Guidelines for Connection of Liquid Cooled Information Technology Equipment (ITE) to Data Center Facility Systems

Revision 1, Version 1.0

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Revision History

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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). The purpose of this paper is to develop standardized practices in connection of vendor-based ACS solutions to Facility Water Systems (FWS) and/or Condenser Water Systems (CWS) with the objective of maximizing scalability, efficiency, reliability at lower cost and minimal operational impact.

There are many types of liquid cooled solutions (including ACS Immersion, ACS Cold Plate, ACS Door Heat Exchanger). Data center technology refresh happens many times during the life of a data center. Introducing standardized connection methods is essential to maximize “open” use and interchangeability of technologies with minimal impact, time and cost. Liquid cooled ITE has been successfully deployed for decades, primarily in support of High-Performance Computing (HPC) functions and typically deployed as part of initial data center construction. However, technology refresh of such facilities has been restricted to a limited scope of solutions, often requiring facility shutdown in the process. Emergence of a broad spectrum of high-density applications such as Artificial Intelligence (AI), Virtual Reality (VR), Augmented Reality (AR) and Machine Learning (ML) have driven expansion of liquid cooled IT solutions. Adding and changing liquid cooled IT is becoming a standard requirement in data center operations, requiring standardized connection practices and procedures to support adoption and modification at scale.

Definitions

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

Pipework: Contains cooling liquid and allows the flow to transport liquids, typically a tubular section, and is connected to form a system that supports flow rate and pressures based on system requirements.

Dewpoint: The atmospheric temperature below which condensation (dew) appears.

Coolant Distribution Units (CDU): The Coolant Distribution Unit, CDU, provides an isolated cooling loop to the ITE. Heat transfer occurs inside the CDU, via a heat exchanger, between the heated liquid from the ITE loop (TCS) and the facility liquid (FWS) on the facility side. There is no coolant flow between the TCS and the FWS from ACS Cold Plate. However, ACS IMMERSION solutions may use a CDU or may contain an internal heat exchanger. ACS Door Heat Exchanger (HX) typically will connect directly to the FWS.

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.

BIM: Building information modeling (BIM) systems used for reduction in collisions and greater collaboration between building trades and designers

Grooved Couplings: ASTM F1476 provides definition and guidance around gasket mechanical couplings (GMCs) including grooved-type mechanical couplings for grooved end pipe, including classification of rigid and flexible. Use of grooved couplings in mission critical applications requires meeting the standards in design, quality control, and a certified, auditable installation procedure to ensure 20+ year performance with no maintenance.

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. Different types of Door HX are found in section 1.3 of OCP ACS Door HX Specification for Open Rack

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Introduction

Connecting Advanced Cooling Solutions (ACS) to Facility Water Solutions (FWS)

This paper summarizes key considerations where standardization of connection solutions advances success of liquid cooled IT solutions, highlighting best connection practices in deployment of liquid cooled IT solutions. ITE upgrades are common in the life of data centers. Simplifying and standardizing the methods of ACS connections is essential to industry success in use of liquid cooled ITE.

Connection of ACS to FWS benefits from standardization for OCP facilities in a similar way that OCP standardization of ITE rack connections and form factors have benefited the data center industry. **ITE is connected directly to the FWS or via a CDU** that creates a protective TCS (Technology Cooling System) separated from the FWS by a heat exchanger. Simplifying and standardizing the connection of ITE and/or CDUs supporting ITE deployments is key.

Guidance in this paper integrates with guidance provided by OCP Advanced Cooling Solutions (ACS) Sub-Projects around Door Heat Exchangers, Cold Plate, and Immersion.

Design Considerations- Adding Liquid Cooled ITE

Liquid cooled ITE connects to the data center FWS either directly or via a CDU. In the case of direct connection to the ITE, there is a heat exchanger inside the ITE. In the case of CDU, the heat exchanger is inside the CDU. As such, the fundamental components of connection include:

- **Connection/ isolation** - reducing Mean Time to Repair (MTTR), optimizing concurrent maintainability
- **Vent, drain, flush** connections to facilitate draining for maintenance and flushing of upstream pipe system without fouling of strainers and heat exchanger.
- **Strainer** to prevent contamination of heat exchanger coils during normal operation.
- **Flow balancing valve** to stabilize pressure differential across the CDU or ITE
- **Metering points** for differential pressure (dP) and flow measurement
- **Alignment** accommodation for both connection simplicity and mitigation of pipe movement issues.

Connection lines under 2inch often benefit from quick disconnects. However, lacking a global standard that is not proprietary in nature, recommendation of a thread standard enables use of quick disconnects as well as threads, as quick disconnects generally attach via threads. General application information and guidance such as mechanical attributes, material/fluid compatibility, thread type, etc. can be found in the OCP white paper Hose and Manual Couplings - Best Practices. Standardizing thread type makes the exchange process easier.

Key areas where standardization would benefit:

- Compatibility of all OCP ACS solutions to ASHRAE (see reference 2.g) defined FWS guidelines
- Pipe sizes, pressure rating
- Connection types, markings, color coding on quick disconnectors near ITE
- Maximizing use of Building Information Model (BIM) precision

Compatibility with OCP ACS: Wherever possible, each OCP ACS technology (Door HX, Cold Plate, Immersion) should seek to use common connection methods to the FWS, either with direct connection to the FWS or using CDUs. This interface needs to conform to OCP standards. The following specifications for FWS are implemented and required for each applied technology.

