’s installation and commissioning procedure. Also the quality of the fluid should be monitored regularly for changes to the baseline specification of the cooling liquid. These pros and cons are shown in Table 1.

Glycol based liquids are liquids where glycol is added to lower the freezing temperature and reduce bacterial growth. The freezing temperature lowers with an increase of glycol in the cooling liquid, which reduces the heat transfer properties of the liquid. It is therefore important to know what the temperature requirements for operation and storage/shipping are to not add too much glycol. However, it should be noted that for glycol levels at and above 25%, there is no bacterial growth in the liquid. Also here the quality of the fluid should be monitored regularly for changes to the baseline specification of the cooling liquid. Glycols commonly used are ethylene glycol and propylene glycol. Propylene glycol is preferred since it is less toxic than ethylene glycol. In small quantities, the propylene glycol is even used in the food industry as an additive. These pros and cons are shown in Table 2.

Dielectric liquids can be used for both single-phase and two-phase cooling. Liquids with higher boiling temperatures operate in single-phase, while liquids with lower boiling temperatures operate in two-phase. The boiling/saturation temperature of the liquids can be altered by varying the operating pressure. One advantage with dielectric liquids are that in the event of a potential leak, the liquid is an electric insulator and does not short the electronic circuits of the IT equipment. Often these liquids have higher density, cost more, and have higher Global Warming Potential (GWP). These affects should be considered in the analysis when selecting coolant liquid (found in Table 3).

In addition to dielectric liquids, refrigerants can also be used for two-phase cooling. The refrigerants have relatively low boiling temperature that allows the liquid to change phase and evaporate. This saturation temperature can be altered by varying the operating pressure. The pros and cons of refrigerants are shown in Table 4.

Table 1, Pros and cons of water with additives cooling liquids.

Water with additives	
Pros	**Cons**
Good heat transfer properties (high conductivity and specific heat)	Additives needed for reducing corrosion risk and bacterial growth
	Ongoing regular maintenance

Table 2, Pros and cons of glycol based cooling liquids.

Glycol based liquids	
Pros	**Cons**
>25% glycol no bacterial growth	Changes to viscosity => changes pump power conditions including power needed
Improved maintenance schedule	Lower conductivity and specific heat with increasing glycol level

Table 3, Pros and cons of dielectric cooling liquids.

Dielectric	
Pros	**Cons**
No short circuit of electronics during potential leaks	Adds liquid weight
	Higher Global Warming Potential (GWP)
	Higher cost
	Limited supplier availability
	Potential for flow instabilities and maldistribution in micro-channel cold plate using 2-phase

Table 4, Pros and cons of refrigerant cooling liquids.

Refrigerants	
Pros	**Cons**
Increase in thermal performance compared to single-phase (lower thermal performance in single-phase)	Environmental - Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) Hydrofluorocarbons (HFCs), Chlorofluorocarbons (CFCs) (saturated), newer Hydrofluoroolefins (HFOs) (unsaturated are better for the environment, but can be flammable, more $, less cooling capacity)
Potential for no and lower pumping power compared to single-phase	Potential loss of liquid under maintenance conditions
Can have lower GWP than dielectric 2-phase liquid	Higher operating pressure than single-phase
Can be inert – nontoxic/ nonflammable/ non electrically conductive	Potential for flow instabilities and maldistribution in micro-channel cold plate using 2-phase
	Specialist knowledge required for commissioning, handling, and maintenance

5.1.1 Wetted Materials

The wetted materials are the materials in direct contact with the cooling liquid. It is critical that material compatibility is established between all wetted materials and the cooling liquid to minimize potential long term risks of corrosion in the cooling loop. Therefore a detailed understanding of all the cooling ingredients and the materials used are essential. Since many of the cooling ingredients can be proprietary, it is good practice to work closely with suppliers of ingredients, cooling liquid, and solutions to ensure all wetted materials are identified and that they are compatible.

For a general overview of commonly occurring wetted materials, see ASHRAE's white paper on water cooled servers – Common designs, components and processes [2]. The ASHRAE list is a snapshot in time and will continue to evolve as new designs and ingredients are introduced. It is important to note that the list is not an endorsement of compatibility for the materials mentioned, and that compatibility still needs to be determined for the particular cooling loop installation.

5.1.2 Filtering

There is strong evidence linking fluid maintenance and quality with system reliability and performance. Filters are used to maintain quality and prevent operational issues arising from contamination from particulates, debris, and bacteria. Particulates are microscopic and are measured in micrometer (μm) requiring filters to match the particulate size expected to be trapped and prevented from circulating within the liquid loop. The filter size is dependent on system design, components and placement. Filters are required to prevent buildup of particulate contaminating the system components, particularly in the case of cold plate liquid cooling, these are related to the fin array width within the micro-channel cold plate, the heat exchanger plate gap width, and the quick disconnects, where particulate contamination can lead to fouling resulting in reduced performance, leaks, or system failure.

The placement of the filter is a consideration for system designers. The filter operation naturally introduces an undesirable pressure drop and good designs are aimed to reduce this pressure drop for increased system efficiency. Designers should put in place consideration for maintenance, planned and unplanned service interventions; with redundancy options to maintain uptime. It is not good practice to take an IT system down for maintenance to the fluid filter. Service and maintenance schedules should be considered based on the liquid type, the liquid loop components within TCS, and the fluid quality requirements.

