Improved Chilled Water Piping Distribution Methodology for Data Centers

White Paper 131

Revision 1

by Isabel Rochow

> Executive summary

Chilled water remains a popular cooling medium; however leaks in the piping systems are a threat to system availability. High density computing creates the need to bring chilled water closer than ever before to the IT equipment, prompting the need for new high reliability piping methods. This paper discusses new piping approaches which can dramatically reduce the risk of leakage and facilitate high density deployment. Alternative piping approaches and the advantages over traditional piping systems are described.

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Introduction

In data centers, the traditional approach to piping distribution has been to use hard copper or carbon steel piping with welded, brazed or threaded fittings for routing and branching of the piping to the air conditioners. Since every fitting used in the piping line increases the leak failure potential in the data center, piping distribution is generally located under the raised floor where channels or trenches are sometimes built under the pipe to capture water in case of any leaks or rupture. This approach worked in static data centers, where there was no need to relocate or add air conditioners.

With the current trend of increased densities in IT equipment and more frequent moves, additions, and changes, air conditioners must occasionally be added to the traditional lay-out where the use of hard piping becomes problematic. These additions require new piping to be installed, increasing deployment time of the equipment and increasing the risk of down time associated with the installation. The result is that there is a need in the industry for a more flexible modular system of piping that can better accommodate changing requirements.

A new trend is data centers that do not use a raised floor. These hard-floor installations are enabled by newer cooling technologies and architectures that do not require a raised floor for air distribution. For many users this allows additional flexibility of placement of data centers and computer rooms. One result of this trend is that overhead piping has become more common. Leaks in overhead piping can be even a greater risk to system downtime and damage than underfloor piping. There is a need in the industry for a more leak-resistant piping system.

Related resource
White Paper 130
The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers

A further trend in data center design is the deployment of cooling at the IT equipment row locations (In-row), or even to individual racks, rather than at the room level. This is done to allow higher density and greater electrical efficiency, and is discusses more completely in White Paper 130, *The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers*. This type of deployment forces the air conditioning units and the associated piping closer to the IT equipment. Again this situation requires a more reliable, modular, and scalable piping system.

The use of seamless flexible piping eliminates the use of intermediate fittings, mitigating the risk of water leaks, reducing deployment time, and increasing the agility of the system. This paper explains this new piping technology and its application to next-generation data centers.

Characteristics of traditional hard piping methods

The use of hard copper or carbon steel piping is the traditional approach in data centers. Carbon steel pipe schedule 40 and hard copper pipe type L or M are most commonly used. Hard piping requires the use of threaded, grooved, welded or brazed fittings at every turn, at every valve, at every branch to multiple air conditioners and at every 1.8 or 6 meters (6 or 20 feet), depending on the available length of the pipe run. It is common to have multiple fittings in one pipe run from the chilled water source to the air conditioner.

Failure modes of hard piping

Each threaded or welded fitting presents a leak potential for the chilled water system. One common reason for leakage is the threading process which removes 50% or more of the pipe wall beginning on day one and weakens that joint.

Another reason for pipe failure and water leakage is galvanic corrosion, where the carbon steel pipe directly meets a brass valve, or is transitioned to copper pipe. "Galvanic" corrosion occurs between any two dissimilar metals in contact with each other and water, and typically attacks the steel pipe to a degree somewhat dependent upon existing corrosion conditions. It is visually recognizable in its latter stages by some degree of deposit buildup where the dissimilar metals meet at the threads, creating a micro-fine leak. At that point, however, most of the damage has already occurred and replacement of that pipe is required, otherwise the leak size would increase as corrosion advances.

Electrically isolating fittings, called dielectrics, are used for connections between dissimilar metals in most piping systems. Dialectric fittings are specified by most consulting and design engineers, but it is not uncommon to find installations where they were not installed or they are installed incorrectly.

In a traditional chilled water installation, it is not uncommon to see a main carbon steel supply or return pipe that branches to the air conditioners with copper piping, so multiple dielectric fittings might be used if several computer room air conditioners (CRAC) are in the data center.