[Note - this guidance was taken from OCP ACS Immersion Document Ver 2.0 section 8]

- **Input/output differentiation**: For each OCP ACS system, FWS interface must be clearly visually marked as inlet or outlet.
  - Inlet: Provision with blue paint, tape or other & arrow symbol indicating direction of flow
  - Outlet: Provisioned with red paint, tape or other & arrow symbol indicating direction of flow
- **FWS compatibility:** All solution connections to FWS systems should meet design requirements to support any FWS with partial vacuums down to 50 kPA (absolute) and pressures up-to 800 kPa (gauge). Both plain water and glycol mixtures upto 50% should be supported, as well as any other OCP compliant coolant definition. Filtration and water quality management of the FWS system follows guidelines of ASHRAE TC 9.9 (see reference 2.g). It is the responsibility of data center owners to identify exceptions to the pressure range guidance. If facility pressure ranges are predicted to exceed OCP guidance, the facility owner is responsible to address pressure control issues.
- **Connection Point Location (High/Low) -** ITE connection to FWS should support connection to overhead or underfloor FWS distribution systems. Where ITE connects to FWS via a CDU, the CDU should support easy access to overhead or underfloor distributions.
- **Pipe Connection Size Planning –** Connection sizing is the key parameter setting the KW capacity of future liquid cooled ITE. Estimating pipe size versus KW capacity is a function of flow and delta T. Table 1 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 ultimately will be required. 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)*(specific heat capacity of fluid)

Constant Flow				Delta T							
Pipe Size		ASHRAE 90.1-2019		4	6	8	10	12	14	16	C
				7.2	10.8	14.4	18	21.6	25.2	28.8	F
DIN	in	l/s	GPM	Max kW							
50	2	2.97	47	50	75	99	124	149	174	199	
65	2-1/2	4.29	68	72	108	144	180	215	251	287	
80	3	6.94	110	116	174	232	290	348	407	465	
100	4	13.25	210	222	333	444	554	665	776	887	
150	6	27.76	440	465	697	929	1162	1394	1626	1859	

Table 1: Maximum practical cooling, pipe size vs. fluid temperature rise by OCP ACF Project Community

OCP ACF Discussions on Reference Designs as well as discussions from Advanced Cooling Solutions Sub-Projects (Door HX, Cold Plate, Immersion) provide additional information on flows, fluid types and delta T recommendations. But connection diameter ultimately defines maximum capacity limitations.

ITE Connection Point Standardization

The connection point where the IT touches the FWS is a key consideration for standardization. By standardizing this initial connection point, concerns around interchangeability and global supply chain can be minimized. Standardization of connection points allows vendors of ACS solutions to manufacture a single, global product, with adaptors as necessary to address local standards.

Recommendation of connection point standards is based on several criteria:

- **Global availability** of standards
- **Supply Chain Impact**
- **Open Source** - OCP does not promote a specific Intellectual Property
- **Verification of Proper Installation** - The ability to visually verify installation will not demonstrate catastrophic failure. Where possibility of leakage exists, containment and leak detection is recommended.

ITE Thread Connections: Rack-based cooling solutions (Door HX, Cold Plate, Immersion) typically connect with 0.75 inch/DN20, 1 inch/DN25 or 1.25 inch /DN40 pipe diameters. Most vendors standardize on one thread type, and ship adaptors as required to meet regional requirements. Failure to identify thread type often leads to delays in installation or leaking connections. Recommendation is that British Standard Pipe Parallel (BSPP) thread become the global standard thread type for OCP connections. In many cases, data center owners will insert quick disconnects, and BSPP thread is globally available from most quick disconnect vendors.

Rack and Door Pipe Connection Thread Standards - BSPP		
.75"/DN20	1"/DN26	1.25"/DN40

Table 2: ITE thread connections, NPT & DN nominal sizes (in inches)

Quick Disconnects: Quick Disconnects have many favorable attributes for connections that are used frequently, particularly in liquid cooled ITE equipment with pipe and hoses less than 1.25inch diameter. The ability to quickly change connections with minimal leakage (non-spill) is a key benefit, but many quick disconnect devices create a pressure drop that can affect design and energy usage. At diameters over 1.25inch, operation of quick disconnects becomes increasingly difficult at FWS pressures due to increased hydrostatic thrust force on the connections (see table 3).

NPS	DN	Area (in)	force (LBF) @100PSI
0.5	15	0.30	30
1	25	0.86	86
1.25	32	1.50	150
1.5	40	2.0	204

Table 3: Pipe size vs. thrust force at 100 psi

Isolation valves upstream of quick disconnects are strongly recommended. There is no global, non-proprietary standard for quick disconnects. Most quick disconnect solutions to FWS attach via thread connections; selection of a global metric thread standard enables use of quick disconnects, as was recommended by global vendors of quick disconnects on this subproject. Data center owners seeking to use quick disconnects are encouraged to review the "Hose and Coupling" paper, OCP Manual Couplings at Hoses

Connection Recommendations ≥ 2 inch/DN50

For connections to CDUs and immersion tanks using diameters ≥2 inch/DN50, grooved couplings or flanges are most common. Feature summary table below.

Connections: 2"/DN50 to 8"/DN200 Class 150 Flanges Vs Mission Critical Grooved Couplings		
	Class 150 Flange	**Mission Critical Coupling**
Bolt Count	**4 to 8 bolts**	**2 bolts**
Alignment adjustment	**none**	**Multi axis alignment**
Movement	None, requires torque verification	design feature
Vibration Mitigation	None	design feature
Inspection method to prevent leakage	torque + pressure test; re-torque as needed	Visual inspection + pressure test = certified for life of pipe system
MTBF	N/A	>185 million hours

Table 4: Class 150 Flanges vs. mission critical couplings by OCP ACF Project Community

Grooved Coupling Connections (see Appendix B1)– For pipe sizes 2 inch/DN50 and larger, grooved couplings provide advantages in speed, reliability and standardization. For most types of pipes used in data center applications, ASTM F1476-01 would be the reference standard. The groove is “rolled” into the pipe, eliminating the need for hot work. Unlike flanges, pipe loading and pressure forces are carried by housing engagement of pipe groove, not bolts. Properly designed coupling and gasket assemblies can provide maintenance free performance over the life of the system with a visual installation inspection. Grooved coupling connections are available for all common metallic and non-metallic pipe solutions used in data centers.

