Data Center Liquid Distribution Guidance & Reference Designs

Revision 0

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Executive Summary

The Advanced Cooling Facilities (ACF) Subproject mission is to develop best practices, collaboration documents and common guidelines facilitating the integration of Advanced Cooling Solutions (ACS) into the Data Center Facility (DCF). Liquid cooled ITE has been successfully deployed for decades, primarily in support of HPC functions and typically deployed as part of initial data center construction.

Adding and updating liquid cooled ITE in future phases of data center operation is becoming a life cycle requirement for many data centers. **Proper planning can enable successful deployment of liquid cooled IT when needed, at reduced time and cost, with minimum capital expense**.   The purpose of this document is to provide guidance for the implementation of liquid distribution loops to data center facility water solutions (FWS).

Areas of planning consideration includes:

- Piping System considerations - sizing estimates, routing, connection methodology
- Reference Design Development - use of BIM content (including piping system, components, and ITE) to develop planning layout documents
- Cooling loop temperature control, isolation strategies and Thermal Ride Through
- Service Level Agreement (SLA) Considerations
- Balancing cost and risk via design consideration, commissioning, and procedures

Table of Contents

Introduction

Whilst the cooling of ITE has gone through periods of being cooled through water cooling circuits, the dominant form of cooling has been through air heat transfer. A new generation of ITE is being developed and is being implemented that is reliant on some form of cooling by way of liquid heat transfer. This document sets out to inform ITE users, facility designers and facility operators on the considerations that should be taken when implementing this type of equipment within a data center

Liquid cooled ITE can be integrated in data centers with existing Facility Water Systems (FWS) via the addition of liquid distribution to the ITE, or by addition of an independent liquid cooling distribution system. In data centers with an existing chilled water FWS solution, one choice would be to provision for connection to the existing chilled water (CHW) system thereby adding load to the chilled water system. Another choice would be to bypass the chiller plant via direct connection to exterior “dry coolers” or condenser water (CDW) system with heat rejection plant where the CDW is a closed loop protected from external elements. The issue of adding liquid cooled ITE using elevated temperature loops that bypass the FWS or do not use FWS systems (i.e. evaporative cooling) is briefly discussed and is likely the topic for another paper.

Sustainability is a goal of OCP guidance. Operation without the use of chiller plants, without use of open water evaporative systems and enabling effective reuse of heat energy are key considerations. In cooler climates, there are often options for “free cooling” that does not waste water and present heat reuse opportunities even at ASHRAE W1 (<17C) or W2 (<27C) supply levels. Immersion cooling and “cold plate” cooling solutions provide capability to use free cooling, without evaporation in all climates, using W4 (<45C) and beyond, potentially up to 60C, presenting opportunities for heat reuse even in warm climates.

The scope of guidance is to highlight key considerations in planning for addition of liquid cooling. Guidance is not intended to be comprehensive, but to provide preparation guidance for future expansion with minimal cost, risk and to differ CAPEX. Examples of considerations:

- Provisional Tap-off connections (or use of CRAH connections)
- Routing (and maintaining) Path of Pipe loop
- Connection of TCS or FWS pipe loop to ITE
- Condensation & Dewpoint
- Thermal energy measurement
- Isolation of loop and water quality testing points
- Pressurization control and pumping of the fluid in the loop (including power source(s))
- Risk, Reliability & Tier Level Discussion
    - Impact on Tier III (concurrent maintainability)
    - Maintenance Risk

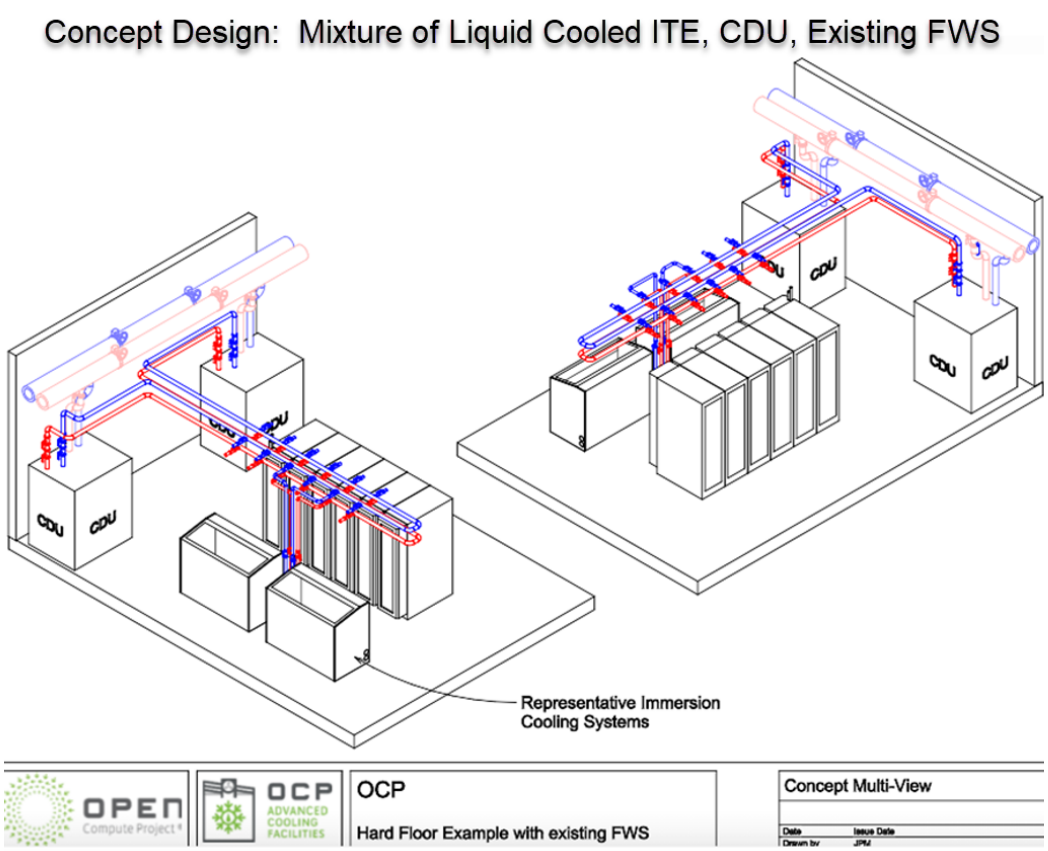
Design Considerations

Case 1 – Connection to Existing FWS System - Concept drawings

For data centers with existing chilled water systems feeding CRAH (computer room air handlers) or fan walls, preparation for the potential addition of liquid cooled ITE starts with concept designs to highlight needs for planning:

- Pipe tap-off connections to FWS
- Space for routing liquid cooling loop (TCS)
- CDU (Coolant Distribution Unit/HX) location (space and maintenance considerations)
- Redundancy
- Connections to liquid cooled ITE

The drawings below illustrate a mixture of liquid cooled ITE (coldplate, doorHX, immersion) solutions served by a liquid cooling loop that is coupled to the FWS via CDUs.



Planning for Pipe Connections – One of the first considerations is connection to an existing FWS. This can be achieved using existing connections (i.e. swapping out a CRAH unit) or by adding tap off connection points for future connections. Estimating pipe size versus KW capacity is a function of mass flow and delta T.

Attached table of "**Pipe Size vs KW"** provides an estimation and illustrates the trade-offs between flow velocity, diameter and delta T. Flow velocity has energy considerations, pipe diameter has construction considerations, and delta T can impact cooling system performance as well as ITE performance. Validation by a licensed engineer is recommended.