Other less common reasons include the failure of the thread sealant over time, poor machining of the threads, gasket deterioration in grooved connections and poor quality of the pipe or fittings, vibration, stress, improper assembly, or excessive operating pressures beyond design.

In hard piping systems, minerals tend to build up on the interior wall causing scaling and oxidation of the copper and eventually creating pinholes and leakage in the piping. Mineral build-up overtime also increases the pressure drop in the water line, especially when it is deposited in elbows or fittings. To avoid this problem, water has to be treated and maintained periodically to ensure proper PH levels. The water is usually treated at the time of start-up and during regular services. Even though it is rare to see pinholes in a closed loop chilled water installation, it has been found in installations were poor maintenance was performed.

Condensation also presents a problem in a chilled water system. Chilled water piping is usually insulated to prevent condensation in the piping exterior. However, it is not uncommon to find moisture on the piping fittings where multiple elbows, connections, and fixtures such as valves, strainers, and gauges make an effective insulation job difficult. Any crack or sealing failure in the insulation presents water potential in the data center and it also becomes an entry point for moisture to permeate under the insulation and travel along the pipe surface for a significant distance.

The presence of condensation at the outer pipe wall in non-conditioned environments also produces corrosive effects. Exterior corrosion is promoted much more when high humidity exists in the environment surrounding the pipe. In extreme cases, condensation will build up to the point where the insulation becomes completely saturated with water. In data centers, exterior corrosion of the pipe does not usually occur due to the humidity controlled environment.

To contain any condensation or water in the event of a leak in a data center, some IT managers and facilities engineers demand additional protection for the IT and electrical equipment. However, this practice is generally not implemented until water becomes a problem in the data center.

In some instances, the concern about the possible loss of cooling that a single leak would cause is so great that IT managers opt to install a completely redundant hard piping system which doubles the total piping installation cost. Alternatively, they opt to install CRACs with a refrigerant based system as a back-up that also requires additional refrigeration piping.

Underfloor hard piping installation

The method for routing chilled water piping depends on the size of the room and the number of air conditioners. For small rooms, the chilled water piping is usually routed through one large main supply and return pipe made of carbon steel or copper. For larger rooms, several large manifolds of carbon steel pipe are used. Each main header or manifold is then branched with copper piping to each air conditioner. **Figure 1** illustrates underfloor hard piping where multiple fittings are used in the installation.

For this methodology, when the owner is concerned about water under the floor, a trench with drains is specifically built for the containment of the chilled water piping to separate it from the electrical wiring. Alternatively, a drain pan can be built underneath each run of piping to collect any possible leakage or condensation from the system. The depth and width of the trench is sized depending on the diameter and quantity of the chilled water pipes running in it. In addition, clearances have to be provided for service of all the different pipes in the trench in case of a leak. In a medium to large data center it is not uncommon to find deep trenches up to 1.5 meters (5 feet), to accommodate all the chilled water piping, valves and servicing.