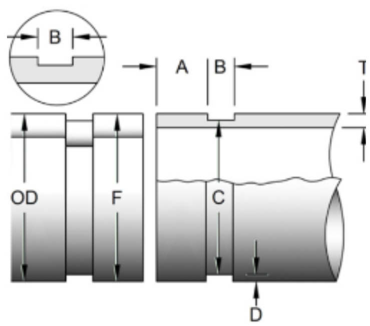

Figure 1: Groove Pipe Connection Dimension

Grooved coupling systems used for "Mission critical" applications should be held to exceptionally high standards of holistic engineering, vertically integrated quality control and certified installation verification processes

- **Holistic Design** - Holistic design is looking at system impact and benefits of integrated systems. Flexibility and movement shall be engineered and defined quantities to accommodate pipe movement, alignment, vibration mitigation. To optimize BIM based precision prefab design and delivery, all coupling connections, fittings and components shall be modeled dimensionally accurate in Revit RFA format content (LoD 350 or 400).
- **Vertically Integrated Quality Control** - housing and gasket should be made by the same manufacturer and individually marked to provide traceability to date, location of manufacture and associated quality tests. Gasket type and performance validated for the type and temperature of the liquids. Housing and gasket certified for pressures ranging from full vacuum (29.9 inch Hg/760 mm Hg) up to maximum system design pressure).
- **Certified Installation Performance** - manufacturer shall certify that couplings are designed to be *leak proof, maintenance free for 25+ years* based on visual verification of proper installation. An auditable commissioning process to provide maintenance free performance for the life of the system shall be provided (see Appendix B)

Flange Connections (Appendix A3)- Use of flanges as connection points has a lengthy history in pipe solutions. However, flange usage for component interchange can be challenged by alignment and alignment stresses created by pipe movement. Flange alignment can change with temperature and building movement, making reconnection of flanges a complex task on pipe solutions. When flanges are used with rigid pipe

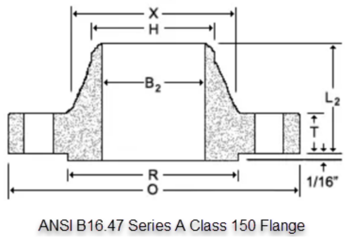

Figure 2: Series A Class 150 Flange

solutions, additional devices are required to enable installation alignment and to mitigate effects of movement and vibration. Water pressure and thermal pipe movement creates loading on flange bolts which may necessitate torque verification as well as complicate maintenance.

Alignment Considerations - Alignment of pipe solutions present challenges in delivery and lifecycle maintenance. Alignment and installation of flange and thread connections require some level of flexibility in the piping solution. As pipe systems change temperatures, movement occurs and creates alignment stress and maintenance challenges. Hoses and alignment devices can simplify and maintain pipe system alignment, but typically have life spans less than 20 years and as such should be treated as maintenance items in both location and scheduled maintenance/replacement plans. Another solution that addresses movement and alignment issues is use of grooved couplings. Properly designed grooved coupling solutions can accommodate pipe system movement, vibration and alignment concerns, with reliability lifespans much greater than 30 years.

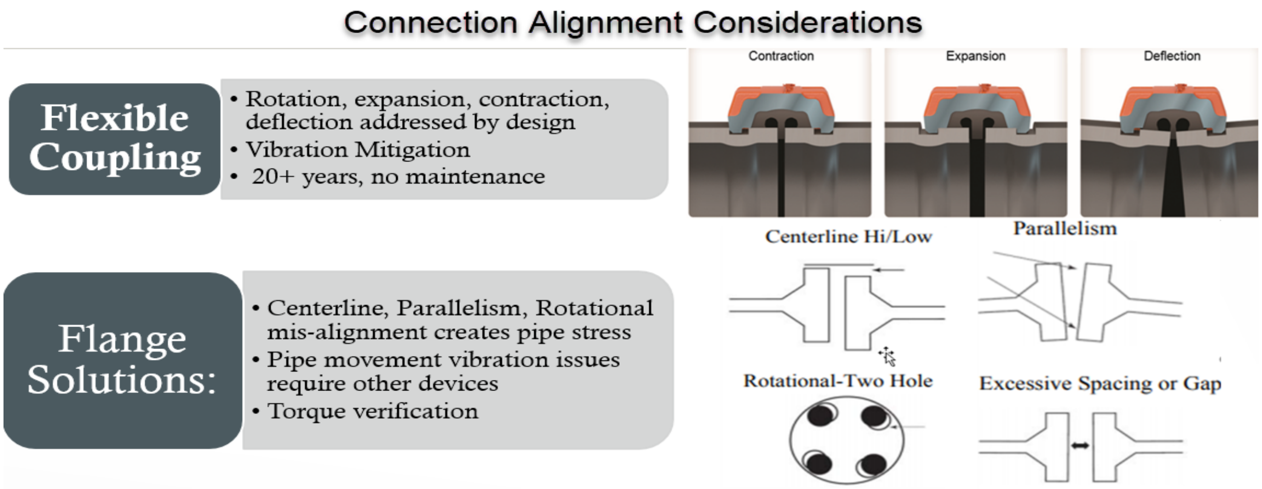

Figure 3: Connection Alignment Considerations

Flexible Hose – Flexible hose connections are most common in connection lines under 2inch diameter. The "[OCP ACS Hose and Manual Couplings - Best Practices]" paper provides guidance and references on hose selection and test criteria and associated standards to consider. Considerations include:

- **Life expectancy** – Pipe solution lifespan used in FWS solutions is expected to equal "life of the building." Components with performance expectations less than "life of the building" should be treated as maintenance items with replacement scheduled well within the manufacturer's warranty and recommendation period. General industry guidance for "mission critical" hoses is 10 years. Access for maintenance and periodic visual inspection should be provided.
- **Critical Bend Radius -** Hoses and flexible connections have critical bend radius limitations that need to be considered in reference design development and can significantly impact solution delivery.
- **Head loss** – Routing of pipe and hose solutions (bends, pinch points) can affect head loss of the liquid distribution and impact pump sizing and energy required.

Flexibility using Rigid Pipe - For connection lines 2 inch and larger, use of flexible couplings can enable flexible pipe connections and address alignment, movement and vibration concerns with a design life of 30+ years without maintenance. Pipe system components with BIM LoD 400 level of definition can be accurately delivered as prefab assemblies, without

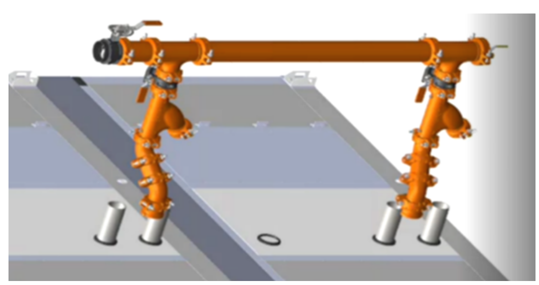

Figure 4: Rigid Pipe Flexibility

critical bend radius limitations. Pipe solutions can avoid risk of pinch points, bend radius and variations in head loss often common in hose solutions

Dew point - As discussed in OCP ACF maintaining FWS liquid temperatures above dew point greatly simplifies liquid distribution solutions. When pipe surface temperatures fall below dew point, condensation may collect on the surface. Per ASHRAE TC 9.9 Guidance, the **recommended dew point limit** for air cooled data centers class A1 to A4 **is 15 °C**. (Allowable dewpoint limits increase per ASHRAE class, see Table 2). Maintaining liquid temperatures above dew point provides a safety barrier to condensation concerns. Systems such as cold plate and immersion cooling not utilizing mechanical cooling (ie. refrigeration/chiller) generally can and should utilize liquids well above dew point limits.

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
ASHRAE TC 9.9 © 2021		

Table 5: Dewpoint Limits

FMEA Analysis to Reduce Liquid Cooled ITE Connection Risk - The connection point and associated components should be evaluated for risk and protected accordingly. Failure Mode & Effect Analysis provides a systematic method to reduce risk by reduction of **severity**, **probability** and **detectability**.

(see OCP ACF Reference Design WP discussion on FMEA))

Connection location and methodology deserves consideration around frequency of disconnection, potential for significant liquid leakage and severity concerns associated with liquid leakage. Location of connection point can greatly influence **severity risk**. Likewise, the potential of significant leakage can be greatly minimized by creation of **standard procedures** identifying the steps to isolate, drain the connection line and to verify system integrity when restoring components. Most connection methods will present the potential for some level of minor leakage. Use of leak detection devices and drip trays is addressed in OCP White Paper on "Leak Detection and Intervention".

Selection of connection methods should align with the severity risk of location. Not every connection requires investment in leak detection and protection. Depending on the frequency of use and ability to detect proper installation (reduce **probability risk**), some connections may not present a risk of leakage.

Connections where an inspection process (radiography/visual inspection + pressure test) can verify leak proof performance are recommended, especially in areas of high severity risk (See Appendix A). Use of leak detection and protection may not be necessary where leak proof performance can be verified. Connection methods that can not be verified should not be used in areas of high severity risk, and use of leak detection and protection is recommended. See Appendix B for breakdown of connection types vs ability to detect issues that may lead to leakage or issues.

Components with warranties or **lifespans less than 20 years should be scheduled for maintenance** and/or extra protection. Examples include hoses, strainers, valves, flanges, movement devices. Several options:

- **Location -** Locating components that require maintenance in low-risk locations
- **MOP –** Method of Procedure for maintenance, replacement. Commissioning and operations team develop an MOP and maintenance schedule that minimizes risk, maximized protection
- **Leakage detection, protection/collection –** where leakage would impact operations, drip trays and leakage detection should be integrated into data center management system and maintenance plans

Key Components / Functions of Connection Lines - Connection lines to liquid cooled ITE provide a variety of functions to optimize system performance over the life cycle of the ITE and the data center.

Standardization of connection lines provides consistency in pressure balancing and distribution. With large scale, multiple unit deployments, replication of line geometries can simplify flow balancing. Where hoses are used, variations in lengths, bending and "pinch points" can produce variations in head loss and should be minimized.

