GUIDELINES FOR IMPLEMENTING PASSIVE TECHNOLOGY COOLING SYSTEMS USING LOOP HEAT PIPE TECHNOLOGY.

Revision 1.0

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Executive Summary

The rapid expansion of data centers has created an urgent need for energy-efficient cooling solutions. This document introduces the guidelines for implementing passive technology cooling systems (TCS) using Loop Heat Pipe (LHP) technology, a cutting-edge innovation that dramatically reduces energy consumption by eliminating the need for pumps within the TCS.

By leveraging the natural principles of fluid vaporization, passive TCS systems offer a low-maintenance, highly reliable solution for data centers, making them ideal for both new installations and retrofitting existing infrastructures. As the demand for sustainable cooling technologies grows, LHP systems can significantly decrease the carbon footprint of data centers while maintaining operational reliability due to their inherently passive nature.

The Open Compute Project (OCP), an initiative promoting open-source solutions for hyperscale data center operators, telecoms, and enterprise IT users, provides a platform for collaborative innovation. The deployment of LHP technology aligns with OCP's mission of driving efficiency, sustainability, and innovation in data center operations by offering an alternative to more energy-intensive cooling methods like water and immersion cooling.

This document serves as a comprehensive guide for data center operators and engineers, covering essential components such as evaporators, quick disconnects, manifolds, heat rejection and the selection of cooling fluids. By following these guidelines, data centers can achieve enhanced performance, reduced energy consumption, and lower environmental impact, all while maintaining the robust reliability required for critical operations.

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1. Introduction

e used in an Open Compute Project (OCP) environment. This is in contrast to an active (pumped) TCS. Passive TCS do not require any power to operate the TCS and typically rely on carefully managed fluid vaporization to create pressure differences that transport and exchange heat with the FWS. Today, the main passive technology used for rack-scale IT cooling is two-phase loop heat pipes (LHP). It should be noted that passive TCS systems using Loop Heat Pipes have huge potential to further reduce the energy consumption of the TCS as by nature they are inherently passive, with no additional pumps. With the growing demand for data center expansion, implementation of these technologies in both new and retro-fit scenarios could further reduce future greenhouse gas emissions.

For ease of understanding, this document follows a similar structure to the Cold Plate Cooling Loop Requirements Rev. 2 [1] document. This document outlines the requirements for an active TCS. Due to the less mature nature of passive TCS this guidelines document has been prepared in advance of these systems being included in the next revision of the requirements documents for cold plate TCS.

This document is applicable to Technology Cooling System (TCS) fluid loop(s). The document assumes that the heat from the TCS loop is transferred to the facility cooling loop, which is called the Facility Water System (FWS). FWS is not covered in this document, and it should be noted that they do require pumps to operate. This document does not apply to the IT equipment being cooled or fully air-cooled specifications, but solely to the TCS loop and its subset of systems and components.These guidelines explain how to implement a passive technology cooling system (TCS) which may b

[1] https://www.opencompute.org/documents/cold-plate-cooling-loop-requirements-rev-2-pdf

2. Technology Definitions

The terminology used in the Data Center is the same as used by ASHRAE[2] when discussing cooling solutions. The terminologies are defined below:

- **TCS, Technology Cooling System**, is the part of the facility cooling system from the facility indoor area to the rack, through the manifold and IT equipment (ITE), and back to the manifold and indoor area.
- **FWS, Facilities Water System**, is the facility cooling system

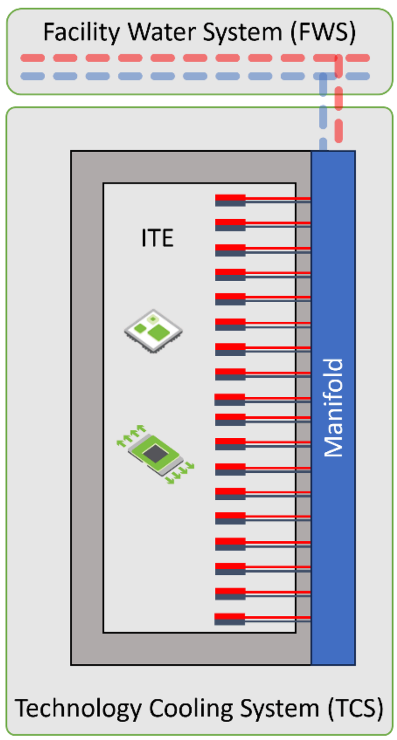

Figure 1: Basic system graphic, with FWS and TCS

2.1. Evaporator

Evaporators are a form of cold plate where liquid is vaporized, but they still provide the same function of dissipating heat. Evaporators can include features such as micro-channels or porous wick structures and can employ different boiling methods (flow, pool and spray). The purpose of

[2] ASHRAE, Liquid Cooling Guidelines for Datacom Equipment Centers, Atlanta, 2014

these design choices is almost always to maximize the thermal performance of the cold plate to enable their usage in high-power applications.