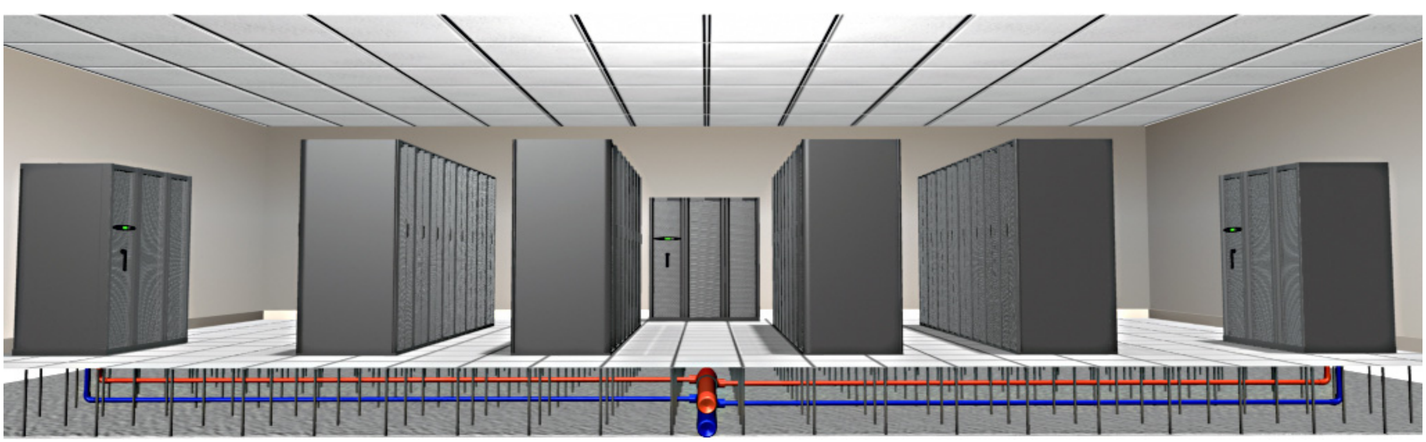
With various distances from the chiller to each air conditioner, start-up of the chilled water system requires each air conditioner be balanced to provide the correct amount of chilled water to each of them. The system balancing is accomplished using isolation and balancing valves which are usually located in the pipe branches under the raised floor; while the actuated water regulating valves are usually located in the air conditioners. By having balancing and isolation valves under the floor, balancing the system takes longer since the balancing valves are not easily accessible.

These systems require one time engineering and they usually remain as static systems due to the infrastructure needed to route the piping and the difficulty to add an extra pipe line to the main header once the room is in operation.

If a leak occurs on the main manifold, the mean time to recover (MTTR) increases, since all CRACs fed from the main branch would loose their chilled water supply. This would cause the room temperature to rapidly increase, resulting in IT equipment failure or forcing the equipment to shut down.

Figure 1

Traditional underfloor chilled water piping installation with branches to different air conditioners using multiple fittings



Overhead hard piping installation

This approach also uses a main header or manifold that is branched to each air conditioner until it arrives to the last system. Isolation valves and balancing valves are usually located in the pipe branches inside or outside the data center or right above the air conditioners.

Since overhead piping presents the potential of condensation or leakage over the IT equipment, a drain pan is used when the pipe crosses any electrical or IT equipment and in some instances the operator specifies a drain pan under all the chilled water pipes in the data center. For these cases, a wide drain pan is provided under the main headers and a smaller pan is used for branches. This methodology is used due to the potential leak failures and condensation that the various pipe fittings present and as a precautionary measure, to protect all the power and IT equipment under the pipe. **Figure 2** shows an example of a traditional installation with overhead piping and drain pans underneath for leakage containment.

Figure 2

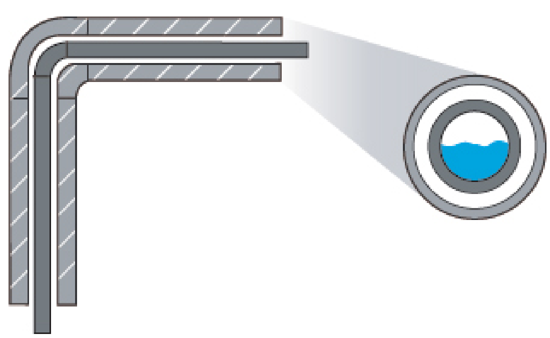
Overhead piping with drain pan above racks

With the valves being located above the ceiling or outside the data center, balancing the cooling system is not easily done. This increases the time required for start-up and balancing of each unit. In case of leakage in an overhead installation, the repair must be performed above the equipment installed on the floor, which increases the potential for water on the floor or worst yet, the equipment.

Double wall piping systems are very seldom used to provide secondary containment. It is used mostly in cases where local codes require it or when the owner or design engineer specifies it. The double containment piping system is composed of an outer pipe that completely encloses an inner carrier pipe in order to contain any leaks that may occur and to allow detection of such leaks. The procedures and installation requirements for double wall piping make this methodology extremely expensive, but more effective than using only a drain pan underneath the piping. **Figure 3** shows a side and front cut-away view of a double wall pipe.