Pipe Size		ASHRAE 90.1-2019 Table 6.5.4.6		Equiv Velocity		ΔT				
						4	6	8	10	C
						7.2	10.8	14.4	18	F
DIN	in	l/s	GPM	m/s	ft/s *	Max kW				
50	2	4.95	78	2.3	7.5	83	124	166	207	
65	2-1/2	6.94	110	2.2	7.4	116	174	232	290	
80	3	10.73	170	2.2	7.4	180	269	359	449	
100	4	20.19	320	2.5	8.1	338	507	676	845	
150	6	42.90	680	2.3	7.6	718	1077	1436	1795	
200	8	69.40	1100	2.1	7.1	1162	1742	2323	2904	
250	10	100.94	1600	2.0	6.5	1690	2534	3379	4224	
300	12	145.11	2300	2.0	6.5	2429	3643	4858	6072	

Based on flow rates per ASHRAE 90.1-2019 Table 6.5.4.6 for Variable Flow

* - Values are based on standard weight carbon steel pipe dimensions, ASTM A53

(yellow) Represents typical design dT for chiller-based systems

(orange) Represents dT lower than typical design/operation of FWS systems

Heat transfer using a single phase fluid (air or liquid) is defined by a basic equation:

Q (Amount of heat) = (volumetric flow rate)*(delta T)*(density)*(specific heat capacity of fluid)

Water has one of the highest heat capacities of any fluid. By volume, water carries around 3300 times more heat than air, which has a significant impact on ITE and data center cooling design considerations, especially as heat densities increase. ASHRAE 90.1 (or equivalent European bodies such as CBISE) provides guidance on maximum recommended velocities. The attached table provides an estimate of the maximum amount of heat that can be transported by a given diameter of pipe. There are a variety of factors that impact the values shown, the table is not meant for design, but for concept considerations.

Delta T (difference in temperature below flow and return or inlet and outlet points)

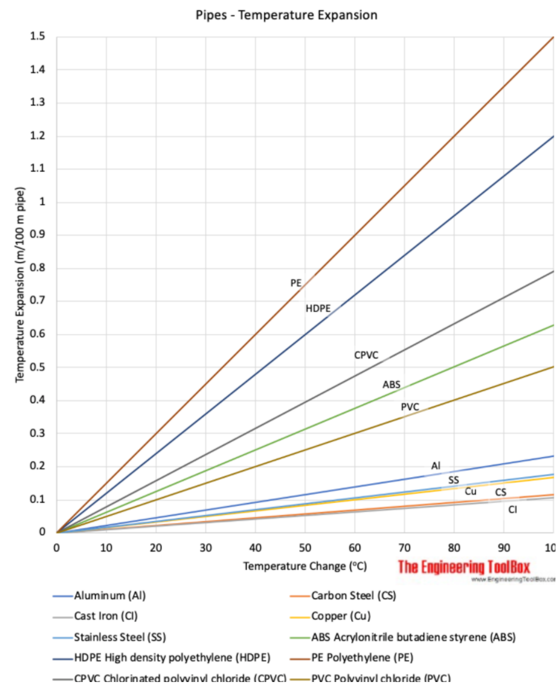
- ITE equipment will have limits on the maximum delta T (fluid temperature rise) allowed
- Chiller Plants are typically designed with an optimal temperature rise and cooling capacity. Increasing return temperatures may impact chiller plant performance.

Specific Heat Capacity of Fluid

- **Glycol, Additives** - additives such as glycol decrease the specific heat capacity of water.
- **Fluid Types -** Fluids used for immersion cooling (dielectric) have significantly lower specific heat capacity than water and will need greater volume to transport the same amount of heat as water.

Pipe Route planning - Adding pipe requires space, preferably straight runs. ITE refreshes occur every 3-5 years. Preserving pipe paths to support addition of liquid cooling through the life cycle of a data center is key to ensuring future requirements to add liquid cooled ITE can be supported with minimal cost and impact on operations. Planning should include sufficient space for pipe component (i.e. value) replacement and drainage points for maintenance. Where condensation may be a concern, space for condensation collection and drainage should be considered.

- Use of BIM modelling is highly recommended to provide three dimension spatial coordination.
- In addition to pipe routing considerations for both FWS and TCS, planning should include tap-off points, provisions for manifolds & pipework components, and Coolant Distribution Units (CDUs), ITE rack and immersion cabinet placement.



Pipe Movement Pipes move in many ways. Thermal expansion, vibration, building movement all can affect pipe system performance, connection reliability, mounting design, alignment stress and flange performance. The thermal range of liquid cooled ITE can present additional design consideration, as the temperature range from installation temperature to peak operating temperature may exceed 30C. Design engineers will need to accommodate expansion and movement in their designs with specialized flex connectors or grooved coupling connections that can absorb and mitigate alignment stress.

Non-metallic pipe solutions have seen some usage in smaller applications. However, movement in non - metallic pipe is much greater than metallic pipe and may require redesign and present some challenges in large scale deployments.

Pipe Material Selection There are a broad spectrum of materials that have been used in data center liquid distribution. The scope of discussions exceeds the focus of this paper, and varies significantly with region, climate, data center function and operating environment. Some considerations listed below:.

Pipe Selection Considerations Liquid To ITE

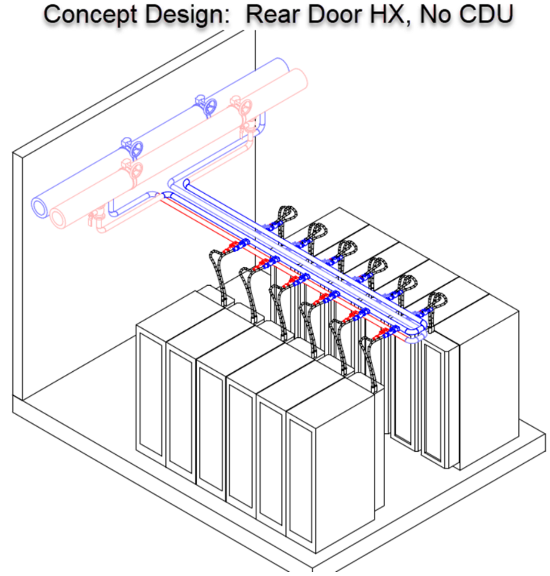
- **Corrosion , transition metals, chemistry**
- **Thermal movement, flange performance**
- **Plenum Rating**
- **CDU vs Facility Loop liquids and conditions**
- **Diameter – < 2” vs > 2”**
- **Weight, wall thickness**
- **Connection method**
- **Local resources, Cost, Sustainability Impact**
- **Friction/head loss**
- **Max Continuous Service Temp**

Coolant Distribution Unit (CDU) planning – When connecting liquid cooled ITE to a FWS system, loop isolation via heat exchanger may be required or advisable for a variety of reasons including pressure reduction, pressure control/isolation, fluid separation, quality control, temperature control. (Considerations of CDU usage, location and maintenance are discussed in greater detail in Appendix B) Each type of ITE solution presents different needs for CDU/HX considerations

- **ColdPlate** (See OCP ColdPlate Guidance) - Cold plate solutions typically include a CDU designed to connect protect/separate FWS from the TCS liquid cooling loop to the ITE chips. These CDUs may be rack based or centrally based, feeding a series of Coldplate ITE. The CDU/HX ensures set points for pressure, water quality, temperature and flow with cold plate cooling are maintained. An additional benefit can be to maintain TCS temperatures above dew point, minimizing need for condensation protection during normal operation. For environments with high dew points, condensation alerts / alarm to the BMS should be considered during transition and maintenance periods wherein the TCS loop may transition below dew point.

- **Immersion Cooling** - While some immersion cooled products are designed to connect directly to the FWS (using an internal heat exchanger coil as the FWS/TCS boundary, many immersion systems use a CDU/HX to isolate the TCS from the FWS so as to independently control pressure, temperature and chemistry/water quality conditions. As with cold-plate, immersion cooled ITE can be supported with liquids well above dewpoint and a CDU may be recommended to ensure colder liquid temperatures associated with chilled water systems (FWS) are not distributed in ITE areas more sensitive to condensation. Many immersion and cold-plate solutions provide CDUs integrated as part of their solution structure.

