

*Choosing System Architecture and Cooling Fluid
for High Heat Density Cooling Solutions*

Executive Summary

According to a report by the American Society of Mechanical Engineers, by 2011, computer and communications rack heat loads are projected to reach 30 kW with heat load densities of more than 500 W/ft² – five times today’s typical overall heat load density.¹

Driving this trend is the practice of manufacturers to crowd more and more computing power into smaller and smaller packages. Other contributing factors include the trend of businesses to reduce capital costs by putting virtualized servers in smaller spaces, and consolidation of multiple remote data centers into centralized mega data centers. This compaction increases power requirements, and more power generates more heat.

The consequences of high heat in the data center include high soft error rates, erratic or unrepeatable information, and outright hardware failures. In fact, the Uptime Institute estimates that, for every increase of 18 degrees Fahrenheit above 70 degrees Fahrenheit, long-term electronics reliability falls by 50 percent.²

The traditional raised floor cooling is not designed to cool high heat densities. Certain baseline measures can be taken to optimize the functioning of the traditional cooling system, primarily by optimizing air flow in the room so hot and cold air does not mix. However, adding supplemental cooling currently is the best solution to cool the hot racks and zones that occur in high density environments and generate sensible heat.

Supplemental cooling can use water or refrigerant-based cooling technologies and is adaptable to open or closed system architectures. In this document, we discuss the pros and cons of these cooling fluids and system architectures, as well as how they guide decision making about the most appropriate supplemental cooling technologies for particular data center applications.

Baseline Strategies to Increase Cooling Efficiencies

Certain changes can be made to the physical infrastructure to increase efficiency of the cooling system, which will help better manage the heat generated by high density equipment. These include properly sealing the data center and then optimizing the air flow within.

Seal the Data Center Environment

Cooling system efficiency is reduced when cooling is lost through floors, walls and ceilings, or humidity is introduced from outside the critical facility. Therefore, the data center should be isolated from the general building and outside environment as much as possible.

Keep doors closed at all times and use a vapor seal to isolate the data center atmosphere. The vapor seal is one of the least expensive and most important methods for controlling the data center environment. As equipment densities

increase, a vapor barrier that isolates the controlled environment from the building environment becomes even more critical.

Without a good vapor seal, humidity will migrate into the data center during the hot summer months and escape during the cold winter months. ASHRAE has defined the recommended relative humidity level for Class 1 and Class 2 data center environments as 40 to 55 percent. Computer room precision air conditioners (CRACs) control humidity through humidification or dehumidification as required. An effective vapor seal can reduce the amount of energy expended on humidification or dehumidification.

Optimize Air Flow

Once the room is sealed, the next step is to ensure efficient air movement. The goal is to move the maximum amount of heat away from the equipment utilizing a minimum amount of energy. Optimizing air flow requires evaluating rack arrangement, CRAC placement/air distribution and cable management, because each impacts