Figure 3

Cut-away view of a double wall pipe



Flexible piping methodology

Recent advances in piping technology using flexible piping permit chilled water transport into data centers with greatly improved reliability and dramatically reduced chance of leakage. This piping is based on a technology that has been used for piping HVAC systems in Europe for over 30 years. The flexible piping is a multi-layered composite tubing consisting of an aluminum tubing sandwiched between inner and outer layers of cross-linked polyethylene. This gives the piping flexibility to be routed through the data center with the rigidity to stay in place. The cross-linked polyethylene or PEX also offers excellent protection against corrosion and the smooth interior walls and chemical properties make it resistant to mineral buildup with hard or soft water eliminating the risk of pinholes.[1]

Improved reliability compared with hard piping

The use of flexible piping allows the system to be routed without the use of elbows or any intermediate joints from the chilled water source to each CRAC. If multiple CRACs are used, a centralized distribution system allows for multiple connections to a main distribution header installed in the perimeter or outside the room. The header provides individual isolation, balancing and branching to each air conditioner in the room, using individual flexible jointless supply and return pipes. This methodology replaces all the intermediate joints in the data center with only two joints per supply and return line; one at the distribution header and one at the CRAC. A traditional hard piping system will have from 10 to 20 joints per supply or return branch to each air conditioner depending on the pipe run, while a flexible piping system with only two per line, reduces the leak potential to only 10 or 20% of the hard piping.

By eliminating any intermediate fittings or valves and with a lower thermal conductivity than copper or steel pipe, flexible PEX piping also significantly reduces the condensation potential in the data center. This is because condensation usually occurs at pipe fittings, connections and valves, due to the difficulty to insulate them effectively.

Centralized distribution, when used with flexible piping, greatly reduces the concerns of co-locating the chilled water piping with IT equipment and of routing overhead piping. Installing a centralized water distribution system in the perimeter of the room allows all the balancing and isolation valves to be installed at the same location, thus reducing the time to balance the complete chilled water system. Dynamic data centers benefit from this approach since having flexible piping permits the relocation of air conditioners by running the flexible pipe to the new location. In high density applications the addition of future CRACs can be achieved by running a line from the main header to the new air conditioners without disturbing the rest of the chilled water piping.

The actual failure rate improvement over hard piping methods is dramatic. The following is a quote from one of the leading manufacturers of this tubing system[2]:

"It has been used in Europe for 30 years, with more than **4 billion** feet of installed tubing performing without a single incidence of product failure. 500 million feet of that is in North America alone. Samples of the tubing have been under high temperature and pressure continuously since 1973, with no sign of decreased performance. Tests, both by Wirsbo and independent sources, predict that the Wirsbo PEX tubing should have a system life in excess of 100 years"

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[1] Plastics Pipe Institute™ - High Temperature Division, *The Facts of Cross-Linked Polyethylene (PEX) Pipe Systems*, 12/3/04

[2] Shelter Technology, http://www.sheltertech.com/wirsbo_pex_tubing.htm (accessed March 4, 2010).