2.2. Condenser

A condenser is a form of heat exchanger that is used to condense vapor into a liquid. To achieve this they will use a temperature difference between the fluid and the ambient temperature of typically air or water that will cool the fluid by conduction through the walls of the heat exchanger. Occasionally features such as grooved tubes are used to increase the surface area of exchange inside a condenser.

2.3. Rack Manifold

The rack manifold connects the cooling system between each server to the condenser. For passive systems there are two types of rack manifold outlined below.

Dry Quick Disconnect Manifold (Closed Loop)

This type of rack manifold uses conduction (metal to metal) connection that can be provided with a hand-mate or blind-mate connection. The heat is rejected directly into the FWS as the manifold transports the liquid from the FWS across the rack.

Wet Quick Disconnect Manifold (Open Loop)

This type of rack manifold connects the vapor and liquid lines from each server to a core loop. The core loop transports the heat to the top of the manifold where the fluid enters a heat exchanger that dissipates the heat into the FWS. The heat exchanger can either be integrated into the manifold, be placed above the rack, or placed in the top of a rack (similar to a CDU).

2.4. Loop Heat Pipe (LHP)

A loop heat pipe is a passive two-phase thermal management technology that has the ability to transport heat over longer distances than a traditional heat pipe. It features a separate evaporator and condenser that are connected with smooth lines (no wick structure inside). Unlike a traditional heat pipe the wick structure is concentrated solely inside the evaporator. This wick structure generates a capillary pumping force that drives fluid around the system passively and enables this technology to be used for rack level data center systems.

For an LHP to be functional the capillary pumping pressure created by the porous media must be greater than the pressure drop caused by the lines (length/bends) and any affect of gravity on the system. Usually the systems use height to boost the performance of the system by using gravity to assist with the liquid return.