Concept Design: Rear Door HX, No CDU



- **Door HX -** Door HX systems remove heat from air cooled ITE, seeking to restore air to (or close to) ASHRAE TC9.9 requirements (typically less than 27°C). Most DoorHX systems are designed to operate with direct connection to the FWS system (See drawing). Avoiding the cost, space and maintenance issues of a CDU is a benefit. However, use of a CDU/HX may be considered beneficial to provide volume isolation, greater flow control and maintenance of distribution piping at a temperature above dew point (reducing risk of condensation in the ITE area). Additional guidance for Door HX is provided in [ACS-Door Hx OCP Spec for Open Rack]

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    - **FWS Manifold** - for rack based cooling solutions being fed directly from the FWS (not limited to a Door HX), a manifold is a common practice. Manifolds would include isolation valves, strainers and balancing valve capabilities as required ([OCP ACF Connection WP])
    - **Over-Aisle HX** - Many of the benefits of door HX solutions can be provided using over-aisle HX solutions, not currently addressed in an OCP ACS subproject.

Layout Planning - In addition to equipment geometry, layout planning should include consideration for transport weight, installed "wet weight", and clearance requirements (installation, operational). Weight consideration could be a significant factor, especially for multi floor data centers

Three Way Valve Loop Planning - In lieu of CDUs, loop temperature and flow control can be balanced using 3 way valves to provide loop temperature balancing.. The 3-way valve solution does not provide loop isolation, and has a limited flow balancing range, but may save cost, space and maintenance when the primary issue is temperature balancing. **Detailed discussion is included in Appendix B.**

Thermal Ride-Through is the amount of time the ITE equipment will be able to operate if there is a breakdown of performance of the cooling solution(or loss of heat transfer to the FWS). A **Loss of flow accident (LOFA)** in any of the liquid loops can lead to overheating conditions of the ITE. A key benefit of liquid cooling is the exceptionally high specific heat of most liquids, in comparison to air, and the superior heat transfer capability of cold plate and immersion cooling that supports operation at much higher fluid temperatures.

High heat densities drive high heat-up rates. Awareness of thermal ride-through is useful in development of EOPs (emergency operating procedures) and SOPs/MOPs where loop flow of any of the CWS, FWS or TCS systems may be affected. Likewise, thermal ride through is a consideration in SLAs (Service Level Agreements. General best practice would be to include redundancy of pumps and back-up power systems (generator and/or UPS), and possibly addition of liquid volume (thermal storage) in the liquid loop nearest the ITE. Calculation of thermal ride through and design impacts generally requires professional engineering design consideration.

Service Level Agreements(SLA) and Risk Considerations

SLA Boundary Point – Addition of liquid cooled ITE introduces discussion of performance and risk ownership between facility owner, ITE solution vendor, and ITE owner. CDUs present a logical point for SLA evaluation. Where tenants seek to employ liquid cooled ITE, facility contracts for cooling consideration may be required provisions for thermal metering, flow, temperature, pressure at the TCS side of the CDU, or the supply side of the CDU where the CDU is part of the TCS.

Understanding ownership can present significant challenges when there are multiple parties involved such as the MTDC operator, ITE Vendor and ITE operator. Who will be maintaining and warranting the water quality of the TCS that could impact on the life of the ITE chip and its performance.

TCS cooling Loop to ITE connections issues and recommendations are addressed in (OCP ACF Connection WP). Those discussions include recommendations on flow balancing, strainer requirements, and standardization of connection methodology to simplify interchangeability of liquid cooled ITE systems and components.

Risk Considerations, Reliability Considerations. Discussions of adding liquid distribution inside data center ITE space often highlight the perception of risk. Data Center pipe solutions have demonstrated decades of reliable performance. A key purpose of OpenComputeProject is to reduce risk by standardization around best practices. Introduction of new liquid cooled ITE solutions and evolution of data center designs requires that perception of risk be evaluated with scientific methods wherever possible.

Risk Assessment - Reducing Risk by Analysis – Data Center pipe solutions have demonstrated decades of reliable performance. However, reliable performance rarely gains attention, and perception of risk should be evaluated with scientific methods wherever possible. FMEA and Reliability tools can help quantify risk and reliability concerns and develop cost effective methods to minimize risk. As data center designs evolve to slab floors, where pipes are run above the floor, use of scientific methods of risk and reliability add significant value.

FMEA – Failure Mode & Effects Analysis is a process of systematic evaluation of failure modes and associated risk factors to assign **Risk Priority Number**. Failure mode Risk Factors would include Severity, Probability and Detection. RPN can be reduced by reducing severity, probability or detection risk:

Reducing Severity Risk:

- **Valve, Strainer, flex hose Maintenance** – valves, strainers and flexible components that anticipate maintenance should be located in minimal risk areas or protected during periods of maintenance
- **Pipe Connection Location -** Locate pipe connections away from areas of highest risk
- **Procedures -** Use standardized procedures for maintenance and operation functions (MOPs, SOPs)

Reducing Probability Risk

- **Condensation Probability** - Historically, liquid cooling water supplies were at risk of dew point/condensation, and drip trays and leak detection methods were often recommended. Many data centers and liquid cooled solutions today operate above dew point, greatly reducing risk severity and probability. ASHRAE recommends a maximum dewpoint level of 15C. Where this limit is observed, use of liquids above 15C poses minimal risk of condensation.
- **Pipe Connection Probability** – As discussed in Appendix D, connections used in locations of highest risk require an inspection/commissioning process that reduces probability of failure to life of the system. Weld (radiography) and mission critical rated grooved couplings (visual inspection) would meet this goal. Connections with potential for leakage (i.e. flanges, thread connections) should be in locations where severity risk is low and leak detection is available. Connections that lack inspection verification (i.e. fused, crimped connections) should be restricted to areas of low severity risk. (Additional discussion in appendix D)

Table 2: Dewpoint Limits Per ASHRAE

ASHRAE Class	Max Inlet Temp °C	Max Dewpoint Temp °C
A1-A4 Recommended	27	15
Allowable Limits		
A1	32	17
A2	35	21
A3	40	24
A4	45	24
B	35	28
C	40	28

ASHRAE TC 9.9 © 2015

Reducing Detection Risk

- **Visibility -** Visibility of pipe runs greatly enhances detection of issues
- **Condensation** - Where condensation is possible, detection & collection methods should be used
- **Connections with potential for leakage -** Leak detection should be considered for threaded, flanged, crimped, fused connections. Leak detection can take the form of an electrical conductive tape that can initiate an alarm at the BMS.

Concurrent Maintainability – Aligning liquid cooling solution with The Uptime Institute Tier Guidance also aligns performance to risks. The question of how liquid distribution to the ITE affects TUI Tier Level Certification should be considered, and directed to TUI. Highlights of Tier level discussions of interest are provided below:

- **Tier IV - "fault tolerant design"** wherein no single fault results in data center functional failure. Typically, this requires full redundancy of any critical system. Redundant cooling loops and TCS supply would be required to meet Tier IV level

- **Tier III - Concurrent maintainability** focuses on continuity of data center operations through planned or predictable maintenance events. Some key considerations:
    - Redundancy of cooling distribution internal to the ITE is not a "tier issue". For example, while cooling supply to the immersion tank, doorHX, cold plate is a Tier III consideration, distribution of liquid and components inside the ITE is not a consideration.
    - Redundancy of ITE might be a consideration. i.e. multiple HPC racks providing identical function set up in N+1 configuration
    - Mean Time To Repair - MTTR is a key factor in system availability. Components that are expected to require maintenance over the life of the system should be accessible and connected in a manner that is quick and simple. Long repairs equate to lower availability.