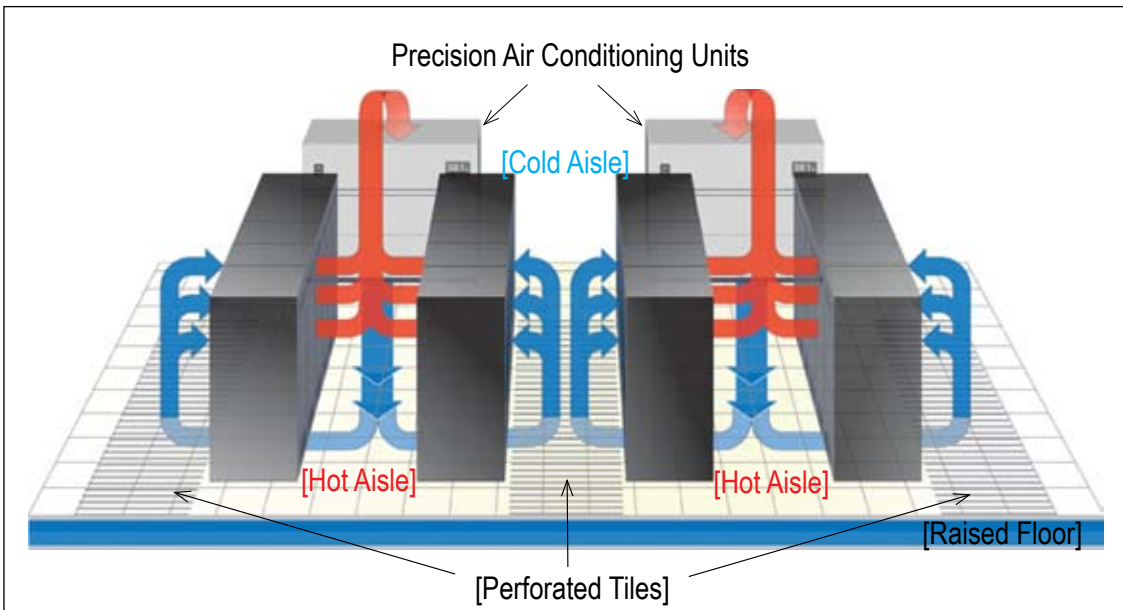


Figure 1. Hot aisle/cold aisle configuration.

the amount of energy expended to move air within the critical facility.

Rack Arrangement

Most equipment manufactured today is designed to draw in air through the front and exhaust it out the rear. This allows equipment racks to be arranged to create hot aisles and cold aisles. This approach positions racks so that rows of racks face each other, with the front of each opposing row of racks drawing cold air from the same aisle (the “cold” aisle). Hot air from two rows is exhausted into a “hot” aisle, raising the temperature of the air returning to the CRAC unit and allowing it to operate more efficiently (Figure 1 on page 2).

This approach is most effective when cold and hot air do not mix. Therefore, perforated floor tiles should be removed from hot aisles and used only in cold aisles. Blanking panels should be used to fill open spaces in racks to prevent hot air from being drawn back

through the rack. Even empty spaces between racks should be filled with blanking panels or racks to prevent hot and cold air from mixing.

Some type of cabling grommet should also be used to prevent the cold air from entering the space through cable openings, which are typically at the rear of the rack. Additional steps, such as using a return ceiling plenum to draw the air back to the CRAC (Figure 2) and physical curtains at the ends of the cold aisles, have also proved to be very effective in minimizing mixing hot and cold air.

CRAC Placement

When using the hot-aisle/cold-aisle configuration, CRAC units should always be placed perpendicular to the hot aisle to reduce air travel and prevent hot air from being pulled down into the cold aisles as it returns to the air conditioner. If the CRAC units cannot be placed perpendicular to the hot aisle, the