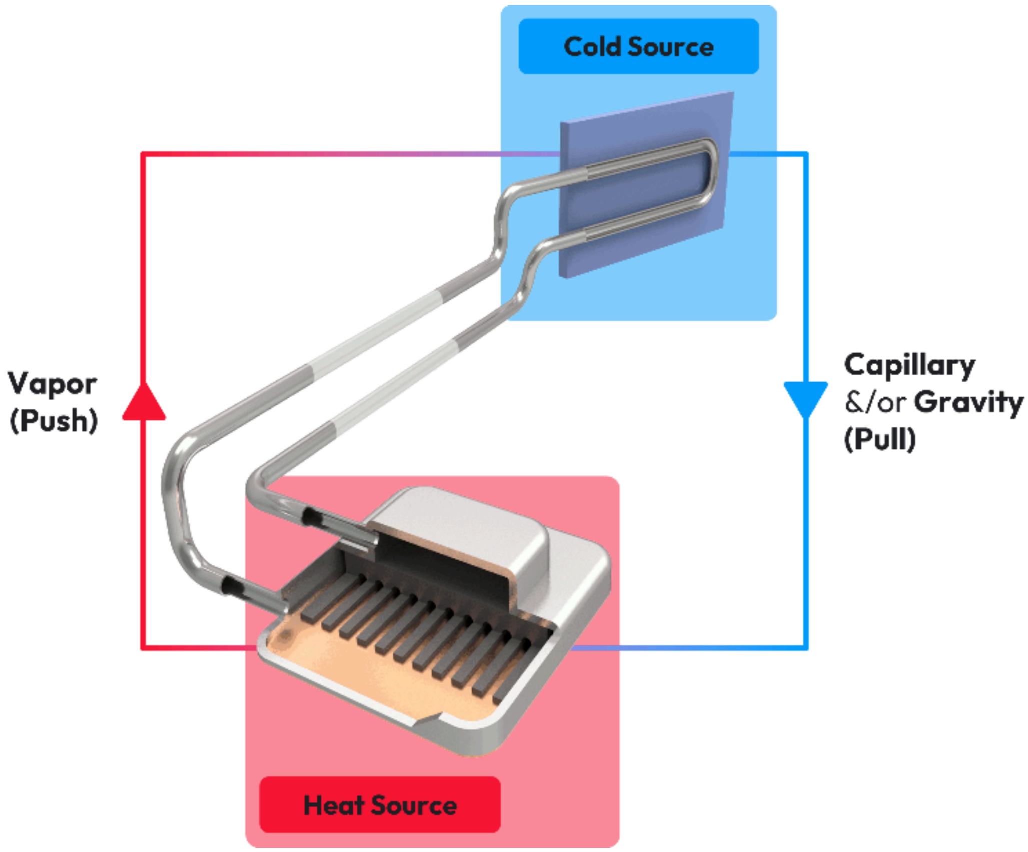

Figure 2: LHP Operating Diagram[3]

2.5. Other definitions

There are many other definitions that relate to cold plate cooling that are not listed here. If you wish to read further definitions the please refer to page 9 of this document[4].

3. Fluid Selection

A range of fluids can be used inside passive TCS including but not limited to water, refrigerants, methanol, acetone, freon and ammonia. In general fluids with lower boiling points are used in two-phase systems. The selection of the cooling liquid should not be made lightly and should take into consideration operational need, material compatibility with the wetted materials in all

[3] https://www.calyos-tm.com/technologies/loop-heat-pipes
[4] https://www.opencompute.org/documents/cold-plate-cooling-loop-requirements-rev-2-pdf

cooling components, IT equipment serviceability, cooling liquid maintenance need, life expectancy, and liquid cost to mention a few. There are different pros and cons for each cooling liquid and the high-level details are discussed below and also summarized in Table 1.

The exact system architecture should also be considered in relation to the fluid loop. If a closed-loop dry quick disconnect system is employed the loop is completely sealed and therefore the risk of fluid leakage is dramatically reduced. In contrast, open-loop wet quick disconnect systems have wet connections that create a potential point for fluid leakage and therefore safety, dielectric and environmental properties should be considered more important.

In dry quick disconnect (closed loop) systems there is no need to monitor the fluid volume inside as there is no reason for it to change unless the device is physically damaged. For wet quick disconnect (open loop) systems a reservoir is included in the system in order to account for small fluid losses caused by the quick disconnectors, the reservoir can be sized or refilled based on the desired lifetime of the solution.

In the event of mechanical damage, if the system is not operational (not attached to a processor) then the liquid will remain in the wick structure and has an extremely low risk of being released. If the system is operational then there is a risk of vapor being released as the fluid will be moving around the system. It should be noted that mechanical damage during operation in a data center is extremely rare, in comparison with transportation and installation phases where mechanical damage is more likely. In these situations, the device will not be operating and therefore have an extremely low risk of fluid leakage.

3.1. Water Based Fluids

Water has very good heat transfer properties, however if it is exposed to air it can easily cause corrosion and bacterial growth, two things that should be avoided. Another property of water is its freezing point at 0C, this can cause issues particularly during shipping and storage. Additives can be added to change the freezing point and to prevent or limit corrosion and bacterial growth but additives impact the heat transfer performance of the fluid, therefore in the majority of passive systems other fluids are used.

3.2. Refrigerants

Refrigerants are widely available due to their use in refrigeration and HVAC systems and similar properties are relevant in loop heat pipe systems. While their thermal properties are often not as good as other fluids, other properties have led to their widespread use. These properties can include dielectric, non-flammable, non-toxic, and varying global warming potential (GWP). It should be noted that some refrigerants are subject to an ongoing review by the European Commission[5] as to the usage of different types of refrigerants (HFOs, PFAs, HFCs, et cetera). As of November 2024 there is currently no information on the outcome of this review and therefore no information has been provided here. An example of a common refrigerant used in LHP systems is R1233zd(E).

3.3. Ammonia

Ammonia is an applicable fluid for Loop Heat Pipe systems and is typically used in small quantities (1-2 ml). Liquid ammonia has a very high standard enthalpy change of vaporization (23.35 kJ/mol) and can therefore be efficiently used in evaporators of loop heat pipes. There is no risk of freezing during the transportation and storage as it freezes at −77.7 °C. Ammonia is not affected by corrosion and bacterial growth. Internal positive pressure is required to keep ammonia in its liquid form, inside the evaporator. Ammonia is also known to have a pungent smell. An example of a specific ammonia is R-717.