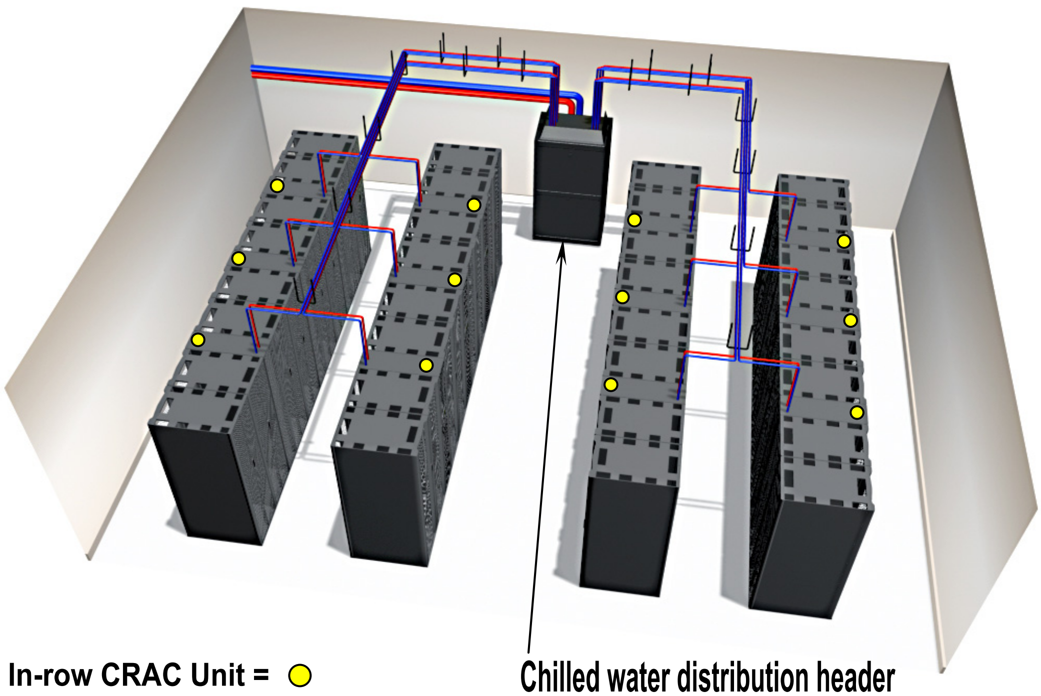
Overhead flexible piping installation
For overhead applications, the flexible piping is routed through the aisles from the distribution header to the air conditioners and a drip pan is only used when the pipe crosses any electrical or IT equipment. Accessories are also available on the market that guide several stacked lines of flexible piping, minimizing the space used overhead for pipe routing. **Figure 4** illustrates the use of flexible piping overhead.

Related resource
White Paper 132
Comparison of In-Row vs. Overhead Cooling

Flexible piping dramatically decreases the leak and condensation potential that most owners have with overhead piping. As data centers opt for overhead wiring and in-row or overhead cooling, the need for a raised floor and the expense that comes with it are diminished. For more information on in-row and overhead cooling, see White Paper 132, *Comparison of In-Row vs. Overhead Cooling*.

Figure 4

Layout drawing of data center with flexible piping overhead



Underfloor flexible piping
The use of flexible piping under the raised floor provides the advantage of having a direct route from the distribution header to the CRACs. This reduces the pipe distance by having straight lines to the air conditioners. Flexible piping can be routed under floor heights as small as 12 inches, and since they usually cross only over power and IT wiring, a drain pan is not necessary for a straight line to the air conditioners. This reduces the installation cost and deployment time when compared to traditional underfloor hard pipe systems. **Figure 5** illustrates the use of flexible piping underfloor.