Case 2 – Elevated temperature Loop (>30C) Considerations

The superior heat transfer capability of liquids enables many liquid cooled ITE solutions to operate efficiently and reliability at temperatures well above the ASHRAE recommendations for air-cooled ITE ASHRAE TC 9.9 identifies six liquid cooling classes (see table below):

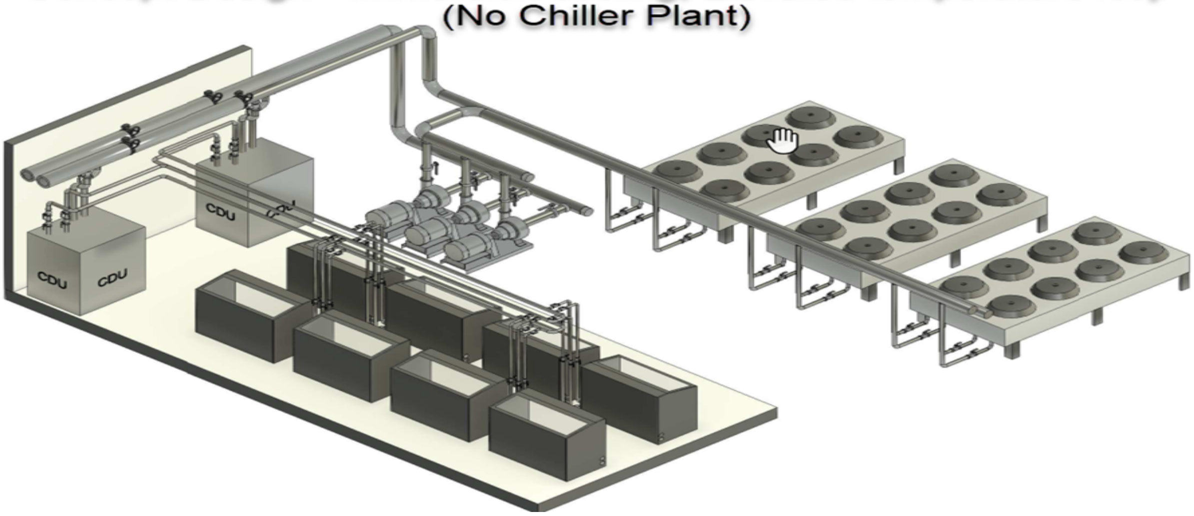
ASHRAE TC 9.9 Table 3.1 2021 Thermal Guidelines for Liquid Cooling

Liquid Cooling Class	Typical Infrastructure Design: Primary Facilities	Typical Infrastructure Design: Secondary/ Supplemental Facilities	Facility Water Supply Temperature, °C (°F)a
W17	Chiller/cooling tower	Water-side economizer	17 (62.6)
W27			27 (80.6)
W32	Cooling tower	Chiller or district heating	32 (89.6)
W40			40 (104)
W45	Cooling tower	District heating system	45 (113)
W+			>45 (>113)

Cold-Plate and Immersion Cooling solutions can operate successfully within liquid cooling classes W32 and above, enabling much greater use of free cooling and potentially energy reuse, not to mention elimination of condensation concerns.

Where facilities are planning on adding liquid cooled ITE to an air-cooled data center (i.e. data hall cooled by IDEX cooling units), a dedicated cooling loop may be a necessity and therefore would be not restricted from an elevated temperature loop, which may be the case if interconnected with the FWS.

Concept Design - Immersion cooling, Elevated temperature loop (No Chiller Plant)



The general guidance provided in Case Study 1 - Connection to Existing FWS still applies with some additional considerations:

"Free cooling" without water usage. In most situations, immersion and cold plate cooling loops can be supported with a simple connection to a dry (no evaporation needed) heat emission device. There may be trade-offs associated with different climates and some types of ITE. ColdPlate and Immersion cooling environments using 35°C-60°C are common. However, some ITE applications may benefit from the cooler end of that spectrum, which may require some cooling assistance in some climates for at least part of the year (ASHRAE TC 9.9 provides recommendations on liquid cooling temperature levels and applications). But even the lowest end of the liquid cooled temperature spectrum still presents the potential to be the most efficient solution for such climates and ITE, with the least amount of water usage

Avoid condensation concerns - The highest dew point limit supported by ASHRAE TC 9.9 is 28 C for Class C data centers. The lowest temperature for consideration in this discussion is 30C. Condensation protection would not be a concern with elevated temperature liquid distribution

Heat Reuse applications - Sustainability and efficiency are key goals of the data center industry and OCP. Liquid cooled ITE solutions such as cold plate and immersion cooling enable usage of higher temperature liquids, resulting in much greater quality of waste heat. The ability to "reuse" heat energy with liquid temperatures over 50C/122F is much greater than 35C/95F air from air cooled ITE. This heat generated by the ITE can be used for other purposes outside of the data center such as for agriculture (warming up greenhouses), swimming pools, residential heating etc. via a district heating system, whilst also improving the ERE metric of data centers.

CDU Usage with Elevated Temperature Loops. While it may be possible to connect liquid cooled ITE designed for W32 or higher directly to an exterior heat exchanger (dry-cooler or heat reuse application), a CDU at the facility boundary may provide benefit in loop separation from exterior liquids, temperatures, pressures (see Appendix B)

Beyond Design - Procedures & Commissioning

Performance of mission critical systems requires not only optimized design, but is also dependent on a complete “commissioning” process to test performance of all systems as well as development of procedures for standard operation, maintenance, and emergency operations (SOPs/MOPs & EOPs)

- **SOPs** (Standard Operating Procedures) - step-by-step sequences for performing routine operations with no maintenance component. Temperature verification, visual inspections, water chemistry checks are examples. Shifting usage of redundant components, i.e. pumps

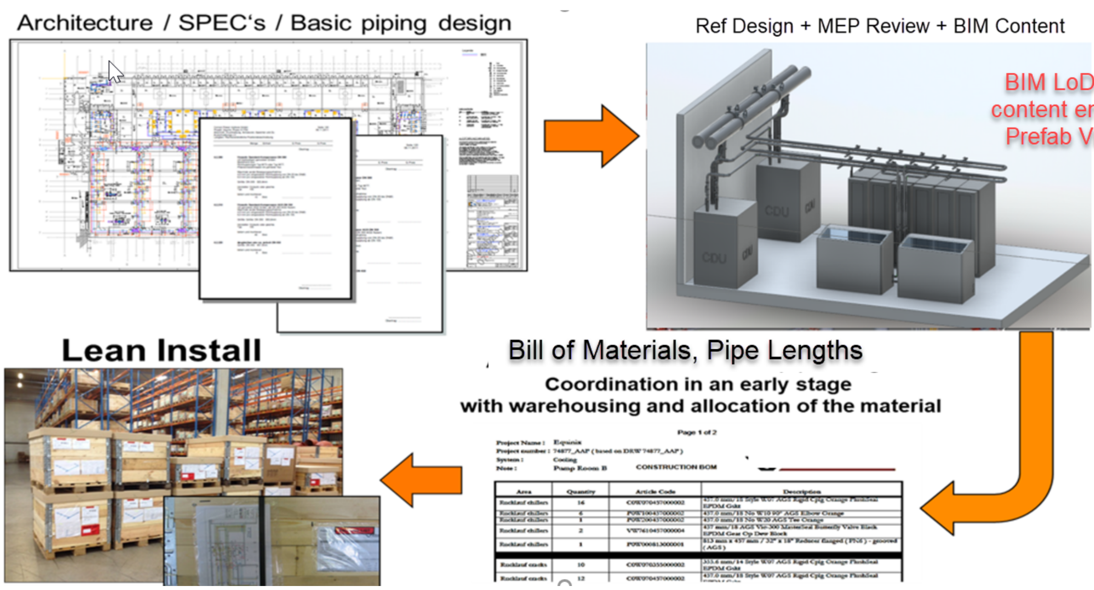
- MOPs **Method of Procedures -** step-by-step sequence for performing an operation such as maintenance. With liquid cooled ITE solutions, individual MOPs should be created for each component that requires periodic maintenance. MOPs should include:
    - Required tools
    - Required permissions, plant conditions
    - Safety tag-outs
    - Procedure for liquid protection, collection, addition
    - Close-out procedure and verification of completion
    - Actions if abnormal conditions are discovered.