3.4. Comparison

In comparison to active systems, passive systems use considerably less fluid, reducing cost, weight and environmental impact. The small volume of fluid is concentrated in the wick structure, as it acts like a sponge.

Rather than comparing refrigerants and different types of Ammonia in general as has been described above, the tables below outline the pros and cons of two common fluids used in passive TCS today. It should be noted that systems are not limited to these two fluids outlined below.

Table 1. Pros and cons of different fluids.

	Water	Refrigerants	Ammonia
Thermal Performance	High	Mid	Mid

[5] https://r744.com/certain-hfcs-and-hfos-are-in-pfas-group-that-five-eu-countries-intend-to-restrict/

Maintenance Schedule	High	Low	Low
Risk of Corrosion	Yes	No**	No**
Risk of Biofouling	Mid-Low	Very Low	Very Low
Risk of Freezing	Yes	No	No
Flammability	No	No*	No
Toxicity	No	No*	No
Electrical Conductivity	Yes	Very Low*	Very Low
Environmental Concerns	No	Very Low, but potential for PFAS,	
Operating Pressure	ODP, GWP*	Very Low	
Relative Cost Scale	Low	Mid	High

*Depends on exact refrigerant chosen

**Assuming the system is designed with compatible materials.

4. Cold Plates / Evaporators

The cold plate (often called an evaporator in these systems) selection should depend on the thermal requirements, the operational parameters, and the wetted materials used. Depending on the temperature requirements of the components in need of cooling, and cooling liquid parameters, such as temperature, and heat transfer properties, the cold plate design can be more or less complex. 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.

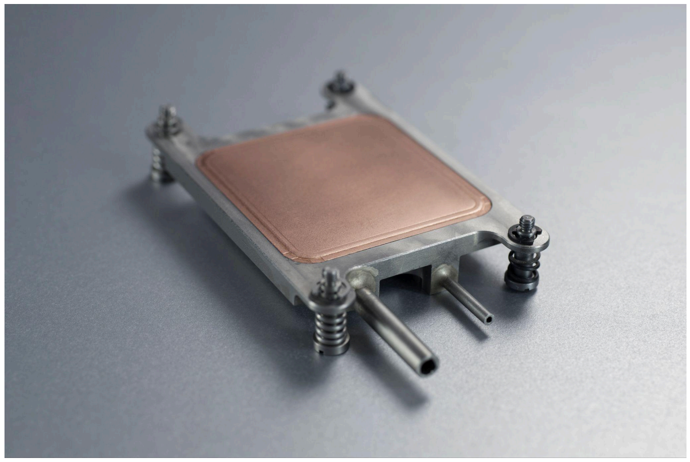

Figure 3: Example of an LHP Evaporator[6]

Two-phase cold plates are built differently from single phase designs as they must optimize the vaporization of a liquid. They can be divided into flow, spray and pool boiling. Often the exact design of an evaporator is proprietary, and the design options can be endless. The basic reason more complex designs are considered is to increase the surface area for vaporization therefore increasing the rate at which heat can be dissipated, suppliers often use porous media (wick structures) to do this.

There are different parameters to consider when designing a cold plate solution. These parameters are shown in Table 2. Almost always 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.

It is important to look at the cold plate performance from a system design level. This means examining the cold plate performance at the highest TDP of the device being cooled and ensuring that the junction temperature remains below any thermal throttling threshold. Factors that affect this are: facility water supply temperature and the manifold heat exchanger thermal resistance.

[6] https://www.calyos-tm.com/technologies/loop-heat-pipes

Beyond this, the cold plate must be designed in a manner that meets the flatness and stiffness requirements of the silicon vendor. There is also temperature variation in different locations on the die and this will affect the performance of the cold plate.

Table 2: Parameters and metrics of importance for passive cold plate selection.

Parameter	Metric
Pressure drop vs Hydrostatic Budget	Pa vs Meter
Operating pressure	Pa
Pressure drop	Pa
Thermal Resistance	W/m^2K or K/W
Max. Hotspot	W/cm^2
Height	mm
Active surface area	cm2
Flatness	µm
Stiffness	N/mm
Wetted Materials	List

5. In-Chassis Hose / Tubing

In-chassis pipework's refers to the tubing or hoses that connect the cold plate(s) to the manifold. Durability and serviceability are both important factors to consider and the system providers also have other factors to consider, most notably the pressure drops created by the piping.