Component Breakdown

- **Balancing valves** may be used to stabilize pressure differentials across multiple components connected to a common loop. Maintain available DP across a temperature control valve to optimize performance (valve authority) and system efficiency. The benefit of balancing valves increases with the number and diversity of liquid cooled ITE devices. Performance issues include temperature rate of change stability during system or loading transitions
- **Temperature/Flow control valves** – Are typically included internal to the ITE or CDU to adjust flow and maintain temperature/DeltaT through the heat exchanger. Use of balancing valves to stabilize pressure differential can enhance the performance of temperature/flow control valves

- **Vent, drain ports** – To simplify exchange and maintenance of ITE and CDU solutions, vent ports should be available at system high-point, drain ports at system low points. MOPs should include instructions on containment/collection of liquid. Drain ports are often incorporated with the strainer
- **Strainers** - to prevent contamination of heat exchanger coils during normal operation, strainers protect ITE and HX by removing random particulates during normal operation.
- **Flush lines** – During initial commissioning and major system updates, pipe systems should be flushed to ensure all contamination from construction processes are removed. ITE and CDU components (HX and strainers) should be isolated from the system during pipe system flush using flush connections.
- **Metering points** – pressure/temperature ports for dP and flow measurement. Redundancy of ports can improve reliability of measurement. Many ITE and CDU solutions have ports included.
- **Isolation valves & disconnects** – Isolation valves facilitate exchange and maintenance of ACS solutions. Ability to vent and drain supply and return lines is also necessary. For smaller diameter lines, quick disconnect devices are often used, typically threaded into the ITE.

Rack Based ITE - Connection lines for ITE racks (Door HX, Cold plate or rack-based immersion will typically be between 0.75 inch to 1.25 inch and connect to the rack via threaded connection point (to which a quick disconnect may often be added by facility owner.

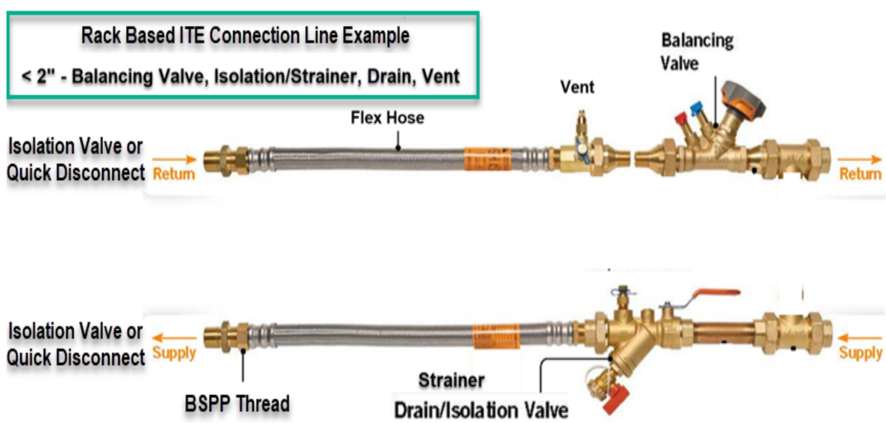

Figure 5: Rack based ITE

CDU & Tank Based ITE

Connection lines are typically 2 inch or greater. Grooved couplings or flanges are typically used for larger diameter connections

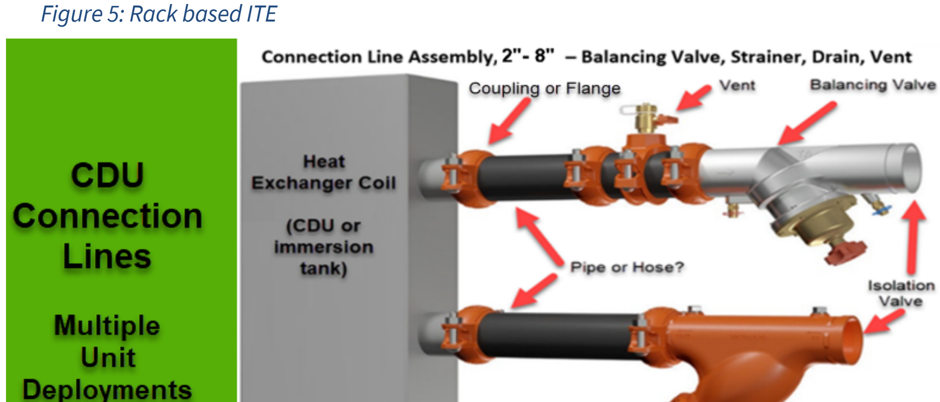

Figure 6: CDU and Tank Based ITE

Conclusion

A broad spectrum of liquid cooled IT technologies is rapidly being introduced into the data center industry. As industry deployments advance from limited quantities to “cloud-scale” - potentially hundreds or thousands of units - standardization of connection methodologies becomes essential. Liquid cooled IT solutions have been successfully deployed for over 40 years, demonstrating that liquid distribution and piping solutions when properly designed and commissioned can be exceptionally reliable. Density and efficiency trends suggest increased deployment of liquid cooled IT in coming years. With IT refresh cycles for data centers occurring every 3-5 years, adding/exchanging liquid cooled solutions is likely to become a standard operation for many data centers. **Optimizing the speed, reliability, and reduction of cost when deploying at scale requires standardization of connection methods.**

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Appendix A: Connection/Disconnection Considerations

Summary - Discussions provided to highlight performance characteristics to be validated. Pipe joining methods can be broken into categories of those that can be disconnected (threaded, grooved coupling, flange) and those that are permanent. The **ability to detect leakage and/or failure prior to occurrence** are key factors to consider when evaluating suitability of location (severity risk) and level of investment into leak detection and protection required (see figure 1).