- **EOPs** (Emergency Operating Procedure)- While emergencies may not be predictable, they can be anticipated. Examples include:
    - LOFA - Loss of Flow Accident. Should a pump fail, a strainer clog, there should be a procedure to ensure that work around solutions be available and a process to engage them
    - LOCA - Loss of Coolant Accident. Design should be optimized to avoid LOCA, but procedures to isolate and collect leakage

- **Commissioning** - Commissioning is the process of verifying system performance, integrity/safety, and the emergency procedures, standard operating procedures and maintenance procedures for the life cycle of the data center. Commissioning starts at the design stage, developing testing plans and operational procedures, ensuring that plant design supports requirements for performance testing, operations and maintenance. Key steps that affect plant integrity and reliability (i.e. pipe connections, strainers) should be verified and recorded by a trained quality control inspector.

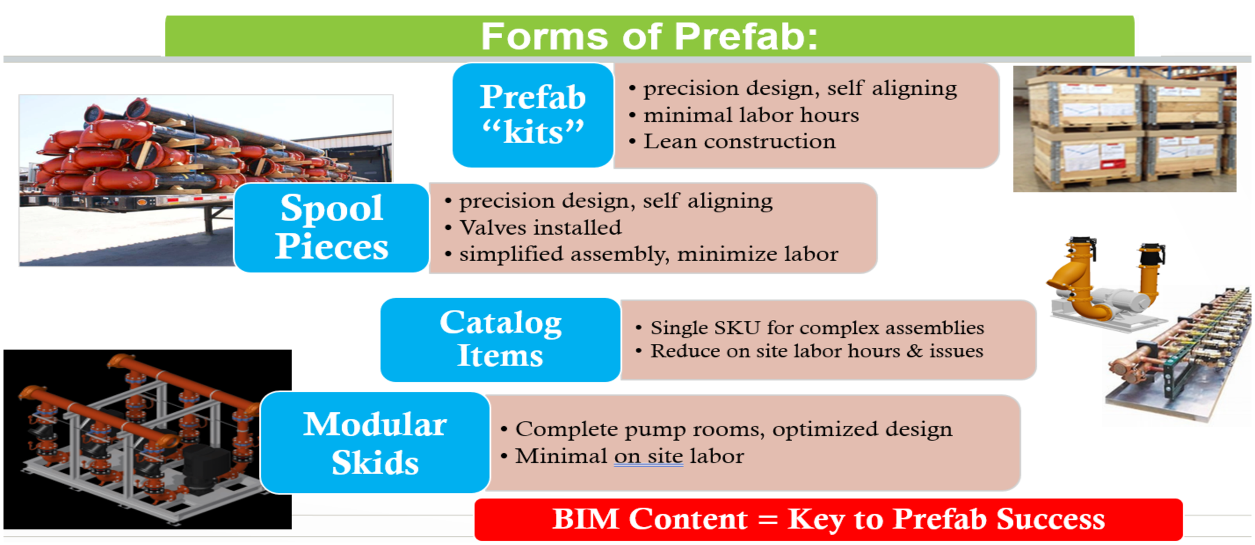
VDC Enablement of Liquid Cooled ITE in Data Center Life-Cycle

Virtual Design and Construction technologies are advancing rapidly and are keys to success in the life cycle planning of liquid cooled ITE. The process of transitioning from "Concept" to "Construction" designs is greatly simplified when solution vendors provide their products modeled with sufficient BIM definition and detail. Correspondingly, it is recommended that Vendors of OCP ACS solutions provide



accurate BIM modeling content of their solutions. Additional details provided in **Appendix A**

VDC to Prefab Delivery - BIM content from vendors simplifies the transition from concept drawings to precision construction grade drawings. Precision construction grade drawings enable offsite manufacture of entire solutions, to be delivered as **prefabrication kits, assemblies, catalog items and modules**. Prefabrication of solutions significantly reduces jobsite man-hours, schedule risk, minimizes critical trade skill choke points and optimizes job-site safety.



Conclusion

Addition of liquid cooled ITE is becoming a standard requirement over the life cycle of many data centers. As ITE refreshes occur 3-5 years, planning for the addition and exchange of liquid cooled IT can greatly enhance the life cycle performance, TCO and operational efficiency. Use of professional engineering planning teams will always be recommended.

However, sharing of reference designs and best practice guidance can significantly reduce the number of unknown challenges associated with adding liquid cooled ITE with minimal CAPEX impact on initial design. As the data center industry continues to advance and deploy greater quantities of liquid cooled ITE, the value of shared content increases and will be reflected in future revisions of this paper.

Appendix A. Recommendations for BIM definition and detail content of Vendor solutions

BIM content enables creation of construction documents with sufficient, but not excessive, detail for accurate planning and delivery of liquid cooled ITE solutions. When product vendors provide this information, it reduces the cost and time for engineers to deliver “concept to construction” drawings and enables rapid delivery of precision prefab kits and assemblies, with minimal waste and risk.

BIM families should have the following characteristics (aligns with LOD 350 definition)

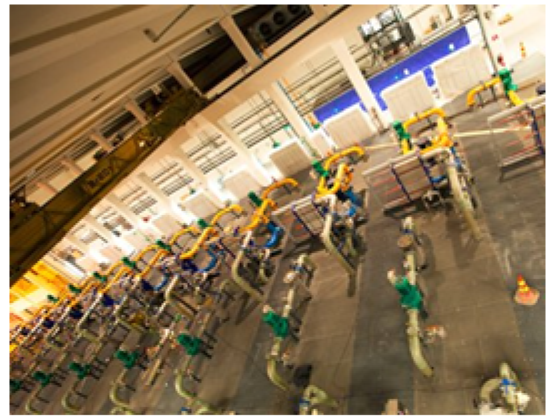
1. **Revit RFA format** (or Equivalent)
2. **Exterior surfaces and clearances with dimensions**. **500 KB is the maximum** recommended size for RFA files.
3. **Connections for piping, power and drain (if applicable) modeled in dimensionally accurate locations and sizes.**
    1. Note: if there are straight run requirements for piping connections to facilitate unit-mounted instrumentation, include the straight runs in the RFA so the designer can connect the piping to the RFA and already have straight runs accommodated.
4. Electrical connections should have voltage, phase, kVA and load classification parameters as a minimum.