In terms of durability the thickness and the diameter of the piping are important. Typically, passive systems use rigid, metal pipes to transport liquid and vapor. In some cases, short flexible lines are included, these are less durable but introduce design tolerances allowing for easier installation and maintenance.

When servicing a component, the server chassis will be removed from the rack and therefore disconnected from the manifold. As the loop is typically a rigid structure it can be unbolted from the chassis. If flexible lines are used on the entry/exit of the cold plate they can access to an individual processor.

When multiple components are being cooled inside one server, two approaches can be taken. One approach is to include a separate loop for each component, the second uses parallel liquid (entry) and vapor (exit) lines as shown in Figure 5.

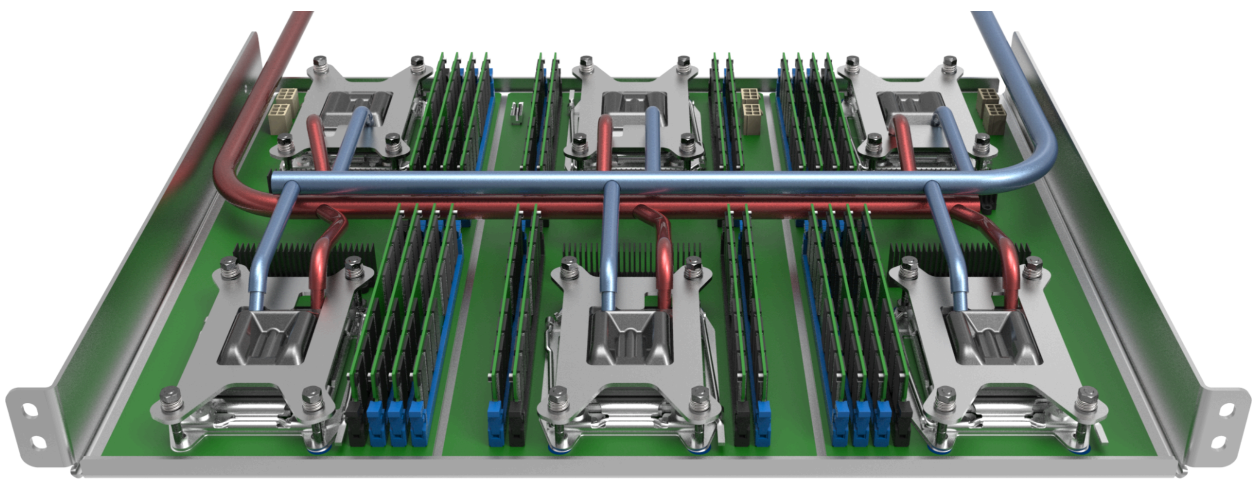

Figure 4: Representative parallel multiple cold plate configuration

The in-chassis tubing, cold plates and quick-disconnects form a repeatable part of the larger system that can be scaled up or down depending on the servers in the TCS. The design of the manifold comes next, and its design will be based on the number of cold plate loops (and therefore the maximum thermal power to dissipate per rack. Note that it is important that the cooling fluid has been selected at this point, as the fluid properties affect the design of the manifold.

Table 3: Parameters and metrics of importance for in-chassis tubing selection. It should be noted that all of these aspects are the responsibility of the system provider.

Parameter	Metric
Maximum Operating Pressure	kPa
Burst Pressure	kPa
Minimum Operating Temperature	degC
Maximum Operating Temperature	degC
Minimum Bend Radius	mm
Inside Diameter	mm
Outside Diameter	mm
Pressure Drop	Pa
Wetted Material	List

6. Rack Manifold

The rack manifold is a key component in the TCS to distribute cooling liquid to the IT equipment and back. The manifold connects to the TCS pipework's, generally via a QD. In passive cold plate systems, the manifold can also act as the heat exchange interface between the FWS and TCS.

To provide the interface between the TCS and the FWS a manifold includes an array of QD connections. For each server there will be QDs connecting the cold plate cooling loops to the manifold, and there will be (typically larger) QDs connecting the manifold to the FWS. The coupling diameters and manifold dimensions are chosen to support the current and future requirements for operational performance required 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 real estate.

The location of the manifold within the rack is usually in the rear; 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 QDs, 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 for the TCS, and connection to the FWS can be at the foot or the rack header (note that for wet QD's systems it is typically at the top to save routing the FWS all the way up the manifold).

Rack manifolds can be made of different materials, including stainless steel, copper, aluminum or various forms of plastic. It is essential the material compatibility is validated and that the pressure, flow and QD sealing requirements are checked.