	Detection 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* (*Mission Critical Rated)	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	None	None	N/A	**Leak detection & failure protection recommended** Visual inspection may provide some validation
Fused	None	None	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				

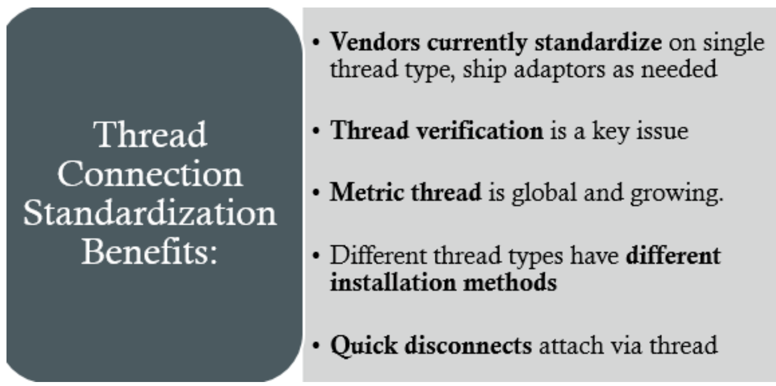
Figure 7. Summary of Connection Method vs Detection Method to Avoid Leak and Failure by OCP ACF Project Community

In addition to the inspection and installation verification methods listed, commissioning of pipe systems should include a pressure test of the entire system, either hydrostatic or low-pressure pneumatic pressure test as recommended by the design engineer and commissioning agent.

Appendix A1. Threaded Connections

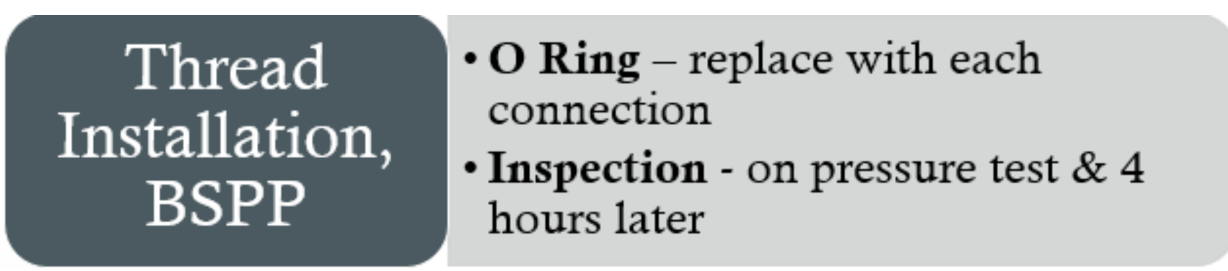
BSP-Parallel Thread (female) is recommended as the global standard for FWS connection point thread-type for door HX and rack solutions (1 inch/DN25, 1.25 inch/DN40). Adoption of this recommendation is expected to take up to 2 years, during which many vendors may choose to meet the recommendation by supplying OCP compatible adaptors.

The key benefit of connection point thread standardization is simplification of installation. Different thread types have different installation requirements. Mixing thread types by mistake can be easy to do and may go undetected, developing leaks over time



Threads come in a variety of types. Manufacturers of liquid cooled ITE equipment historically often standardize around one global thread type for the connection point to their product, and then provide adaptors (thread or quick disconnect) as preferred to local regions. The recommendation from Open Compute Project Advanced Cooling Facilities is that the connections to the liquid cooled ITE be BSPP.

The focus of this discussion is understanding best practices and issues associated with connection of two types commonly seen in plumbing and pipe distribution networks.



Appendix A2: Grooved Coupling Considerations

Key Points to Check

Grooved couplings designed to mission critical standards should provide a visual inspection method to verify proper installation. When properly installed, mission critical rated grooved couplings have demonstrated ability to perform without leakage for the life of the pipe solutions. Correspondingly, the commissioning process should include visual inspection and pressure test:

Variables to Control	Potential Issue	Non failure Detection Method
Coupling not properly installed	Coupling housing must be fully engaged in groove	Visual Inspection + Pressure Test
Improper groove geometry	Coupling housing must be fully engaged in groove	Visual Inspection + Pressure Test
Pipe surface imperfections	Water seepage due to microchannels	Visual Inspection + Pressure Test

Figure 8: Grooved Coupling Installation Verification

When couplings are used in areas of high severity, an auditable, traceable method to verify inspections were performed with successful results is recommended

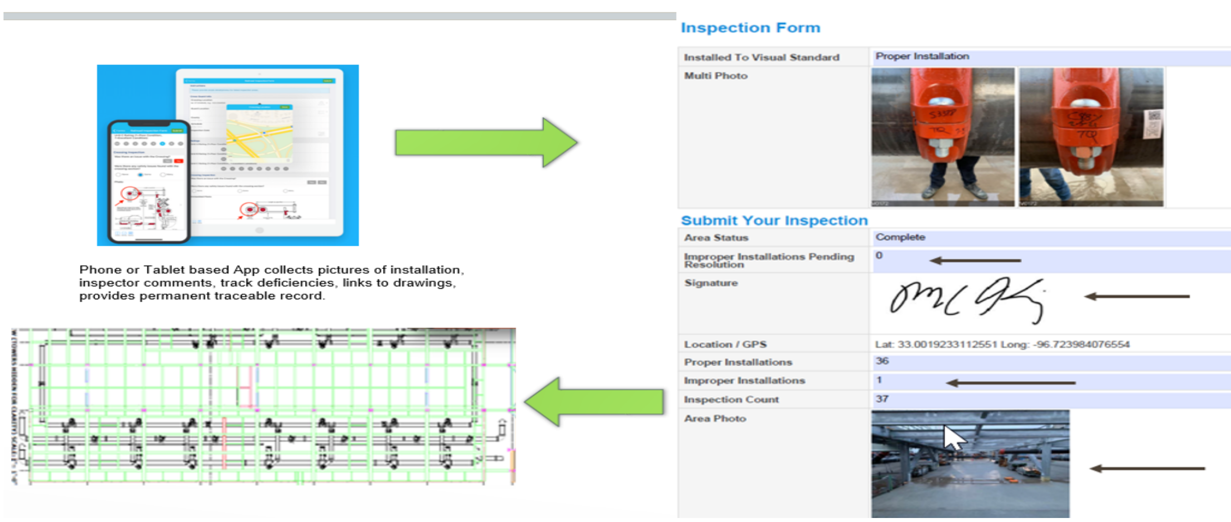


Figure 9: Example below of an auditable, traceable installation inspection process

When properly installed and commissioned, “mission critical grade” grooved coupling solutions provide exceptional reliability, with MTBF in excess of 180 million hours. Commissioning should include visual inspection to verify installation, combined with pressure testing.