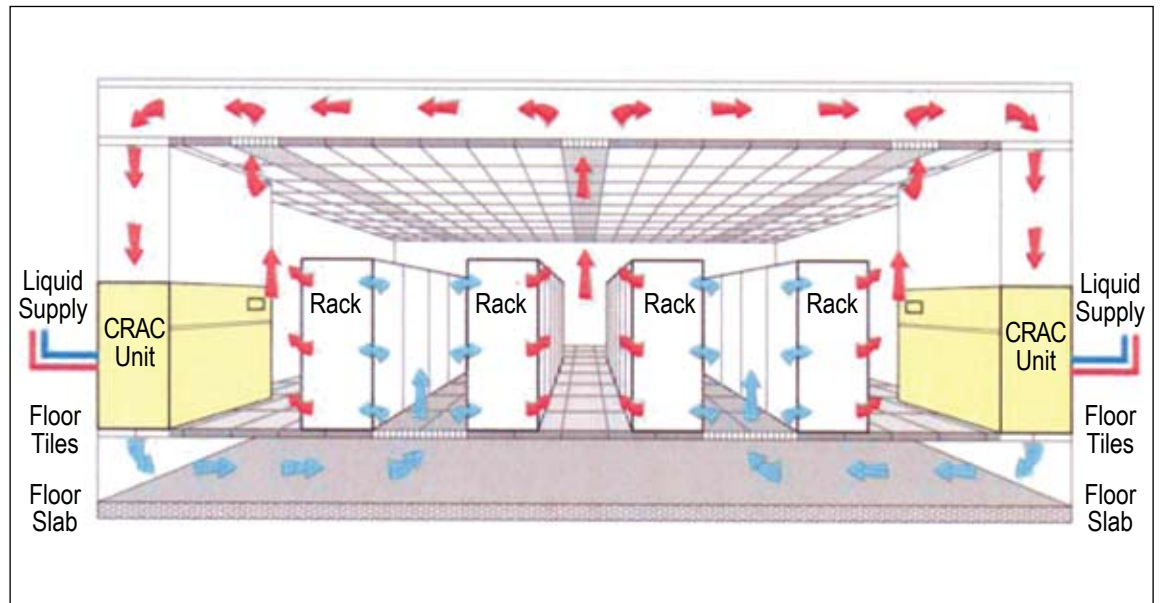


Figure 2. Raised floor implementation using a dropped ceiling as a hot air return plenum³.

return ceiling plenum can be effective in minimizing the mixing of hot and cold air, as is the case in Figure 2.

Cable Management

The explosion in the number of servers that data centers must support has created cable management challenges in many facilities. If not properly managed, cables can obstruct air flow through perforated floor tiles and prevent air from being exhausted out the rear of the rack. Check the under-floor plenum to determine if cabling or piping is obstructing air flow. Overhead cabling is becoming increasingly popular, which eliminates the potential for obstruction. Deeper racks are now available to allow for increased airflow. Sometimes existing racks can be equipped with expansion channels to add depth for cables and airflow. Be cautious when using cable management “swing arms” as they are not compatible with all IT equipment air flow patterns.

Finally, but perhaps most significantly, investigate bringing high-voltage 3-phase power as close to the IT equipment as possible and increasing the voltage of the IT equipment. These steps will minimize the number and size of the power cable feeds under the floor. This can sometimes be accomplished by using high-voltage 3-phase managed power strips within the rack, but may also require the use of multiple-pole distribution panels or PDUs located within the row of IT equipment racks.

If racks have extensive server cabling in the rear that obstructs the hot air exhaust from the servers, fans can be added to the rear of racks to draw the hot air out of the rack. However, be aware that these fans consume energy and generate additional heat that must be removed from the room.

For more information on physical infrastructure changes that optimize air flow in the data center, see the white paper, *Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency* available at www.liebert.com.

Supplemental Cooling

Adopting the baseline strategies described above is a good place to begin when faced with increasing heat loads in the data center. However, they may not be enough to effectively remove the heat generated by high density applications. In that case, adding supplemental cooling to the traditional cooling is recommended. Supplemental cooling systems (distributed cooling modules) bring cooling closer to the source of heat, reducing the amount of energy required for air movement and, because of the higher temperature of the air entering the coil, the capacity and efficiency of the cooling system is increased as well.

Supplemental cooling was pioneered by Emerson Network Power with its Liebert XD™ System. This approach overcomes the cooling capacity limitations of traditional air cooling systems in high heat density applications by using a fluid (pumped refrigerant or water) cooling infrastructure that supports cooling modules placed directly above or alongside high-density racks to supplement the traditional air cooling system.

Raised-floor cooling becomes less effective as rack densities exceed 5 kW and load diversity across the room increases. At higher densities, equipment in the bottom of the rack may consume so much cold air that remaining quantities of cold air are insufficient to cool equipment at the top of the rack. Typically in high heat density situations, equipment located in the top of the data center rack fails

more often than equipment in the bottom of the same rack. The height of the raised floor creates a physical limitation on the volume of air that can be distributed into the room, so adding more room air conditioners may not solve the problem.