Additional input of design and lifecycle value:

1. Water-side pressure drops and flow rates identified.
    a. Note: because these can vary based on application, it’s most important the parameters are in the model, assigned to the connectors, and editable so the designer can adjust based on the FWS design temperatures).
2. Telecom connectors identified and specified
3. End user data recommendation: ability to add additional COBIE data such as serial number, date of install/warranty, etc
4. All models should be hosted to the floor on which they are placed in the model.
5. Useful Parameters, not required. (Designers/engineer)
    a. Weight
    b. Floor Load (PSF)
    c. Max fluid temperatures
    d. Max fluid pressure drops
    e. Max fluid flow rates
    f. Max fluid working pressures

Appendix B. Cooling Distribution Loops

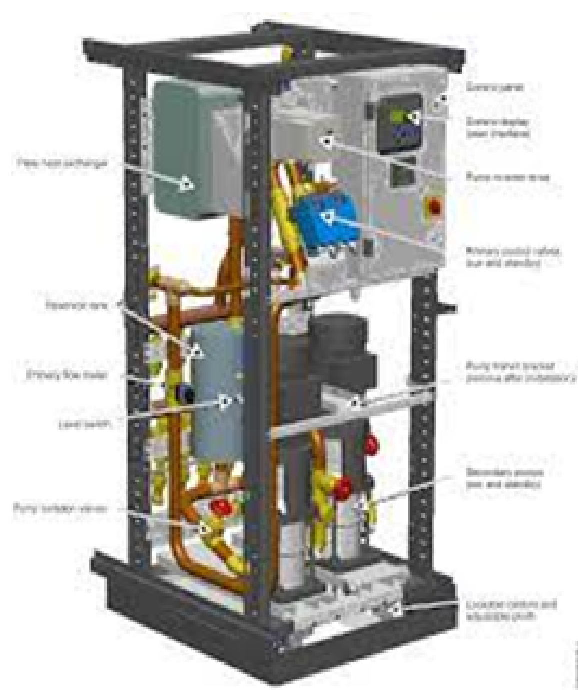
Cooling Distribution from ITE to the external environment can be optimized with coolant loops, separating fluid types, temperatures, quality requirements and pressures. Heat exchangers provide full isolation - protecting one loop from all issues associated with other loops.



When temperature balance is all that is needed, a 3 way balancing valve may provide an optimal solution. When the protections of an isolated loop is required, a heat exchanger provides the ultimate security. Isolated loops (using heat exchangers) can be split in two main categories:

1. Facility size cooling systems, which normally are room size. They are inevitably OUTSIDE of the server room, and are normally built on side either using loose components or skids

2. Cabinet size, self-contained, which typically sit inside the server room, and are referred as **Coolant Distribution Units**. A Coolant Distribution Unit (CDU) typically includes heat exchanger, pump(s), monitoring/control systems, filters and fluid maintenance access. Primary function of a CDU is cooling loop isolation required when the fluid type or conditions required by the ITE is different from that of the FWS, CWS system or heat reuse applications. In some cases, multiple loops may be beneficial, requiring use of multiple levels of CDUs.



CDU options include 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.

Key Functions/Benefits of CDU

Liquid cooling and heat transportation requirements vary throughout the heat transportation paths from ITE to the exterior of the data center. CDUs provide loop isolation, enabling optimization liquid transfer for the application and environment. As quantities of liquid cooled ITE increase, linking multiple liquid cooling/ transportation loops may be recommended for optimum efficiency, performance and risk avoidance. Examples of loop isolation may be a benefit include

- **Loop Temperature Requirements** - Optimum temperature for liquid cooled ITE solutions are often different from optimum FWS/chill water temperatures. Likewise, when a chiller plant is not used and direct connection to an external cooling source, a CDU can provide temperature stability and balance performance of both loops. Risk of **condensation** inside the ITE space can be prevented by use of a CDU at the entrance to the ITE space.
- **Quality Control -** Liquids used in ITE equipment often require tightly controlled standards of particulate and chemical composition, different from facility water solutions.
- **Pressure, DP Control** - Liquid loops supporting ITE often require different operating and maximum pressures than FWS systems. Ensuring adequate pressure differential and flow control is key as well
- **Fluid Separation -** Fluid type and chemistry vary depending on application. Glycol content for freeze protection, cold plate, dielectric fluid for immersion all may need to be separated from the FWS water.
- **Volume Isolation** - Restricting the quantity of liquid into the ITE space may align with risk control evaluation
- **Service Level Agreement (SLA) Boundary** - Different liquid cooled ITE solutions present diversity of requirements. The CDU can provide a simple boundary between facility ownership and ITE liquid requirements.

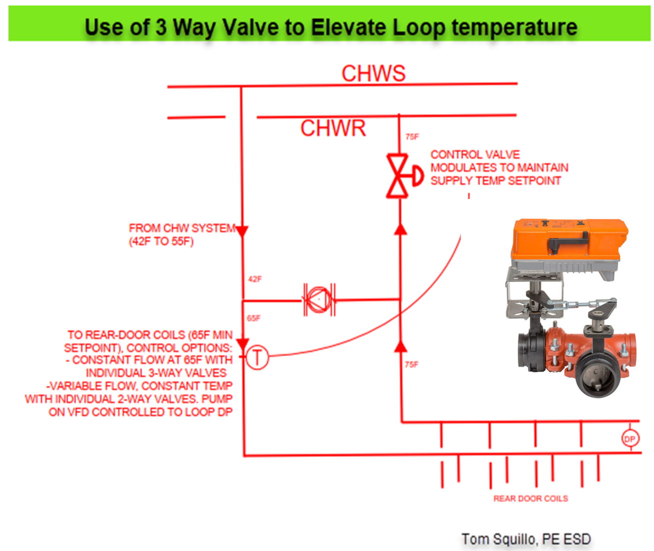
CDU Issues to Consider:

- **Maintenance, MOPs –** Heat exchangers, pumps require maintenance. In the case of smaller CDUs, maintenance may be swapping of the entire component. Larger CDUs will require service in place, typically exterior to the ITE space. Drainage resources and maintenance access need to be considered in design
- **Space –** Space for CDUs requires planning, as does associated pipe runs
- **Redundancy/Concurrent Maintainability –** All loops in the heat transfer path need to remain functional to support heat removal. MOP’s, SOPs, EOPs are required to ensure a LOFA (loss of flow accident) does not impact data center reliability and performance

- **Efficiency/Lift** vs **Cost/Size –** Heat exchangers incur a temperature rise from one loop to another, also known as “lift” that can impact data center efficiency. High efficiency, low lift heat exchangers typically cost more, require more space and more maintenance to maintain performance

Loop Temperature Control via 3 way valves

In situations where elevation of loop temperature is the only concern, a three way valve may provide an alternative to CDUs. Three way valves control loop temperature by mixing warm return fluid with incoming cool fluid. In the case of connection to FWS, a 3 way valve (diverting shown in figure) may be used to ensure temperatures connecting to the TCS are above dew point but within the optimum temperature range for the liquid cooled ITE solution.



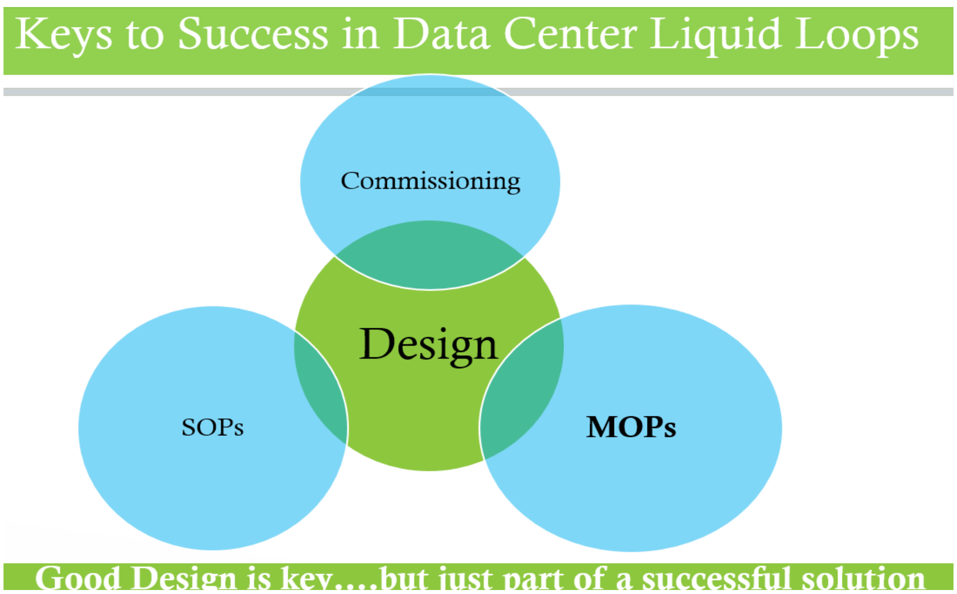
Likewise, in connection of FWS with external heat exchangers and heat reuse applications, a 3 way valve can be used to ensure external loop temperatures are above freezing and optimal for the external environment and application.