5.1.3 Commissioning and Maintenance

Plans for commissioning and maintenance are required before deploying liquid cooling systems. The system needs to be implemented according to design and within specification. Proper installation and setup protect the capital investment, and best practice is to utilize qualified commissioning experts with relevant experience in liquid installations within the data center or telecoms environment.

System commissioning can include material compatibility, cooling liquid baseline adherence, design tolerances, operational performance and fault conditions. Examples of commissioning checks can include leveling and seismic protection of fluid flow pipework, ensuring connectors and interfaces can open and close, and that monitoring equipment can report and confirm that sensors are operational. As an example of commissioning process for whole building commissioning to facilities see ASHRAE Guidelines 0-2013 [3].

Regular maintenance schedules are required to maintain uptime and ensure the system is within the baseline specification and includes checks on pipework connections, cooling liquid baseline test, connector test leak detection and sensor operation. The combination of visual inspection and monitoring systems analysis will present the best view for operational teams. It is good practice to consider additional maintenance checks when the system is partially offline or new additions are provisioned. Always seek guidance from the equipment vendor for appropriate specifications and maintenance schedule.

5.1.4 Environmental Considerations

Energy consumption and operating efficiency is a large part of a data center’s overall environmental impact, but there are many more opportunities throughout the data center lifecycle to employ sustainable practices. Data center facilities may consider impact related to materials selection and management, packaging and shipping, serviceability, and end-of-life management.

A comprehensive life cycle assessment (LCA) can be beneficial in evaluating, sustaining and improving the overall environmental impact of a data center facility, as well as specifically within the TCS. Guidance can be found through ISO14040/14044 [4] and related documents. The LCA should include all stages of the product life-cycle, from raw material extraction through decommissioning and end-of-life.

Materials in particular warrant careful consideration not only from a material compatibility perspective, but also from the perspective from management and reduction of hazardous substances, which should be evaluated on an on-going basis. Measures such as flammability, toxicity, exposure limits, and greenhouse gas (GHG) emissions are important.

Coolants are of particular importance when considering environmental impact and sustainability of the liquid cooling system. Globally, fluids are given a closer look and measured against metrics with respect to environmental and personal safety. Impact may be in part measured by referencing global warming potential (GWP), and ozone depletion potential (ODP) of any liquids or gases used. GWP is a relative measure of heat trapped by greenhouse gases. Additionally, ODP is a metric used to indicate the amount of ozone layer degradation. In recent years, more emphasis has been placed on deploying liquid cooling solutions using liquids with lower GWP values, as well as ODP. For legacy cooling systems where coolants with higher GWP are already deployed, consideration should be given to eliminate risk of coolant leakage, and a coolant reclamation program should be in place.

In addition to coolants, materials of construction should be selected to reduce hazardous substances of concern as well. Functional components should be evaluated through a hazard assessment, guidance can be found through referencing regulations such as European Union RoHS Directive and its amendments [5], REACH [6], among others. Typical substances of concern in liquid cooling systems with regard to REACH and RoHS may the presence of lead or hexavalent chromium in metal components, as well as polybrominated plastics. When selecting plastic materials for use in liquid cooling systems, flame retardant materials should be evaluated for the presence of halogenated additives.

5.1.5 Parameters of Importance

The cooling liquids have different thermal properties that are important to consider when evaluating the thermal capabilities of the different liquids. The parameters of importance for thermal evaluation of the liquids are shown in Table 5. These parameters need to be considered in the geographical location and climate where the liquid cooled installation will be located.

Table 5, Parameters and metrics of importance for thermal capability of the liquid coolant.

Parameter	**Metrics**
Thermal conductivity	W/m K
Specific heat	J/g ºC
Latent heat	J/g
Dynamic Viscosity (as a function of temperature)	Pa s

Density (as a function of temperature)	kg/m^3
Freezing point temperature	ºC
Flash point temperature	ºC
Saturation temperature (boiling temperature)	ºC
Saturation pressure	Pa

5.2 Cold Plate Selection

The cold plate selection should depend on the thermal cooling requirements, the operational parameters, and the wetted materials used. It is essential that the wetted materials in the cold plate as well as any other cooling components in the TCS cooling loop are compatible with the wetted materials list for the cooling liquid used. Depending on the temperature requirements of the components in need of cooling, and cooling liquid parameters, such as flow rate, temperature, and heat transfer properties, the cold plate design can be more or less complex. An example of a more complex design is the commonly used micro-channel cold plate, where the micro-channels are used to generate an extended heat transfer surface to increase the cooling performance. On the other hand, an example of a more simplified cold plate design is a block with internal piping. Of course there is an increased cost associated with increased design complexity. If the thermal cooling requirements can be met with a less complex design, it is best practice and most cost efficient to not introduce unnecessary complexity.

5.2.1 Parameters of Importance

There are different parameters to consider when designing a cold plate solution. These parameters are shown in Table 6. Usually a thermal interface material (TIM) is used to enhance the heat transfer properties between the components in need of cooling and the cold plate. This is not discussed here. The physical fit and connection to the internal liquid loop needs to be taken into consideration as well.

There are also parameters of importance for microchannel cold plate designs, where the spacing between fins is an important parameter to determine filtering requirements to avoid fouling.

Table 6, Parameters and metrics of importance for cold plate selection.