Supplemental cooling has a number of additional benefits, including:

- Ability to target zones and hot spots with overhead and next-to-the-rack cooling modules
- Increased cooling system scalability with plug-and-play cooling modules
- Greater floor space savings due to available cooling modules positioned above the racks
- Applicability in raised floor and non-raised floor environments
- Improved energy efficiency that lowers operating costs

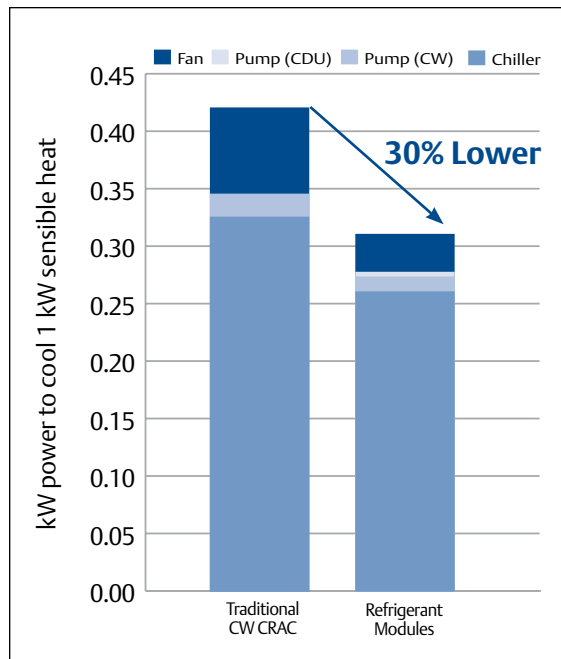


Figure 3. Annual power consumption of traditional raised floor cooling system compared to supplemental cooling using the Liebert XDP™ with pumped refrigerant technology.

The energy savings of supplemental cooling using the pumped refrigerant technology is substantial: typically at least 30 percent lower annual power consumption operating at 100 percent load, as shown in Figure 3, and considerably more than 30 percent savings at partial (50 percent) load.

The energy efficiency of supplemental cooling using pumped refrigerant is discussed in more detail on page 6.

Traditional floor-mounted cooling systems with under-floor air delivery will continue to play an essential role in data center environmental management. It is recommended that traditional systems be configured to deliver the required cooling for the first few kW/rack of heat load as well as solve the room’s full humidification and filtration requirements. Supplemental cooling is typically deployed for densities beyond 5 kW per rack.

For more information on supplemental cooling, see the white paper, *Blade Servers and Beyond: Adaptive Cooling for the Next Generation of IT Systems* available at www.liebert.com.

Factors to Consider When Choosing Supplemental Cooling Technologies

To effectively supplement traditional cooling and address high density areas, cooling must move closer to the source of heat. Choices concerning cooling fluid and system architecture must be made when deciding what technology to employ.

Cooling Fluid

Higher density applications require fluid-based cooling to effectively remove the high concentrations of heat being generated. The fluid choices are water, refrigerant and dielectric fluid. Because dielectric fluid

is a substantially less efficient and costly cooling fluid when compared to both water and refrigerant, it will not be considered here.

Water has several positive attributes as a cooling fluid, including low cost, availability and non-toxicity. However, water cooling of electronics can be problematic. Water is a conductive liquid, so cooling system leaks can be electrically disastrous, and it is corrosive and requires careful engineering of the materials used in system construction. Because water-cooling is single-phase fluid in this application, relatively high flow rates are required.

By contrast, R134a **refrigerant**, which is used in the pumped refrigerant cooling system, is non-conductive and is a vapor at room conditions. It is nontoxic, non-flammable, environmentally friendly (Ozone Depletion Potential of zero) and fully approved for use as a coolant (it is used in myriad air conditioning applications, including automobiles). In two-phase operation, refrigerant provides very high performance heat transfer. Required flow rates for water based systems tend to be four to eight times higher than two-phase refrigerant, and pressure drops in the cooling system are significantly lower in refrigerant systems than for water systems. Although R134a is not yet widely used in electronics cooling applications, there is a very solid technology infrastructure to support its use (for example, supermarkets use R134a-based cooling systems extensively).

Using a refrigerant based cooling technology also improves the scalability of cooling systems for future needs. This is important, given the projections for continued dramatic increases in power draws and heat loads. Most of the major

server manufacturers currently are working on solutions that bring fluid-based cooling modules into the rack to answer future heat densities of 30 kW and beyond, making them compatible with the next generation of cooling solutions, such as “on-chip” cooling.