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 may 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 fluids passing through it. 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].

Considerations for shipping manifolds and installation into racks are documented in the OCP Integration and Logistics whitepaper[8].

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[7] ASHRAE, Liquid Cooling Guidelines for Datacom Equipment Centers, Atlanta, 2014.

[8] https://www.opencompute.org/documents/ocp-liquid-cooling-integration-and-logistics-white-paper-revision-1-0-1-pdf

The rack manifold comes in two common foundational configurations detailed below, and the choice of manifold also dictates the choice of QDs (and vice versa). Exact configurations are dictated by the end customers server architecture.

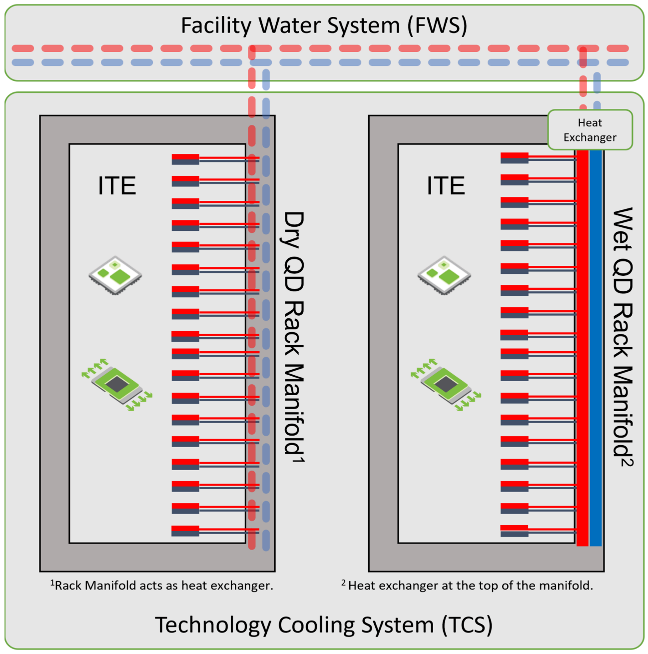

Figure 5: Diagram to highlight difference between dry and wet QD configurations.

1.1. Dry Quick Disconnect Manifold (Closed Loop)

A dry QD system uses mechanical plates to interface between the cold plate cooling loop and the FWS. Only the liquid from the FWS passes through the manifold. It should be noted this increases the pressure drop on the FWS considerably, therefore increasing the requirements of the FWS. The mechanical connection is also not ideal for optimizing the heat transfer, as it uses conduction. Increasing the flow rate of the FWS can improve the performance if necessary. As the loops are completely sealed there is an extremely low risk of fluid liquid.

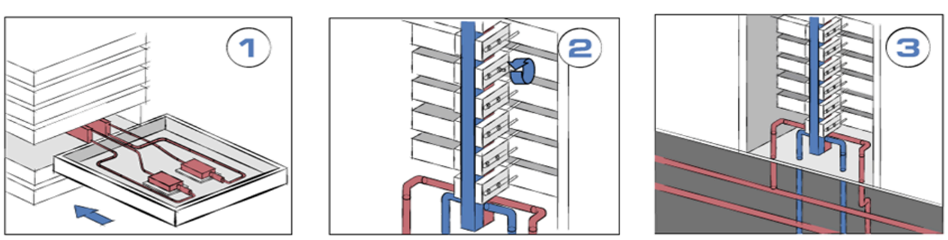

Figure 6: Image to show dry quick disconnect system

1.2. Wet Quick Disconnect Manifold (Open Loop)

A wet QD system allows for flow of the cooling fluid from the cold plate loops, into the manifold's core loop, where it is transported to the top of the manifold and the heat is exchanged with the FWS. The heat exchanger must be placed at the top as the passive system is supported by a gravity assisted liquid return, this is a constraint of this manifold design. The heat exchanger can either be part of the rack, or follow a similar design to that of a Central Distribution Unit (CDU) but without the need for pumps on the TCS. This type of manifold uses high-pressure couplings between the manifold and the cold plate loop that can maintain pressure limits of TCS and burst pressure of the couplings. There is a risk of small fluid leakage from the quick couplings and a risk of small volumes of air being introduced to the loop.