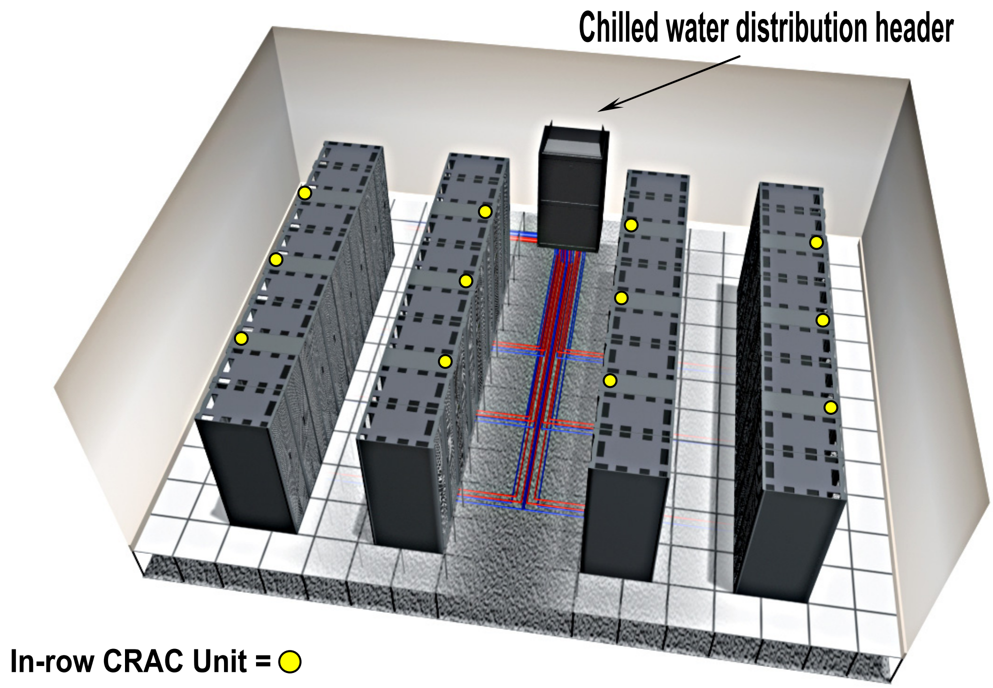


Figure 5

Underfloor flexible piping installation with branches to different air conditioners

Comparison between hard piping and flexible piping

The following sections compare hard and flexible piping against various attributes including mechanical, physical, agility, availability, total cost of ownership (TCO), and failure modes.

Mechanical and physical attributes of hard piping and flexible piping

Table 1 provides a list of the main mechanical and physical attributes of the flexible piping and hard piping used for chilled water systems.

Table 1

Physical attributes of hard and flexible piping

Physical attributes	Carbon steel schedule 40	Hard copper piping type "L"	Flexible piping PEX
Pipe weight in kg per linear meter (2.54 cm nominal size pipe without water)	2.49	0.975	0.324
Pipe weight in pounds per linear foot (1" nominal size pipe without water)	1.67	0.655	0.218
Temperature rating	Up to 399°C (750°F)	Up to 204°C (400°F)	Up to 93°C (200°F)
Rated internal working pressure in megapascal	19.7 MPa @ 38°C 19.7 MPa @ 93°C	3.41 MPa @ 38°C 2.79 MPa @ 93°C	1.38 MPa @ 23°C 0.689 MPa @ 93°C
Rated internal working pressure in psi	2857 psi @ 100°F 2857 psi @ 200°F	494 psi @ 100°F 404 psi @ 200°F	200 psi @ 73°F 100 psi @ 200°F
Type of fittings	Welded, brazed, grooved or threaded fittings	Soldered, brazed, grooved or threaded fittings	Multipress threaded or compression fittings
Size range	3.2 to 660 mm (1/8" to 26")	6.4 to 305 mm (¼" to 12")	12.7 to 5.08 mm (½" to 2") in North America 12.7 to 609 mm (½" to 24") in Europe[3]
Termination connection	Welded, brazed or threaded	Soldered, brazed or threaded	Multipress threaded or compression
Corrosion resistance	Limited, depends on the relative humidity of the environment and PH of water	Very good	Excellent
Thermal conductivity	High	High	Medium to Low

Agility and availability of hard piping and flexible piping

New technologies such as blade servers are resulting in IT loads that are greatly exceeding the rated cooling system capacity, resulting in the need for additional cooling in the data center.

Hard piping does not provide flexibility for future expansions. In order to keep the existing air conditioners operational, a new pipe line is usually branched from the chiller to the additional units. The installation cost and deployment time are high due to the difficulty to route piping in a building that has an existing chilled water system and the difficulty to braze or thread new

[3] Shelter Technology, *PEX piping for Plumbing" presented at 40th ASPE convention*, Oct 2004, http://www.plasticpipe.org/media/PEX_ASPE_2004.pdf#search='wirsbo%20pex%20pipe%20sizes (accessed March 4, 2010).

joints in an existing data center. Even if the air conditioners will only be relocated, a new hard pipe line must be routed from the branching header to the new location, which again involves multiple brazed or threaded joints.

Flexible piping provides the agility and availability for the addition or relocation of equipment. A flexible pipe is installed without the need for fittings or brazed joints from the distribution header to the CRAC location. Since the balancing and isolation valves are installed in the header and the main piping from the chiller to the header is already installed, there is no downtime for the existing chilled water system and deployment time is reduced due to the simplicity of the pipe installation.