From an *efficiency perspective*, refrigerant performs better than water for high-density cooling. The R134a refrigerant used in the Liebert XD system is pumped in the piping system as a liquid, becomes a gas within the cooling modules when the heat from the rack is transferred into the fluid circuit, and then is returned to either a pumping unit or a chiller. In the pumping unit/chiller, the heat is emitted from the fluid circuit as the gas is condensed back to a fluid before it is pumped back to the cooling modules. This phase change of the fluid contributes to greater system efficiency. R134a is more effective in moving heat than water, and water is more effective than air.

It should be noted that the R134a is being pumped in the Liebert XD piping circuits, unlike a direct expansion refrigeration system where a compressor is operating. This allows the pumped refrigerant circuit to operate at a considerably lower pressure and, because no oil is needed in the pumped refrigerant circuit, oil traps and other oil-related issues are avoided.

In the Liebert XD system, refrigerant is delivered to cooling modules mounted as close as possible to the source of heat. This reduces the energy required to move air and it also minimizes the possibility for hot and cold air to mix, creating additional energy savings. Additionally, pumped refrigerant technology and distributed cooling modules reduce chiller capacity requirements by approximately 20 percent. This increases

energy savings and also enables additional cooling capacity without adding more chillers.

Note:

Appendix A shows how chilled water and R134a refrigerant stack up against important criteria, including energy efficiency, for choosing the cooling fluid for high density heat removal.

System Architecture

Cooling can be brought close to the load through either a closed or open architecture.

Closed Architecture

According to ASHRAE, the closed architecture fully encloses the rack with the cooling coil inside. An example of a high heat density cooling system with closed architecture is shown in Figure 4. (Note that the rack in this figure has an automatic door opening function that opens the doors in case of a failure. This converts the rack to the more advantageous open architecture solution when needed.)

Using supplemental cooling in a closed architecture, the electronic and cooling equipment are located together in a sealed

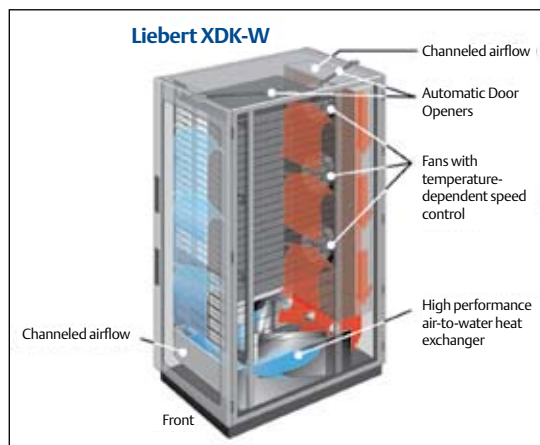


Figure 4. Example of high heat density cooling system with closed architecture.

environment. This approach provides high-capacity cooling at the expense of flexibility and fault tolerance if failure-mode precautions are not built in. Closed cooling offers limited flexibility of rack combinations and often no back-up emergency cooling. If the cooling fails, racks are isolated from room cooling. The ride through time until an over temperature limit is reached in case of a failure depends in general on the heat load, air volume, thermal mass, and initial conditions in the room, or rack. For a closed architecture solution this condition can be reached very fast, in extreme cases in less than a minute.

While this approach is appropriate for small implementations, assuming failure-mode ventilation, an open architecture approach is preferred for cooling in a data center environment.

Open Architecture

As defined by ASHRAE, open architecture systems utilize cooling coils near the heat load either inside or outside the server rack and utilize the room air volume as a thermal storage to ride through short power outages. An example of a high heat density cooling system with open architecture is shown in Figure 5.