The arrangement shown in figure requires a pump to boost diverting valve branch pressure to a level suitable to force back into the supply branch ‘T’ the amount of warm return water necessary to achieve target ITE loop temperature. This configuration needs attention to control sequence, only operating the pump when the 3-way valve is positioned to allow enough flow for proper pump operation. It should also be noted that the ITE loop should always have enough flow to facilitate accurate temperature regulation. One should avoid ITE loops that deadhead the flow, or assure adequate bypass provisions. Other configurations are possible that offer tradeoffs regarding operating scenarios.

Benefit/Concern	Loop Isolation VS Temp Balance	
	Isolated Loop (CDU)	3 Way Valve
Temperature, delta T	Yes	Yes
Quality Control	Yes	No
Pressure	Yes	No
delta P	Yes	Possible
Fluid Separation	Yes	No
Volume isolation	Yes	No
SLA boundary	Yes	No
Cost	Higher	Minimal
Complexity	Higher	Minimal
Space Requirements	Greater	Minimal
Maintenance	HX, pump, valves	Valves, Smaller pump
Summary - 3 way valve is an option if only goal is loop temperature elevation		

Appendix C. Keys to Success in Data Center Liquid Loops

Success in data center liquid loop deployment depends on a balance of **good design**, a **commissioning process** that starts at the design level, fully validates performance and generates/validates **operating procedures** for standard operation, maintenance, and emergency conditions.



Optimize Design -

- Use **reference designs** as a starting point
- **Risk Analysis** - Review design for modes of failure, probability, and detectability **(Appendix D: FMEA**)
    - **Minimize severity risk** - change design, add protection
    - **Minimize probability of failure** - use connection methods less likely to fail
    - **Maximize detection** - where failure/leakage probability, maximize ability to detect

Operating Procedures - Use of standard/Maintenance and emergency operating procedures (SOPs/MOPs & EOPs) greatly reduces the probability of "operator error" which is the number one risk factor in data center operations.

Commissioning - Begins in the design phase and includes component testing, system testing, operational testing and validation of procedures. Commissioning should test real world failure modes and stress the system to the extreme side of design. During significant failure of electrical or mechanical systems certain electrical and mechanical paths will see up to 1.5 times the static state the system was in prior to failure.

Commissioning process includes:

- Validate system performance, integrity
- Develop & Validate procedures - standard, maintenance, emergency (SOPs, MOPs, EOPs)
- Identify the commission and testing procedures that will be used in the equipment RFP.
- Equipment will be tested in extreme conditions of elevated temperature and power demand, including
    - 100%, 125%,150% in the electrical design requirements
    - 100%, 125%,150% in the mechanical design requirements

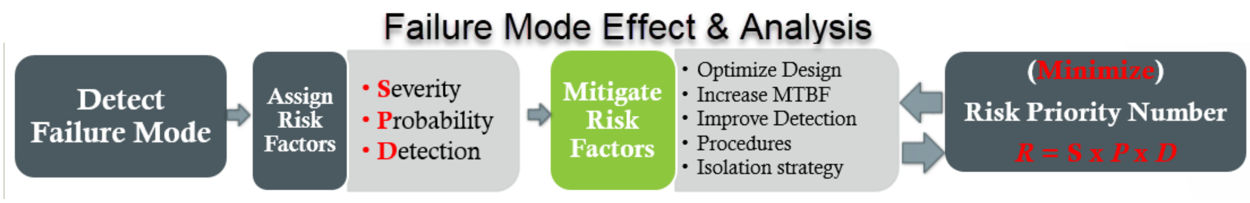
Design Highlights:

- **Redundancy Considerations**: While liquid cooling is much more efficient, effective than air cooling of ITE, liquid distribution through a data center is much more defined and constrained than air distribution. Liquid loop performance, concurrent maintainability requirements will often require consideration of redundancy and distribution interruption (see discussions on CDUs, for example).
- **Thermal RideThrough -** Should cooling chain stop, how long until ITE shutdown on heat.
- **Design Simplification** - elevated temperature range capability of liquid loops provides several key benefits in design
    - **Condensation** - Easy to avoid
    - **Elimination of Chiller Plants** - Global free cooling options
    - **External Heat Exchangers** - Heat Reuse options
    - **Temperature buffers** - Liquids have much higher specific heat capacity than air. Liquid volume can be designed to buffer temperature transitions in emergency conditions.
- **Standardized Connections** - Use of standardized connections enables design simplicity and addresses global supply chain challenges. (See OCP ACF Connections WP). Label with arrows and color code supply and return lines and connections.
- **Scalability** - Use defined BIM models (LoD 350-400) to create precision construction prefab solutions that assemble/install in existing facilities with minimal jobsite construction to impact operations.

Appendix D. Probability Risk Factor Reduction (FMEA)

Risk management can be addressed with analysis tools like the FMEA (Failure Mode and Effect Analysis. First step is identifying failure modes, then assign risk factors (severity, probability, detection) which combine to create a Risk Priority Number. A variety of actions can then be taken to reduce the RPN by reducing the risk factors and increasing detection:

- **Severity** - change design to reduce severity of failure mode
- **Probability** - use components or methods with higher reliability
- **Detection** - integrate detection methods or technologies (i.e. leak detectors & visual detection)
- **Procedures** - Many risks can be avoided by defining procedures and precautions. (MOPs, SOPs, and EOPs)



Examples of FMEA inputs:

Failure Mode Effect Analysis (Example Only)

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended	Resp.	Actions Taken	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
What is the design element or feature under investigation?	In what ways could the component or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the component or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?	What actions were completed (and when) with respect to the RPN?				
Rack Isolation Valve	*Water Leak*	*minor drip that may damage equipment*	*5*	*Loose Stem Packing*	*1*	*Occasional walk through by staff*	*6*	*30*	*Add leak Detection*	*Don*	*Design updated with rope leak detection*	*5*	*1*	*2*	*10*
		major leak that would damage equipment	*8*	*Flange Gasket Failure*	*2*	*Occasional walk through by staff*	*6*	*96*	*Add leak Detection*	*Don*	*Design updated with rope leak detection*	*8*	*2*	*2*	*32*
	Failure to Close Fully	*Not able to perform service without loop shutdown*	*7*	*Debris or rust ridge prevents full range of motion*	*2*	*No known controls in place to detect*	*8*	*112*	*Redundant Isolation Valve*	*Don*	*Update Design for Redundant Valve*	*6*	*1*	*8*	*48*
Welded Fitting	*Water Leak*	*Not able to perform service without loop shutdown*	*7*	*Defective Weld*	*3*	*Initial Pressure Test and Leak Check*	*3*	*63*	*Segment Loop with Isolation Valves*	*Don*	*Update Design for Segmentation of Loop with Valves*	*4*	*1*	*3*	*12*

Source https://integrispa.com/resource/fmea-template/

Reducing system risk is achieved by optimizing design, reducing probability, increasing detectability, or creating a procedure to ensure precautions are followed.