A failure or leak on the hard pipe main supply or return from the chiller to the data center would require the shutdown of all the air conditioners in order to repair the failure which can take from several hours to days. This would have the same effect if a distribution header is used, since hard piping is also used from the chiller to the header. If a failure were to occur on that pipe, all the CRAC piping from the header would also require shutdown until the failure is repaired. If a leak or failure occurs in a hard piping system on one of the sub-branches from the main pipe, just the air conditioners branched from that pipe loose chilled water when the line is isolated for repair. Repairing a hard piping system requires the isolation and interruption of cooling at all the CRACs tied to that pipe and usually the leaking component is replaced or the fitting is brazed again at the point of leakage.

With flexible piping, if a leak occurs from the distribution header to the air conditioner, only one air conditioner would require shutdown for repair, without interrupting cooling in any of the other air conditioners. If a leak occurs at the distribution header fitting or at the CRAC fitting, the fitting is replaced. However, if a leak occurs in the flexible pipe line itself, a repair would mean that the entire flexible pipe must be replaced. The new pipe would be replaced by isolating the line at the centralized distribution system and at the air conditioner, interrupting cooling at that single CRAC without interrupting cooling in any of the other air conditioners.

Total cost of ownership of hard piping and flexible piping

The total cost of ownership is reduced with the use of flexible piping and a centralized distribution header compared to a brazed pipe system. A 200 kW data center with a new cooling system installation would obtain an increased speed of deployment of at least 40% and an installation cost reduction of approximately 20% if it is performed with flexible piping and a centralized distribution header. This reduction in installation cost is a result of not having additional labor for brazing intermediate fittings and installing intermediate valves, as well as a reduction in time to balance the chilled water system.

In an existing data center, the installation of one additional air conditioner from the distribution header using flexible piping reduces the installation cost by at least 50% and the deployment time by 60% compared to a traditional brazed piping system.

Maintenance of a chilled water system using flexible piping is easier and faster to perform since the inspection of all the valves is done in a centralized location, while in an underfloor installation, these valves are located at different areas of the data center.

In data centers where the raised floor is used only for the routing of chilled water pipes, the elimination of the raised floor further reduces the capital expense of the installation if an overhead piping system is used. **Table 2** compares hard and flexible piping as they relate to the benefits that data center users have identified as the most important for a chilled water piping system.

Table 2

Comparison of hard and flexible piping

	Hard piping	Flexible piping
Agility	Slow speed of deployment due to multiple brazed joints required. Balancing of system is not easily accessible either under the raised floor or above the ceiling tiles. Non-scalable expansions or relocations require one time engineering and downtime for other units.	Increased speed of deployment by 40%. Balancing of the water system is located in a centralized accessible location. Scalable, allows for moves, adds, changes, and future expansions without disturbing other units.
Availability	Leak potentials at every fitting and joint decreasing reliability.	Increased reliability by eliminating intermediate joints drastically reducing leak potential.
MTTR	If leakage occurs on the main, repair may take from hours to days depending on the leak. If leakage occurs on a distribution branch in the data center, repair may take several hours, causing shutdown for several units.	If leakage occurs from the chiller to the centralized distribution header, repair may take from hours to days depending on the leak. If leakage occurs on a flexible branch in the data center, new flexible piping can be routed and repair may take up several hours causing shutdown on one unit only.
Installation	Higher installation costs. System balancing requires more time adding cost to start-up. Brazed, threaded, or mechanical joints and fittings are used, and intermediate isolation and balancing valves are required.	Lower installation cost. System start-up and balancing is less complex with the centralized distribution system. No brazed joints, intermediate fittings, or valves are required.
Turning radius	Allows a shorter turning radius using elbow fittings.	Minimum bending radius is 5 to 7 times the outside diameter of the tube.
Maintainability	Visual checks for leaks at each joint and valve, visual check for condensation at fittings and valves and visual check at corrosion points. Water and glycol concentration measured and validated.	Less time spent in visual checking for leaks and condensation formation on valves at the centralized distribution header (all valves are in one location). Water and glycol concentration measured and validated, routine maintenance
Pressure drop	The use of elbows for turns and mineral buildup causes additional pressure drop	Smooth interior and larger radius turns without fittings reduce the pressure drop for typical piping runs
White space	Piping is run underfloor or overhead, no white space is occupied by the piping system	White space is required for the centralized distribution header in the room.
Distances	Long pipe distances can be performed with hard pipe since several pieces of pipe are joined through fittings.	Maximum distance recommended is 46 meters (150 ft) from the distribution header to the air conditioners due to the complexity that longer distances would create for the installer.
Upfront cost (installation and material)	Hard pipe cost is lower but the overall installation cost is higher due to the increased labor required for brazing and threads and system balancing requires more time adding cost to start-up.	PEX piping has a higher cost, however the overall installation may be lower due to the elimination of brazing or threaded fittings and the system start-up and balancing is less complex with the centralized distribution system.
Pipe location	Can be installed outdoors or exposed to sunlight.	PEX must not be stored or installed in areas where it is exposed to sunlight, either direct or indirect.