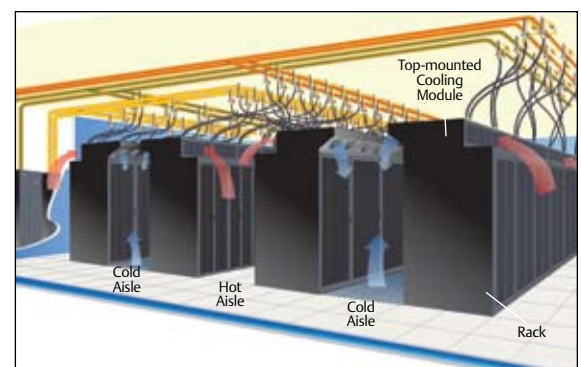


Figure 5. Example of high heat density cooling system with open architecture.

In open architecture, where supplemental cooling modules are on or near racks, but not part of an enclosure, room air is used as a buffer in the event of a failure, making it a safer alternative in many cases. For an open architecture solution, the ride-through time is much longer than for a closed architecture; typically it is several minutes. With large rooms and low heat densities the time can be much longer, in some cases more than one hour. Figure 6 shows the ride through times for different heat densities in an open architecture configuration in a relatively small room.

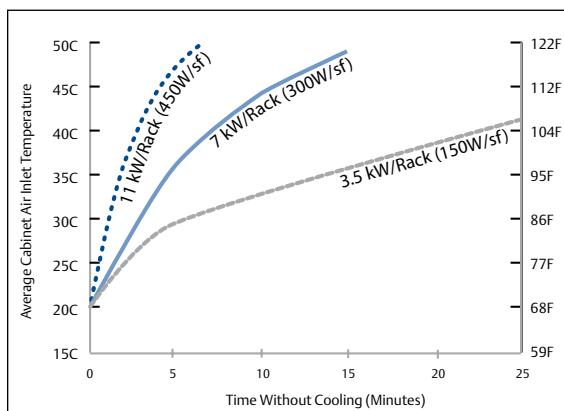


Figure 6. Temperature rise at loss of cooling, as determined by a full-scale test conducted by Hewlett-Packard Company and Emerson Network Power.

In addition to providing better thermal ride through in the event of a catastrophic failure than does a closed architecture, an open architecture allows greater flexibility to reconfigure as additional cooling capacity is needed.

Note:
A comparison of cooling system architectures according to various cooling solution requirements is shown in Appendix B.

Choosing Cooling Technology Solutions

Once the cooling fluid and architecture to be employed are known, specific technologies for bringing cooling closer to the load may be chosen based on the alternatives illustrated in Figure 7, the Liebert XD Circle.

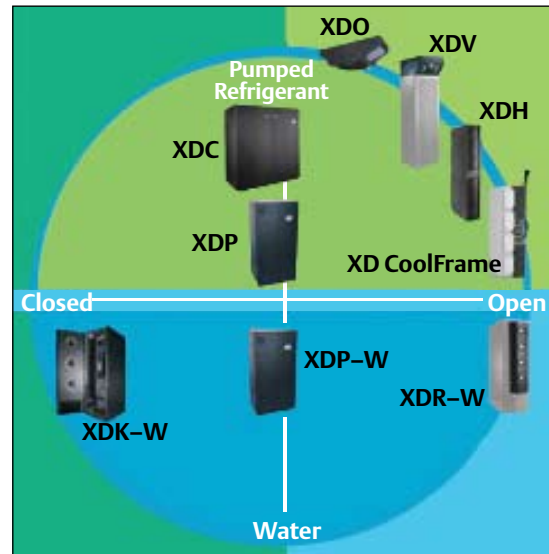


Figure 7. The Liebert XD Circle.

For the upper right section of the Liebert XD Circle with **pumped refrigerant technology and open architecture**, several different types of energy and space efficient high capacity cooling modules are available: Liebert XDO, XDV, XDH and XD CoolFrame. Each module is available in different capacities and they are all supported by the Liebert XDP pumping unit or the Liebert XDC chiller that connects directly to the modules. Both the Liebert XDO and the Liebert XDV modules are located above the rack. These cooling modules draw in hot air from the hot aisle, then discharge cool air into the cold aisle where the equipment air inlets are located. Because the Liebert XDO and Liebert XDV do not use water and the fluid temperature

is always kept above the actual dew point by the Liebert XDP or Liebert XDC, they can be used above racks without any water-related risks.