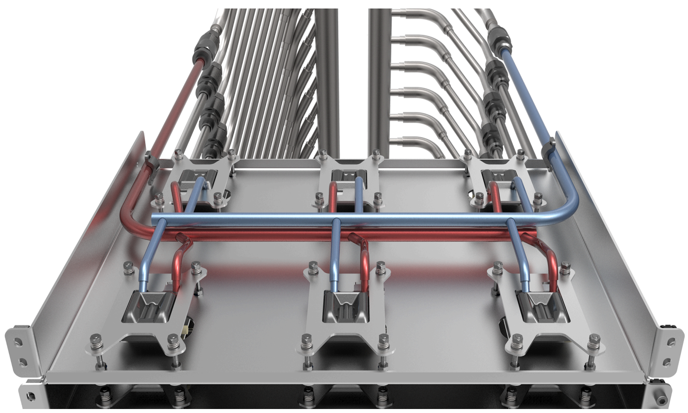

Figure 7: Rendered image to show wet quick disconnect system between server and manifold

1.3. Comparison

There are pros and cons to using each type of manifold, these are summarized in Table 4.

Table 4, Pros and cons of different manifold design.

	Dry QD Manifold	Wet QD Manifold
Thermal Performance	Mid	High
Maintenance Schedule	Low	Mid

Risk of Leakage	Very Low	Mid
Added Pressure Drop on FWS	High (10-15kPa)	Low
Relative Cost Scale	$	$$

1.1. Parameters of Importance

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

Table 5, Parameters and metrics of importance for manifold selection.

Parameter	Metric
Internal diameter or dimension	mm or inches (mm x mm or inches x inches)
Thermal resistance between FWS and working fluid	K/W
Physical dimensions: • Height • Width • Depth	mm or U inches mm
Weight	kg (empty and filled)
Manifold rack extrusion into white space	None (in-rack) or Extrusion (location and m2)
Wetted Materials	list

TCS connector style and dimension	inches (e.g., Blind-mate, hand-mate, threaded)
TCS connection location	Foot of rack or top of rack
Maximum rated pressure (for open loop systems only)	Pa
Maximum Liquid Flow Rate (for open loop systems only)	Liters/min
Number of ports	#

2. Quick Disconnects

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. This section outlines aspects for the quick disconnects between each in-chassis loop and the manifold.

In systems employing hand mate 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.

Two categories of quick disconnects are available and are dependent on the choice of manifold:

2.1. Dry Quick Disconnects

Condensers of the loop heat pipes are used in the QDs system to maintain a connection to the rear rack liquid manifold with manual locked QDs or blind-mate QDs.

Manual QD (“dry lock”) uses clamps to attach condensers to the manifold mechanically. Specific position of each condenser does not matter, and precision of manifold vertical position is not critical. Manifold itself is either a combination of the tubes with a rectangular section or a flat shell wrapped around a set of regular circle section pipes (detailed scheme on Figure 9). If the server needs to be disconnected/connected to the manifold it should be un-clamped or clamped from/to the manifold. TIMs can be used on each surface to increase thermal conductivity.

Blind-mate QD is organized via a combination of the special condenser shapes and corresponding set of cavities on the manifold. Natural friction with applied TIM maintains the connection/disconnection process for blind-mate QD. Since each condenser should be inserted into the specific cavity on the manifold thus manifold positioning becomes a more critical point for the implementation. The manifold must be customized with cavities made in an appropriate shape in advance as a part of the manufacturing process.