Note: shading indicates best performance for the characteristics

Failure mode comparison for hard piping and flexible piping

A chilled water system may encounter different failure modes depending on the location of the piping, the type of installation, and the piping methodology used. **Table 3** summarizes the possible failure modes for each type of piping and the best performance is highlighted.

Table 3

Failure mode comparison of hard and flexible piping

	Hard piping	Flexible piping
Punctures	Less susceptible to leakage due to puncture by a sharp object.	More susceptible to leakage due to puncture by a sharp object.
Single point failures	Failure in a branching pipe causes loss of cooling in all CRACs connected to the branch.	Failure in a line causes loss of cooling in only one CRAC.
Joint leaks	Multiple joints and fittings in the pipe increase leak potential due to possible galvanic corrosion, failure of thread sealant over time, poor machining of the threads, gasket deterioration in grooved connections or poor quality of the threaded fittings.	Reduced amount of joints - two per line per CRAC. Multipress threaded fittings crimp the PEX-AL-PEX tube making a stronger connection than a threaded or gasketed fitting.
Earthquake / vibration	Vibration or earthquake movement can cause leakage at joints and fittings.	Less susceptible to break or leak in vibration or earthquake conditions.
Stepping on	May damage brazed or threaded fittings which can produce a leak.	Less susceptible to damage due to the flexibility of the pipe.
Insulation dripping from condensation in the data center.	More potential for condensation due to difficulty to insulate multiple valves, strainers, and fittings. Small cracks or spaces left without insulation may cause condensation.	Less potential for condensation due to the elimination of intermediate valves or fitting between the distribution system and the CRACs.
Abrasions / cuts	Resistant to exterior abrasions or cuts	Less resistant to exterior abrasions. Cut can damage the PEX piping exterior.
Pinholes and mineral buildup	Susceptible to pinholes and leakage due to mineral buildup if water is not treated periodically.	Very resistant to mineral buildup due to smooth interior walls and chemical properties.

Note: shading indicates best performance for the characteristics

Conclusion

Even though hard piping for chilled water systems has been used as the traditional solution, using a centralized distribution header with individual flexible lines to each air conditioner significantly improves the reliability of the system since the leak potential is drastically reduced. Also, a failure in a flexible pipe system will only require isolation on one CRAC which allows the rest of the units to continue cooling the load, while a failure in a hard piping system may require isolation of several CRACs if the failure is in one of the branching pipes, jeopardizing the availability of the data center without enough cooling to support the load.

The concern of water in the data center is also reduced with a flexible piping system for three reasons:

1. The overall piping system failure rate is greatly decreased due to the dramatic reduction in joints
2. The fundamental reliability of the base piping itself is higher
3. The potential for condensation is reduced by not having intermediate fittings or valves to insulate, which are the main points of condensation formation in a chilled water system.

Flexible piping is an enabling technology for hard floor data center installations and for row-oriented and rack-oriented high density cooling systems. The trends toward higher density and hard floor installations will naturally result in a rapid increase in the use of flexible piping for next-generation data centers.

Acknowledgements

Special thanks to **Isabel Rochow** for authoring the original content of this white paper.

Resources

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The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers
White Paper 130

Comparison of In-Row vs. Overhead Cooling
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