Parameter	**Metrics**
Heat transfer performance	W/m^2 ºC or ºC/W
Operating pressure	Pa
Pressure drop	Pa

Flow rate	m^3/s
Liquid inlet temperature	ºC
Liquid outlet temperature	ºC
Height	mm
Active surface area	m^2
Filtering requirement	µm

5.3 Coolant Distribution Unit Selection

The coolant distribution unit (CDU) is a dedicated component that facilities heat transfer and removal between dedicated liquid loops. The CDU components could include sets of interfaces, pumps, liquid-to-liquid heat exchangers, reservoir tanks, valves, controls, monitoring and sensors; for power, flow, and temperature measurement. The variety of components utilized within the CDU require the materials to be validated through material compatibility to the cooling liquid used. The size and form factor of a CDU can range from in-rack to row level depending on the deployment requirements primarily determined by the cooling requirement.

The CDU isolates the TCS from the FWS providing a connection between TCS and FWS liquid loops and a means to control the heat transfer between the FWS and the TCS for row level CDU or in the case of in-rack CDU within the TCS closed liquid cooling loop. The CDU also maintains pressure, flow, temperature, dew point control, cleanliness, and leak detection. By separating the FWS and the TCS with a CDU, this limits the impact of potential leaks (less liquid volume in the TCS loop, lower pressure, and flow rates). In terms of optimization, CDUs provide thermal control for the cooling liquid providing operators with the means to maintain a balance between the IT equipment; thermal requirements, compute load variables and power optimization.

The number of racks serviced by CDUs can scale from single cabinets to groups or clusters of combined racks. The liquid will be distributed via dedicated pipework with connection points to plumb in each rack. Sizing and control settings of the CDU depends on the heat load generated by the IT equipment as an aggregation of the combined electronics power level. Individual power levels vary by component, and sizing of the heat load is required considering thermal margin for future technology implementations. The coolant liquid properties and characteristics such as thermal conductivity, viscosity, specific heat and density will influence the performance of the cooling capacity and pump power.

5.3.1 Parameters of Importance

There are different parameters of importance when evaluating different CDU options. Some of these parameters are described in Table 7. An additional parameter that should be considered for all liquid cooling components is material compatibility between the wetted materials and the cooling liquid. It is important to work with the CDU provider to identify all the wetted materials used to ensure material compatibility.

Table 7, Parameters and metrics of importance for CDU selection.

Parameter	Metrics
Maximum cooling capacity	kW
Total liquid volume	m^3
Approach temperature	ºC Definition as used in ASHRAE (TCS supply temp – facility liquid supply temp)
Exhaust temperature	ºC
Acoustic sound power or sound pressure	BA or dBA
Pump capacity	l/min
Pressure Flowrate (PQ) curve	Pa & l/min
Power draw and variable load capabilities	kVA at specific Voltage and add variable load metrics eg. 100%, 80%, 30%
Physical dimensions: · Height · Width · Depth	 mm or U inches mm
Weight	kg (empty or filled)
FWS liquid connector style and dimension	inches (eg. Blind mate, hand mate, threaded)
TCS liquid connector style and dimension	inches (eg. Blind mate, hand mate, threaded)

5.4 Rack Manifold Selection

The manifold is a key component in the TCS to distribute cooling liquid within the rack to and from the IT equipment. In liquid cooling deployments where an in-rack CDU is used, the manifold could also provide the supply and return of liquid between the IT equipment and the in-rack CDU. The characteristics of a manifold structure are to host a series of couplings that are distributed along the manifold for connection to the IT equipment liquid loops. There are various coupling types; blind mate, hand mate, screw type in a variety of diameters (see the quick disconnect coupling selection, Chapter 5.5). The coupling diameters and manifold dimensions are chosen to support the current and future requirements for flow rate and operational performance required for the liquid path to support the topology and the number of cold plates within the IT equipment. The manifold location is desired to be within the rack footprint for efficient use of white space real estate.

The location of the manifold within the rack is usually in the rear (as shown in Figure 1); however, it can be in the front or side depending on IT equipment and power distribution design. The manifold location is chosen to ensure serviceability access to liquid couplings, power interfaces, networking and other I/O requirements including cable and hose management for the operation of the IT equipment. The IT equipment slides in from the front of the rack; manifolds are designed to allow for unrestricted insertion and removal of the IT equipment. The manifold provides a central point of connection to the TCS liquid loop, layouts of the liquid loop can vary (this is not discussed here) and connection to the cooling liquid supply can be at the foot or the rack header. The connection to the TCS includes high-pressure hoses and couplings that can maintain pressure limits of TCS and burst pressure of the couplings (see the pressure safety requirements, Chapter 6.2). The manifolds have limited working parts, aside from liquid couplings, with service life expectancy to support the typical data center life of 10-20 years. The ability to service, maintain, and potentially upgrade the manifold could be required. Access to the manifold for integration and commissioning and lifetime serviceability is to be considered. Careful consideration should be given to design and selection of a manifold that maintains the pressure drop requirements of the TCS liquid loop and the IT equipment. Also considerations for fluid velocity should be made to not exceed maximum velocities (ranging between 1.5 m/s to 2.1 m/s) for different pipe diameters to avoid erosion issues as specified by ASHRAE [7].

5.4.1 Parameters of Importance

There are different parameters to consider when evaluating different rack manifold designs. Some of these parameters are shown in Figure 8.

Table 8, Parameters and metrics of importance for manifold selection.