With proper installation and inspection, mission critical grade grooved coupling solutions have demonstrated reliable performance without maintenance for well over 25+ years. Studies performed by the Department of Defense and Alion Research determined MTBF of mission critical couplings to be in excess of 185 million hours:

Reliability Study Chart, Mission Critical Rated Coupling Solutions[1]

Connection Type	Failure Rate (per 10^6 Hours)	MTBF (Hours)
Mission critical rated Grooved Coupling/Fitting	0.00537726	185,968,230

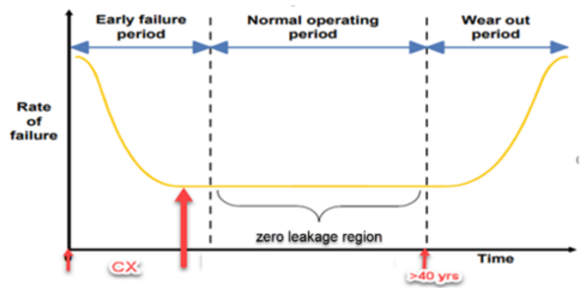


Figure 10: Reliability Study

Appendix A3: Flange Joints

Key Points to Check

Verification of proper flange installation requires multiple steps. Attached excerpts from an ASCE publication are provided to provide high level perspective:

- **Alignment** - Proper alignment of the joint before tightening is critical - both center alignment, parallelism, rotational alignment and proper gap. Rigid pipe systems will require some sort of alignment device or flexible joint to enable successful use as a connection method for ITE cooling.
- **Gasket Creep** - Flange gaskets typically relax after loading, as much as 20-50% of thickness, typically within the first 4-6 hours.
- **Torque** - to minimize uneven loading of gaskets, bolts should be tightened in a crisscross pattern. Torque verification should be performed at initial installation and reverified at least 4 hours after initial installation. Accessibility to torque test is required.
- **Maintenance** - Over the life of a pipe system, vibration, pipe movement (i.e. thermal changes) may require re-torque of bolts. Flanges in high risk locations should consider leak detection or periodic torque verification, especially after transition events.

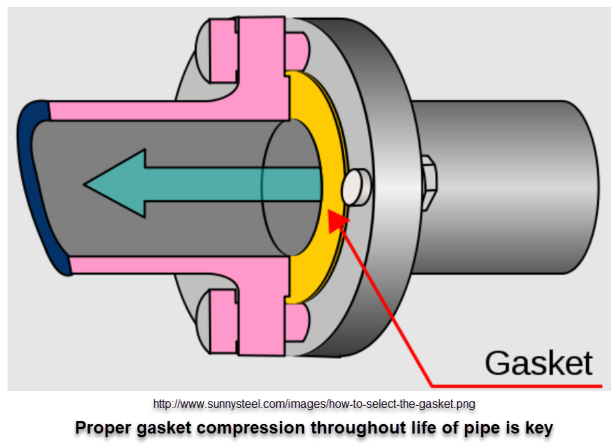


Figure 11: Proper Gasket Compression

AWWA C207 (2013), AWWA M11 (2004) and ASME PCC-1-2013 provide detailed flange specifications and assembly guidelines to help installers, inspectors and engineers avoid field problems

Flanges commonly come with two types of faces – raised face (RF) and flat face (FF). Raised face flanges have a raised area that surrounds the pipe bore. Flat face flanges don't.

Raised Face Flange - most common flange face type, has a raised surface above the bolting circle where the gasket is placed. Sealing is accomplished by compressing the gasket between mating flanges in the raised area of the flanges. The raised face focuses more pressure on a smaller gasket area, which increases the pressure containment capabilities of the joint.

Flat face flanges - Do not have a raised area, the whole surface is flat. The gasket used with the FF flange has full contact with the whole flange surface. The FF flange avoids the bending moment that can be put on a flange as bolts are torqued. Flat face flanges are typically used in less arduous applications, like low-pressure water piping, low temperature and pressure environments. In many low pressure situations, raised faced flanges can be connected to flat faced flanges

Appendix B: Fixed Connection Methods - Welds, Fusion, Crimped

Appendix B1: Weld Connections Considerations

Key Points to Check

A good weld is a work of art and can provide reliable performance for the life of the pipe system. However, pipe welding requires exceptional skills and training, highly dependent on the welder. Weld defects are often unable to be detected visibly. Visual examination will not detect faults beneath the surface of the weld. Conditions interior to the pipe are often difficult to examine without a scope. Excessive slag can create flow variations and contribute to water contamination over the life of the pipe.