Probability, Ability to Prevent Failure/Leakage - Where severity (impact of failure) is high predictability of leakage or failure is key.Characteristics of connection types (thread, flange, grooved coupling, weld, crimped, fused) are discussed in OCP ACF Pipe Connection Guidance WP. Summary table provided below:

Ability to Prevent Leakage by Installation Inspection

	Inspection Method to Prevent		MTBF Data	Leakage/Failure Protection Recommendation
	Leakage	Failure		
ReConnection Methods				
Threaded	None	Visual	N/A	**leakage detection and protection recommended -** failure unlikely
Flange	Torque check	Torque check	N/A	**Leak detection/protection recommended.** Re-torque verification over life of pipe of critical joints
Grooved Coupling*	Visual	Visual	>185 million hours	Auditable record of proper installation inspection required to avoid additional protection.
Fixed Connection Methods				
Weld	X-Ray	X-Ray	N/A	Record of Radiography to avoid additional protection
Crimped/pressed	???	???	N/A	**Leak detection & failure protection recommended** Visual inspection may provide some validation
Fused	???	???	N/A	**Leak detection & failure protection recommended**
Pressure test is always a requirement				
***Grooved Coupling performance based on mission critical standards of design, quality control, certified inspection process**				
Pipe movement (thermal, vibration, building, seismic) can create leakage and possible separation in pipe systems if not addressed				

Appendix E. Closed Loop Cleaning Best Practices

Purpose for New Construction –

- To remove mill scale, mud, iron, grease and oils. The presence of these materials will cause plugging of heat exchangers, system fouling, and contribute to microbiological growth if not removed.
- To passivate and protect the metals in the system from corrosion. Provides a protective film to minimize corrosion. Reduces Bacteria present in the system.

Identify primary metals of construction in the system - mild steel, yellow (copper based), aluminum (aluminum not recommended for use in Data Center closed loops).

Recommended water velocities are 3 - 5 ft/sec for mild steel, less than 3 ft/sec for copper

Typical chemical cleaning and passivation products often contain

- Molybdate, Phosphates, Nitrites, Azoles
- Organic and inorganic acids/caustics, polymers, surfactants

Determine what chemical materials cannot be discharged in the wastewater effluent.
Chemical products that can meet discharge requirements and satisfactorily clean and passivate are recommended. Chemicals not meeting discharge requirements require a plan for post treatment or waste hauling of the cleaning solution. Identifying system volume is helpful for planning proper amounts of chemical treatments.

Prior to Cleaning/Flushing

- Bypass Heat Exchangers to Avoid Plugging. Use strainers where heat exchangers cannot be bypassed
- Require proper PPE for the Safety of employees and contractor employees.
- Eyewash station recommended in chemical treatment area.
- Ensure vents are in place so the entire system can be filled.

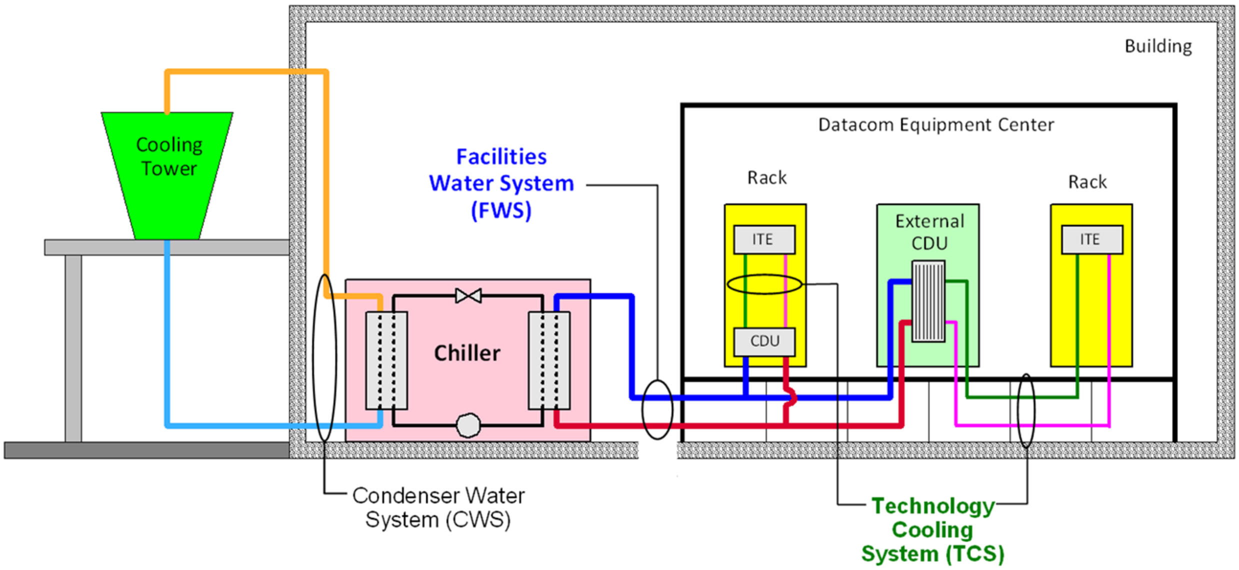
Flushing

- After filling and venting, begin circulating the water to main lines only if possible.
- Stagger bringing online heat exchangers to reduce bumping from air pockets.
- Dose the system with the Cleaning and Passivation product(s). Maintain required active ingredient concentrations and pH by testing and monitoring.
- A minimum of 24-48 hours is recommended, with 48-hours being Best Practice.

Draining/System Restoration

- After the prescribed minimum passivation period is over, prepare to drain the system according to local Municipality and Regulatory Agency guidelines.
- Clean all strainers and in-line filters and drain the system.
- Immediately refill the system, adding the closed loop chemical treatment slowly as makeup water is added to minimize flash corrosion on mild steel.
- Circulate completely for 1-2 hours. Promptly adjust chemical treatment active levels as needed.
- Startup Side Stream or filtration. Expect some iron throw in the first 2-4 weeks. Maintain iron levels below 3ppm by changing filters or media as often as required. Filtration removes remaining suspended solids to prevent under deposit corrosion.
- Begin regular system monitoring and testing including:
    - Closed Loop Treatment Inhibitors
    - Microbiological Growth
    - Corrosion Coupon Monitoring

Definitions



Information Technology Equipment (ITE): The computational servers, connectivity, networking and communication devices, data storage found in the datacenter and typically contained in racks

Conductive fluids: Coolant fluids that are capable of conducting electric current where both negative and positive particles are present. Variances in fluid conductivity depend on the Ionic strength and temperature, increased temperature increases conductivity measured in Siemens per meter (S/m) alternatively milli-Siemens per centimeter (mS/cm).

Non Conductive fluids: Coolant fluids that are incapable of conducting an electric current, commonly referred to as a dielectric. They can be referred to as insulators and contain or stop the flow of electrons.

Pipework: Contains liquid and allows the flow to transport liquids, typically cylindrical (*reword*), and is connected together to form a system that supports flow rate and pressures based on system requirements.

Coolant Distribution Units (CDU): As used in ACF discussions, the fundamental components of a Coolant Distribution Unit are a heat exchanger and pumps to provide isolation of cooling loops in the transportation of heat from ITE out of the data center. Advanced Cooling Solutions (ACS) discussions on use of CDUs for linkage of specific applications such as cold plate to FWS solutions. There are a variety of situations where a CDU may be used in an FWS solution as well.

Manifold: The manifold distributes cooling liquid from a central pipe to multiple pipes, alternatively from multiple to one, and can be located with the CDU, at the row-level or inside the rack. The cooling liquid requires two-way transport called supply and return.

Couplings: A device that used to connect pipework of the same or different diameter. Grooved couplings connect two sections of pipe that have a groove rolled in the end (global standards associate specific groove dimensions based on pipe outer diameter. “Mission Critical Grade” grooved couplings are coupling solutions with design, quality control and installation verification process to support 20+ year performance without issues.

Pipework Design: The integrity of pipework starts off with design requirements which include multiple components such as; spatial requirements, minimizing frictional points, pipe diameter, pipe joints, isolation, condensation, cost, heat load, and cooling duty, building codes including seismic and regulatory compliance. (Check cold requirements documents)

Heat exchanger: For the purpose of heat transfer between two isolated liquid circuits and prevents mixing. Flow arrangement of fluids can be counter-flow where liquid passes from opposite ends or parallel-flow where liquids travel in parallel in the same direction.

·References

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About Open Compute Foundation

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