Parameter	**Metrics**
Total liquid volume	m^3
Internal diameter or dimension	mm or inches (mm x mm or inches x inches)
Coupling insertion diameter	Inches/mm

Physical dimensions: · Height · Width · Depth	 mm or U inches mm
Manifold rack extrusion	None (in-rack) or Extrusion (location and m^2)
FWS liquid connector style and dimension	inches (eg. Blind mate, hand mate, threaded)
TCS liquid connector style and dimension	inches (eg. Blind mate, hand mate, threaded)
TCS connection location	Foot of rack or top of rack
Operating pressure	Pa
Liquid Velocity	m/s

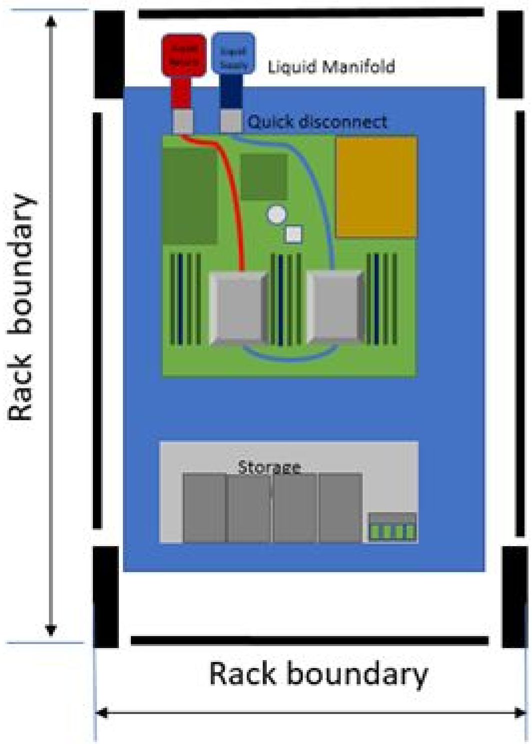

Figure 1, An example of rack manifold solution shown in an aerial view, where the figure shows the rear mounted manifold inside of the rack boundary/foot print.

5.5 Quick Disconnect Coupling Selection

Within the TCS, quick-disconnect couplings serve as a critical component to overall system performance and reliability, while also facilitating serviceability and modularity of the IT equipment. Quick disconnect coupling sets may be symmetrical or utilize a male/female configuration (plug/socket, insert/body, etc). A shutoff valve to seal off fluid flow during disconnection is typically integrated into the coupling to protect surrounding equipment, as well as to limit the amount of cooling fluid lost on each disconnection. Quick-disconnects with minimal fluid spillage are recommended and are often referred to as drip-less, non-spill, or flush face.

Activation of the shutoff feature is driven manually by the operator for hand mate couplings, or automatically through blind mate via insertion or removal of the IT equipment in the rack. In systems employing hand mated connectors, consideration should be given to ergonomics (e.g. latching mechanism, force to connect, space constraints) to ensure easy serviceability. Blind mate couplings generally require additional allowance for tolerancing and misalignment. The wetted interface of the quick disconnect to TCS components (rack manifold, CDU, flexible hose, etc) may be achieved in a variety of ways. For flexible hose connections, barbed or compression style terminations offer a simple and reliable joining method. For more rigid connections, such as to a rack manifold assembly, a threaded termination is common. O-ring boss fittings such as SAEJ 1926 [8] or G/BSPP ISO 1179 [9] can provide a robust and reliable joint, while still promoting ease of installation and fabrication.

5.5.1 Parameters of Importance

Parameters for consideration when specifying couplings for liquid cooled cold plate systems can be found in Table 9. Please note that operating and burst pressures are different. Operating may be defined as the maximum system pressure during normal service conditions. Burst pressure is indicative of the minimum pressure at which the component will fail catastrophically.

Table 9, Parameters and metrics of importance for quick disconnect selection.

Parameter	**Metrics**
Flow Rate	L/min, gpm
Flow Coefficient	Kv, Cv
Operating Pressure	Pa, psi
Burst Pressure	Pa, psi
Pressure drop	Pa
Spillage (liquid expunction)	mL, cc
Inclusion (air introduction)	mL, cc
Temperature – Operating, Storage / Shipping	°C, °F
Connection Force	N, lbf
Connection Cycles	Mechanical cycles / connect and disconnect
QD style and hydraulic diameter	Inches (eg. Blind mate, hand mate, threaded, mounting configuration)
Terminations	Barbed, compression style, threaded

5.6 Pump Selection

Pumps are the heart of the system providing liquid flow to vital components. Pump selection is arguably the most important aspect of the system which needs to be considered in the early stages of any liquid cooled solutions. Pumps are available in a multitude of form factors with designs and manufactured material used to match the liquid type and pump location. Design considerations for redundancy for the purposes of maintenance and failover mitigation can result in dual pump configurations either inline or in parallel. Connections to pipework should consider spatial constraints, layout, dimensions, material compatibility, and connection type. Pumps are driven by motors of various types, which needs to be part of the considerations when evaluating or optimizing the installation for energy efficiency.

Location of pumps determines the constraints and selection criteria. Pumps located within the TCS vary significantly compared to in-rack or in IT equipment. Specifically, where pumps are used within the IT equipment, conformity to the chassis height, determined as “U” height, plays a major factor of selection. Space is at a premium within the IT equipment and integration of a pump forms part of the overall IT equipment layout within the server chassis. IT equipment vendors developing liquid cooled solutions where liquid flow is managed within chassis consider designs to match the thermal load of the components. For this purpose, pumps can be directly attached inline to the cold plate or separated to provide an assisted flow.