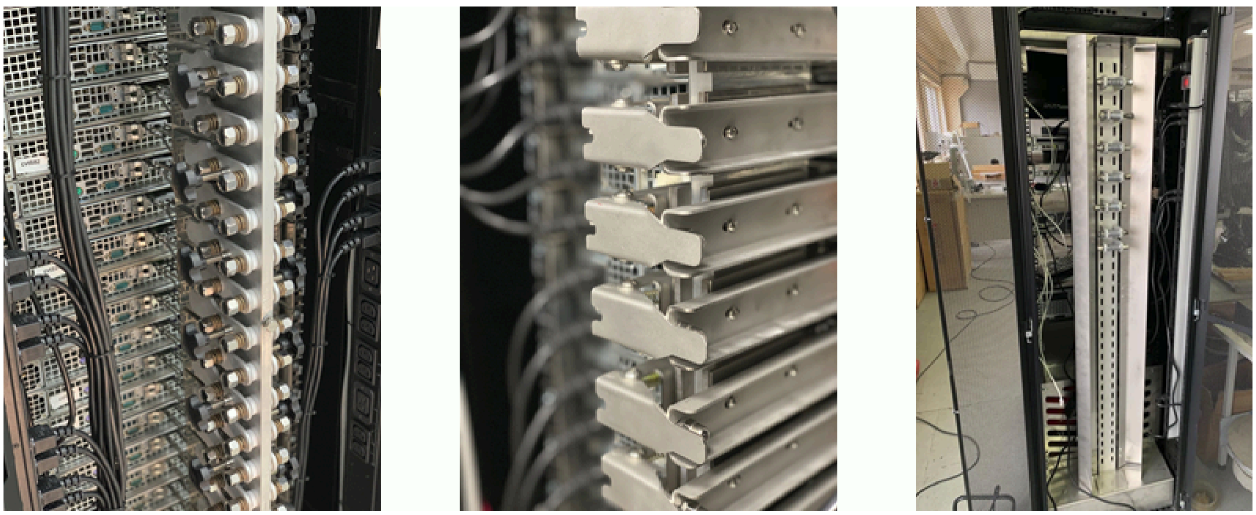

Figure 8: Dry (Mechanical) Quick Disconnect[9]

For both options the LHPs are fixed in the server and move with it accordingly.

2.2. Wet Quick Disconnects

Wet QDs systems use coupling sets that 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 and similarly the amount of air introduced to the system on each connection. Quick-disconnects with zero-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. Extra care should be

[9] www.greenloopcooling.com

taken in the selection of the quick-disconnects as they must be applicable for use in two-phase (liquid and vapor) systems with the chosen fluid.

The comparison outlined in Table 4 also applies to QDs.

2.3. Parameters of Importance

Parameters for consideration when specifying couplings for liquid cooled cold plate systems can be found in Table 6 and 7. 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 6, Parameters and metrics of importance for dry quick disconnect selection.

Parameter	Metric
Temperature – Operating, Storage / Shipping	°C, °F
Connection Force	N, lbf
Connection Cycles	Mechanical cycles / connect and disconnect
QD style	Blind-mate or hand-mate

Table 7, Parameters and metrics of importance for wet quick disconnect selection.

Parameter	Metric
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	Blind-mate or hand-mate
Terminations	Barbed, compression style, threaded

3. Hardware Management

Passive cold plate TCS are self-regulating and therefore do not require a control system, they simply operate when heat is produced by a component as this causes the physical reaction to occur following vaporization of a liquid in the system. However, it is best practice to still monitor the system. The systems can be primarily monitored from the sensors embedded inside the electronics inside each server and the sensors on the FWS side.

For passive cold plate TCS the most required sensors to be monitored are listed below.

- Server

  - Component junction temperature (CPU, GPU, etc)

- FWS
  - Liquid inlet temperature
  - Liquid outlet temperature

For more information, please refer to the cold plate cooling loop requirements document, page 38[10].

[10] https://www.opencompute.org/documents/cold-plate-cooling-loop-requirements-rev-2-pdf

4. Conclusion

Passive technology cooling systems using Loop Heat Pipe technology are very new to the market and bring a different set of constraints than active systems. However, the benefits of going fully passive could have massive implications for the future energy consumption of data center cooling systems.

It is expected that due to the reliability of these systems and there extremely low maintenance requirements they would be most applicable to enterprise data centers where reliability is more important than performance.

Early adoption by the market will prove pivotal in determining the future of these technologies and their applicability to Data Center cooling infrastructure as an alternative to active cooling systems such as water, immersion, and pumped 2-phase.

Glossary

LHP: Loop Heat Pipe

TCS: Technology Cooling System

QD: Quick Disconnect

CDU: Central Distribution Unit

FWS: Facility Water System

License

About Open Compute Foundation

The Open Compute Project (OCP) is a collaborative Community of hyperscale data center operators, telecom, colocation providers and enterprise IT users, working with the product and solution vendor ecosystem to develop open innovations deployable from the cloud to the edge. The OCP Foundation is responsible for fostering and serving the OCP Community to meet the market and shape the future, taking hyperscale-led innovations to everyone. Meeting the market is accomplished through addressing challenging market obstacles with open specifications, designs and emerging market programs that showcase OCP-recognized IT equipment and data center facility best practices. Shaping the future includes investing in strategic initiatives and programs that prepare the IT ecosystem for major technology changes, such as AI & ML, optics, advanced cooling techniques, composable memory and silicon. OCP Community-developed open innovations strive to benefit all, optimized through the lens of impact, efficiency, scale and sustainability. Learn more at www.opencompute.org.