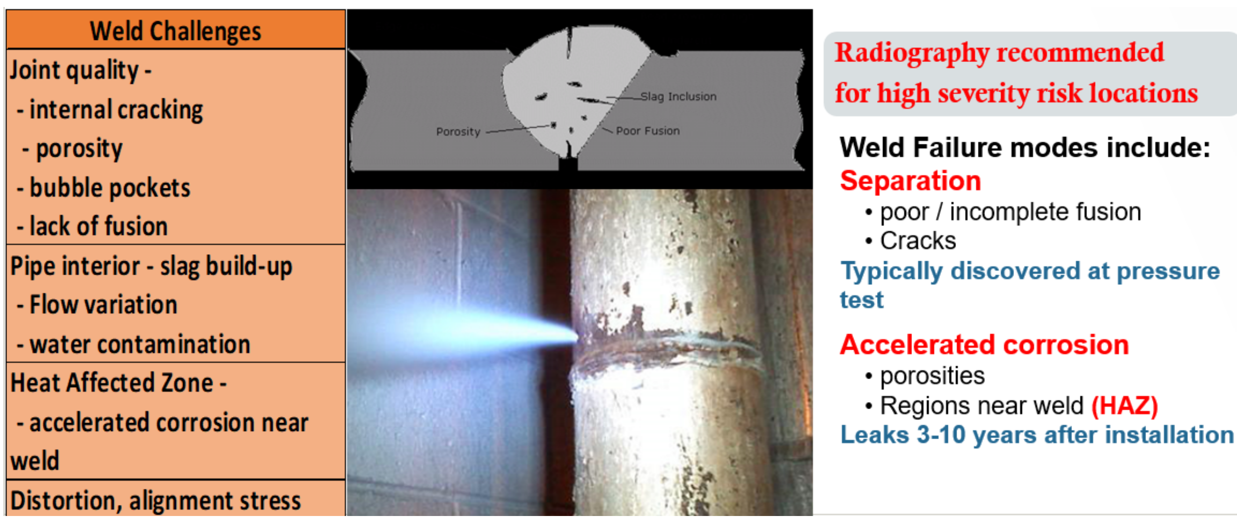


Figure 12: Welding Challenges

Radiography is an inspection method that provides high confidence in weld performance. Radiography can be expensive, time consuming, and difficult to perform, but is recommended in regions of high severity risk.

Welds do not accommodate pipe movement or mitigate vibration and pipe systems will typically need to address those issues with movement, vibration and alignment devices that may be much less reliable than welds and may require maintenance.

Appendix B2: Commissioning - Fused & Crimped Connections

Key Points to Check

Fused Connections reliability is dependent on the installation process control. There are many variables that can affect performance of a fused connection. Use of any connection in areas of high severity risk should require ability to verify proper installation or provide added protection to minimize damage from leakage or separation

Variables to Control	Potential Issue	Detection Method
Depth of fusion section	Is pipe fully inserted into connection?	To be used in areas of elevated severity risk, fused connections should provide method to verify proper installation.
Transition Time	Connection cool down can result in incomplete insertion	
Temperature, jobsite	Affects cool down rate, heating time	
Not using enough heat	If heat time is insufficient, will not make full connection	
Cleanliness of Pipe	Incomplete fusion area (oil, dirt)	
Water contact	Any water contact on fusion area will interfere with proper fusion	
Support during Cool Down	Movement during cooling weakens bond	
Adjustment during cooldown	Twisting, adjusting alignment after 5 seconds weakens connection	
Mis-alignment	> 3 degrees of mis-alignment may affect bond	Alignment verification
Ref: Aquatherm Installer Manual; Making the Connection with Pex: The Good, Bad & the Ugly		

Figure 13: Fused Connection Variables, Issues and Detection

Crimped Connections - there are a variety of crimped connection methods for pipe systems 2 inch and under. As with fused connections, to be used in areas of elevated risk, crimped connections should provide a method to verify proper installation. Leak detection, protection, collection should be used where questions exist and risk is of a concern.

Figure 14: Pressed Connection

Note - Welding, Fusing, Crimping do not provide reconnection capability, which may be necessary to support ITE refresh, system adaptability and some maintenance

functions. Threading, grooved couplings, and flanges are most applicable to discussions on connection/reconnection of liquid cooled ITE.

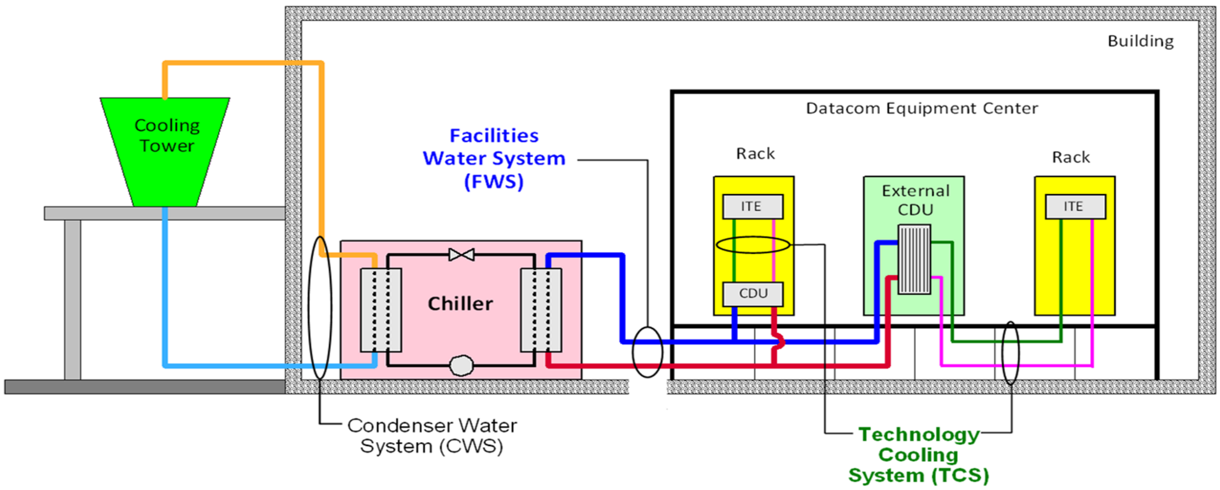


Figure 15: CWS, FWS, TCS cooling loop

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