As with good system design, consideration for pressure drop and efficiency should be considered by the designers. In addition, considerations dealing with the cooling liquid itself should include compatibility with pump internal materials, and filters, which are considered good practice due to the potential for particulates to clog the pump and reduce efficiency, even leading to failure. The liquid characteristics include viscosity where changes in viscosity will alter efficiency and pump life. Pumps inadequately selected are potential risks for reduced operable life. Another consideration is the operating environment including ambient and operating temperatures of the liquid, which will determine component materials used within the pumps, since the cooling liquid will come into direct contact with the pump internals.

The pump requirements will depend on the pipework layout/design, where parameters such as length of pipes, quality of bends, and material selection can cause friction and turbulence leading to an increased pressure drop. These parameters together with head pressure losses and vertical height differences need to be included and considered in the pump requirements.

5.6.1 Parameters of Importance

Parameters for consideration when selecting pumps for liquid cooled solutions are shown in Table 10.

Table 10, Parameters and metrics of importance for pump selection.

Parameter	**Metrics**
Minimum Flow Rate	l/min, gpm
Maximum Flow Rate	l/min, gpm
Pump capacity	l/min

Filter	Type, # Micron eg Mesh 50 Micron
Maximum and minimum suction height	mm
Tension	V, eg 110-230 V
Frequency	MHz
Total Liquid Volume	m^3
Power	W
Weight	g or kg
Operating Temperature	ºC
Acoustic sound power or sound pressure	BA or dBA
Listing of materials in contact with liquid	Eg, valves, O-ring, springs, piston, connectors
Power draw and variable load capabilities	kW or kVA at specific Voltage and add variable load metrics eg. 100%, 80%, 30%
Physical dimensions: · Height · Width · Depth	 mm mm mm
Mean Time Between Failure (MTBF)	h
IP Rating	Eg, IP 66,
Pressure Flowrate (PQ) curve	Pa & l/min

6. Liquid Cooling Requirements

6.1 Certification Markings

Each liquid cooled technology needs to comply with all certification regulations, which are valid for the geographic location where the liquid cooled system is used. Different regions have different requirements.

- UL and FCC markings in the US
- CE certification in Europe
- Countries might have their own additional requirements that need to be adhered to

Examples of certification marks for different regions can be found here: https://en.wikipedia.org/wiki/Certification_mark.

6.2 Pressure Safety Requirements

The liquid cooled installation and its parts need to comply with local codes. Some of the standards to be aware of are the safety standards from the International Electrotechnical Commission (IEC) for IT equipment are IEC 60950-1 [10] and IEC 62368-1 [11].

- The IEC 60950-1 “Information Technology Equipment – Safety – Part 1: General Requirements” is an earlier standard, which is prescriptive in nature. For the EU and the US, this standard is outgoing and is expected to be withdrawn on December 20, 2020 in favor of the IEC 62368-1 standard.
- The IEC 62368-1 “Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements” 3rd edition (2018) is the new safety standard.

It should also be noted that ASME B31.n series, and specifically B31.3 “Process Piping” (2018) [12] contains requirements for interconnecting piping. Another thing to note is that the IEC 62368-1 standard is requiring leak tests at 3x under normal operating pressure and 2x under abnormal and single fault conditions, while the ASME B31.3 requires leak test at the 1.5x design pressure. The liquid cooling loop and its ingredients must be tested to the highest pressure of the safety standards mentioned above. Typical operating pressure for the TCS loop is usually in the range of 140 - 450 kPa (i.e. 20 – 65 psi) when using in-rack and row level CDUs, while the facility CDU might provide a higher pressure.

6.3 Risk Management

It is required to follow local regulations and to have a detailed risk assessment and processes in place before installing liquid cooling in Data Centers. It is recommended for the risk assessment to include a leakage mitigation plan, including designs for reduced leakage risk, leakage detection, leakage intervention, spill/leak management and containment strategy, and strategy for pump failures. A few examples of this are:

- Determine service and maintenance requirements of the cooling liquid and hardware before deployment of liquid cooled racks
- Determine redundancy requirements of cooling solution

- Cooling fluid material safety data sheet (MSDS) and Technical Data Sheet (TDS) availability for anyone working in the data center
- Sufficient spill management and absorption materials must be present to manage a catastrophic spill
- Appropriate disposal procedures in place for spill/leak management and/or replacement of cooling liquid
- Liquid containment strategy, which complies with local regulations
- Two-phase and other highly evaporative liquid implementations should prevent any gas leakage into the atmosphere
- Full health and safety documentation must be present
- Full action plan for liquid cooling loop and IT equipment if leakage detected

6.4 Liquid Cooling Classifications

There are four different liquid cooling classifications for the IT equipment and two classifications for the liquid cooled ready rack with embedded manifold. The classifications are:

IT Equipment

- **Hybrid basic:** IT Equipment with Central Processing Unit (CPU)/Graphics Processing Unit (GPU) cold plates (with or without VR cold plates)
- **Hybrid intermediate:** IT Equipment with CPU/GPU & Dual In-line Memory Module (DIMM) cold plates
- **Hybrid advanced:** IT Equipment with CPU/GPU & DIMMs & additional (specify) cold plates
- **Full Liquid:** IT Equipment Cooling with Full liquid cooling

Liquid Cooled Rack

- **Liquid cooled ready rack without door heat exchanger (DHX)**
- **Liquid cooled ready rack with door heat exchanger (DHX)**

6.4.1 IT Equipment Classifications

The **Hybrid Basic** cooling uses cold plate cooling for the high power compute components, such as CPU/GPU, and air cooling for all other components on the IT equipment in need of cooling. The IT equipment contains components such as CPUs, GPUS, networking components, memory modules, voltage regulators, storage devices, Field Programmable Gate Arrays (FPGAs), integrated circuits and capacitors each generating heat. These components draw power to operate, which in turn generates heat, which varies by component type with the highest proportion of heat originating from CPUs and GPUs. A liquid cooling approach is to ensure that these higher heat generating components are efficiently cooled using liquid cooling cold plates. The rest of the IT equipment components are cooled using air cooling. Often air cooled IT equipment designs are redesigned to liquid cooling, where the air cooled heat sinks are replaced by cold plates. The amount of heat going to the cooling liquid depends on the component power levels and IT equipment design, but it is not uncommon that the CPU/GPU cold plates captures 70-75% of the IT equipment heat. This basic hybrid classification also encompasses solutions that use cold plates for the CPU/GPU Voltage Regulators (VRs), since many times the CPU/GPU cold plates can easily be extended to also cool the closely placed VRs.

The **Hybrid Intermediate** is an extension of the basic classification, where cold plates are used for CPU/GPU, with the extension of cold plates to the DIMM (Dynamic Random Access Memory, DRAM) modules. The liquid cooling cold plates transfer the heat through conduction to the liquid. This is still a hybrid liquid cooling, since air cooling is used to cool all other lower power components. Increases in memory module density on the DIMMs, reduction in DIMM pitch, and proximity to other high heat sources produce cooling challenges, and by being able to direct cooling to critical components within the IT equipment improves overall cooling effectiveness. The added benefit of capturing high heat loads to the liquid cooling loop significantly lowers fan speed to cool the rest of the low power components, since the components with the most stringent temperature cooling requirements are now liquid cooled.

The **Hybrid Advanced** is an extension to the Hybrid Intermediate classification. In the hybrid advanced, cold plates are used for CPU/GPU/DIMMs and other components. For a complete understanding of this classification, the designer needs to provide the information of what additional components are liquid cooled using cold plates.

The **Full Liquid** cooling classification is full liquid cooling of the IT equipment, which increases the percentage of components cooled by directly attached cold plates close to 100%, and in these systems, several cold plates are used to transfer heat from the CPU/GPU, Memory, Voltage regulators, Storage devices, Accelerators/FPGAs and networking components. Many of the components on the IT equipment will have a cold plate or part of a cold plate attached for direct thermal path to the liquid. The remaining thermal load is typically from the integrated circuits and capacitors on the mainboard. These components are cooled by radiation or by the closest liquid cooled path. It is therefore important for the designer to note that the thermal load on some of the components will significantly increase due to the added load by close components [13].

6.4.2 Liquid Cooled Rack Classifications

The **liquid cooled ready rack without DHX** rejects heat through air to the room. The amount of heat rejected depends on the total heat generated within the rack, the amount of heat captured by the cooling liquid depending on the IT equipment classification, and the amount transferred by the air. The heat from the air is rejected to the room, and the data center designer needs to know the thermal demand on the room to ensure cooling requirements can be met.

The **liquid cooled ready rack with DHX** has the capability of capturing all the heat from all the equipment in the rack, resulting in a room neutral environment. This is when no heat is rejected to the room and all heat is captured by the liquid (except for unintentional heat losses). This rack classification can use different level of IT equipment cold plate classifications. The heat captured by the air is then picked up by the DHX, where the DHX should be sized after the cooling need. Achieving near 100% heat capture can be beneficial, when no additional air cooling can be provided in the room or heat reuse is required. The thermal demand on the room is negligible with some ambient air cooling required only for radiated thermal losses from the rack. If not all the heat or excess heat is captured by the DHX, the designer should give the information on the amount of heat transferred to the room.

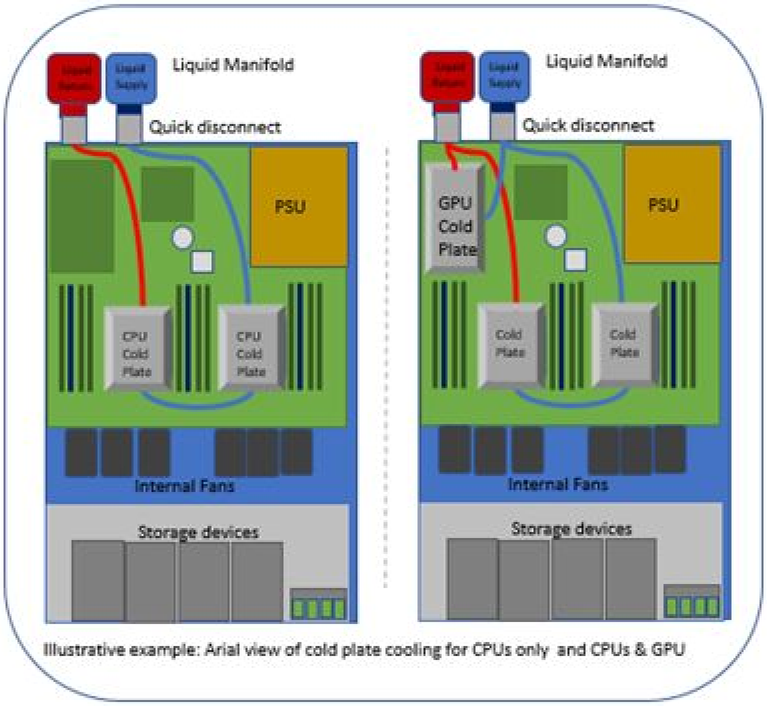

Figure 2, Example designs of hybrid basic IT equipment.

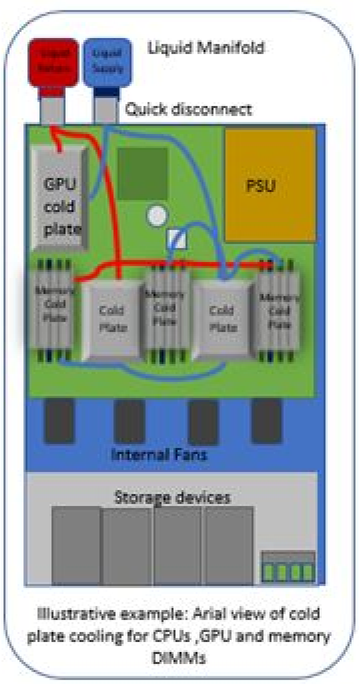

Figure 3, Example design of hybrid intermediate IT equipment.

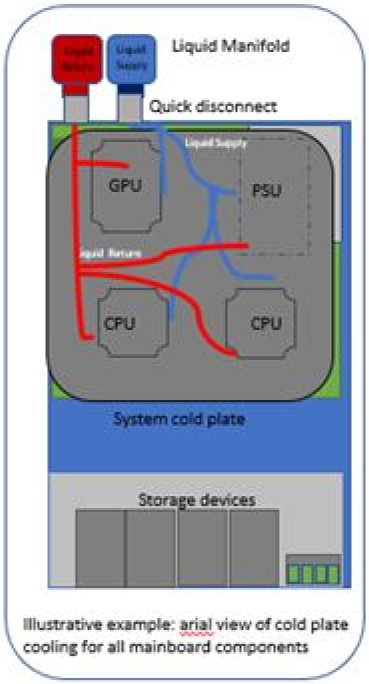

Figure 4, Example of full liquid cooling IT equipment design.

6.5 Sensor Requirements

In order to control fluid flow and maintain safe operation of a liquid cooled system, critical sensors are required in specific locations. These sensors are needed to monitor and control flow, pressure, and temperature. In addition, having access to a comprehensive set of sensors will allow for adherence to proper maintenance protocols as well as provide for critical alarming on failure events. The table below lists the sensors to be considered within the system, chassis, rack, and CDU. ASHRAE TC9.9 Datacom book 14 [14] establishes a comprehensive list of all critical sensors within the system. According to ASHRAE's definition, a system is the top-level management plane, which includes all chassis elements (f.ex. servers, storage, and network switches) and could include the CDU and other rack elements. An example of this is a rack containing several chassis of different types, but controlled with one top level manager, which thereby achieves one cohesive system (i.e. rack). A chassis is defined as the physical elements within the system. An example of this is a stand-alone 1U server, which has its own chassis management control. A subset of the ASHRAE sensor list, i.e. the sensors used by the liquid cooling system, is shown in the table below.

The DCIM compliance in [14] is divided into three different categories: Tier 1, Tier 2, and Tier 3. Tier 1 represent a basic set of telemetry/sensors, which does not include any liquid cooling sensors. Tier 2 includes a more comprehensive set of telemetry/sensors with some liquid cooling sensors, while Tier 3 represents the most comprehensive set of telemetry/sensors with additional liquid cooling sensors compared to Tier 2. The two different requirements represented here are aligned with these categories in [14]. The minimum sensor requirements for liquid cooling are aligned with Tier 2, while the advanced sensor requirements are aligned with Tier 3 as described below.

- **Minimum sensor requirement** – Tier 2 as defined in [14], which includes system liquid inlet temperature and max allowable system liquid inlet temperature.
- **Advanced sensor requirement** – Tier 3 as defined in [14], which includes the Tier 2 sensors and also system adjusted liquid inlet temperature and system liquid outlet.

Table 11, Critical Liquid Cooling Sensors.

	System Level*	**Chassis Component Level***	**Other System Level***	**CDU**
Thermal	System air inlet temp	CPU temp	System environmental class	Liquid supply temp
	Bulk air delta T	CPU temp max	System volumetric liquid flow rate	Liquid return temp
	Bulk air outlet	Memory temp	System adjusted volumetric liquid flow minimum	Volumetric liquid flow rate
	System liquid inlet temp	GPU temp	System Liquid supply pressure	Liquid supply pressure
	System liquid outlet temp	FPGA temp	System liquid return pressure	Liquid return pressure
	System liquid inlet temp max allowable	Accelerator temp		
	System adjusted liquid inlet temp max allowable	High-power ASIC temp		
Power	System input power	CPU power		Input power

	Chassis input power	GPU power		
	System cooling subsystem power	FPGA power		
		Accelerator power		
		High-power ASIC power		

* Sensors from ASHRAE DCIM Datacom Book #14.

6.5.1 DMTF Redfish

The Redfish forum, within the DMTF (Distributed Management Task Force) [15] standards body, is a forum that drives industry standard protocols using a RESTful interface for purposes of managing IT equipment. As part of this organization's work efforts, IT telemetry was adopted in partnership with ASHRAE TC9.9 and since released. The RESTful interface is based on representational state transfer (REST) technology, an architectural style and approach to communications often used in web services development. DMTF Redfish schema mapping can be found in Appendix A of "Advancing DCIM with IT Equipment Integration" Datacom Handbook [14].

6.6 Leakage Detection and Intervention Requirements

The main approach to leak mitigation should be a robust leak prevention design strategy. However, a detailed spill and leak management plan is still of importance when installing a liquid cooled solution. The management plan should include both leak detection and intervention. It is important to note that the plan should meet the data center requirements.

In the TCS cooling loop, the detection can be done at different locations. Indirect methods of detection may be applied via monitoring and analysis of existing hardware and sensors. Some examples are at the CDU, rack, chassis, QD couplings and/or compute node. If the CDU can detect small pressure drops and/or changes in flow rates, it might be used as an efficient leak detection device. Direct methods deploy dedicated leak detection hardware located in high risk areas. Typical direct method devices may be found as spot detectors, or wires, which register leakage when coming in contact with a conductive liquid. For reliability detection, the sensor(s) should be positioned in areas where cooling liquid will pool up in an event of leakage. Often sensors are placed under the rack and/or under the facility floor to detect potential leaks from the rack and/or in the delivery of the cooling liquid. Since the compute node is often the most expensive component of the IT equipment, there might be a requirement to detect potential leaks in close proximity to the compute node. It is important to note that with an increase of sensors to determine the location of the leak there is also an increase in cost. The cost benefit analysis needs to weigh the cost of additional sensors against the need of meeting specific requirements such as uptime.

There are also different intervention options to consider. The lowest level of intervention is manual intervention when a notification is sent out to the facility personnel that a leak has been detected. The next level can be automatic electrical intervention, when a notification is sent of a leak event and an automatic electrical de-energization is done of the IT equipment. This can save the hardware that gets exposed to the leak/cooling liquid, and recommissioning has to address how to deal with the wet but saved equipment. A more sophisticated approach is the automatic electrical and fluid intervention. This is when a leak notification is detected, the IT equipment is being de-energized, and the cooling liquid is shut-off. This can save extensive hardware exposure to leakage, which can simplify the recommissioning of the exposed IT equipment. The reduced risk with having automatic intervention solutions comes with a cost, which again needs to weigh against the requirement of the installation.

Leak detection classifications

- **Indirect:** using existing pressure, flow, and temperature sensors and algorithms to determine leaks
- **Direct:** using leak rope/cable detection as the sensor at a specific location (as defined above)

Leak intervention classifications

- **Manual:** using manual intervention after leak detected f.ex closing flow control valves and shutting down IT equipment
- **Automatic:** using automatic intervention approach after leak detected f.ex de-energized IT equipment and/or cooling liquid shut-off

6.7 Comparison Metrics

The following classifications and metrics can be used to compare different liquid cooling installations with each other.

Table 12, Comparison Metrics.

Classification	**Metrics**
IT equipment width	19’’ or 21’’
Rack width	# inches or mm (24’’/600 mm) or custom
Rack height	# U
Rack depth	# m (1.1 and 1.2 m) or custom
Rack service area - Back	# m x # m
Rack service area - Front	# m x # m
Wall Power/rack	# kW/rack
IT equipment chassis height (i.e. server, blade)	U (1U, 2U, any U, custom)

Fully loaded rack weight (i.e. rack with IT equipment and cooling liquid)	# kg
Manifold location	Front, Back
Manifold connector type	Manual connect, Blind mate
Cooling liquid	Water with additives, Glycol based, Dielectric, Refrigerants
Rack cooling classification	With or without door heat exchanger
IT equipment cooling classification	Basic hybrid, intermediate hybrid, advanced hybrid, full liquid
Cooling type	Single-phase, Two-phase
Maximum TCS cooling liquid supply temperature to racks	# ºC Can be based on the facility cooling liquid max temperature according to ASHRAE's definitions (W1: 17 ºC, W2: 27 ºC, W3: 32 ºC, W4: 45 ºC, W5 > 45 ºC) + temperature rise over the CDU
Maximum TCS cooling liquid return temperature from racks	# ºC
Coolant Distribution Unit (CDU)	In-rack, Row, Facility (and dimensions of the CDU)
Number of Racks/CDUs	#
Maximum CDU approach temperature	# ºC Definition as used in ASHRAE (TCS supply temp – facility liquid supply temp)
CDU Power	# W

Total cooling subsystem (fan/pump) power/rack	# W
Total power subsystem losses/rack	# W
Total power into the compute components*	# W (including CPUs, GPUs, Memory, Storage, Networking)
Maximum allowable pressure on TCS side	# Pa
Maximum allowable pressure on facility side	# Pa
Maximum pressure drop on TCS side	# Pa
Maximum pressure drop on facility cooling liquid side	# Pa
Maximum CDU TCS flow rate	# l/s
Maximum CDU facility cooling liquid flow rate	# l/s
Maximum operating temperature on FWS side	# °C
Leak Detection	Indirect/Direct
Leak Mitigation	Manual/Automatic

*https://docs.google.com/viewer?a=v&pid=sites&srcid=bGJsLmdvdnxlZWhwY3dnfGd4OjM4ZmNhZjk4YjNlZjUwYTk

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8. About Open Compute Project

The Open Compute Project Foundation is a 501(c)(6) organization which was founded in 2011 by Facebook, Intel, and Rackspace. Our mission is to apply the benefits of open source to hardware and rapidly increase the pace of innovation in, near and around the data center and beyond. The Open Compute Project (OCP) is a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure. For more information about OCP, please visit us at http://www.opencompute.org