The Liebert XDO is suspended from the ceiling and it is typically selected when maximum flexibility for adding or relocating racks in the future is required. The Liebert XDV module is convenient to use when space is limited between the top of the rack and the ceiling.

The Liebert XDH module is recommended for use when floor space is available or high capacity per module is required. Air from the hot aisle is drawn in through the rear of the Liebert XDH unit, cooled, and then discharged horizontally through the front of the unit into the cold aisle.

The Liebert XD CoolFrame is designed for the Egenera BladeFrame EX system. It cools the exhaust air from the rack before it enters the room.

In the lower right section of the Liebert XD Circle, with **water based technology and open architecture**, the Liebert XDR-W module is available. It is supported by the XDP-W pumping unit that houses the isolating heat exchanger between the Liebert XDR-W water circuit and the building chilled water, as well as the control valve, pumps and system controls. As with the pumped

refrigerant-based solutions, the pumping unit, Liebert XDP-W, controls the fluid temperature to always be above the actual room dewpoint to prevent condensation on the piping and the coils. The Liebert XDR-W is attached to the back door of the enclosure and cools the exhaust air from the rack, so the impact on the room is close to neutral. This makes the Liebert XDR-W an ideal solution in applications where overhead space is not available or the hot aisle/cold aisle arrangement is not practical.

For the lower left section of the Liebert XD Circle with **water based technology and closed architecture**, the Liebert XDK-W is available. It is supported by the Liebert XDP-W pumping unit. The Liebert XDK-W, which is available in several different sizes and capacities, is a completely sealed rack with closed air circulation for cooling. The heat load is dissipated into the water system through an air-to-water heat exchanger in the bottom of the rack. It has an automatic front and rear door opener that operates in case of emergency so the room air can be used to cool the servers during a ride through period.

Key to the performance and space efficiency of the Liebert XDK-W is the isolating Liebert XDP-W pumping unit. It isolates the Liebert XDK-W water circuit from the building chilled water, as well as controls the fluid temperature to always be above the actual room dewpoint.

Conclusion

High heat in critical spaces compromises availability. Efficient heat removal depends on using supplemental cooling in conjunction with the computer room precision air conditioners. When implementing a supplemental cooling solution, the appropriate cooling equipment may be selected once choices have been made about the cooling fluid (water vs. refrigerant) and the cooling system architecture (open vs. closed). In most cases, the most efficient, safe and flexible choices in cooling equipment for high density heat removal are available using pumped refrigerant technology in an open cooling system.

References

1. American Society of Mechanical Engineers, 2007. Hannemann, Robert. and Chu, Herman. *Analysis of Alternative Data Center Cooling Approaches*.
2. The Uptime Institute, 2006. Menuet, Rob, PE, and Turner, W. Pitt, PE. *Continuous Cooling is Required for Continuous Availability: Data Center Managers Need to Match Their Availability Expectations to the Appropriate Class of Continuous Cooling*.
3. ASHRAE, *Datacom Equipment Power Trends and Cooling Applications, 2005*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org.

Appendix A

Comparison of cooling fluids based on cooling solution requirements.

Cooling Solution Requirement	Pumped Refrigerant Technology	Water Based Technology
Flexibility to Equipment Reconfiguration and Changed Room Layout	★★★ Pre-piped room and quick connect couplings can allow good flexibility to reconfigure.	★ Pre-piped room and quick connect couplings can allow flexibility to reconfigure. However, reconfiguration cannot be done without introducing water-related risks to the data center.
Capacity to Cool High Heat Densities	★★★★ Phase changing of the fluid in the circuit yields higher capacities in limited space.	★★ One-phase fluid in the circuit can limit capacity.
Minimum Floor Space Usage	★★★★ Pumped refrigerant technology enables floor space-saving overhead solutions.	★★ With water based technology, non-overhead solutions are typically used because of water related risks.
Energy Efficiency	★★★★ Phase changing of the fluid in the circuit yields very good energy efficiency due to smaller pumps and less pressure drop in the heat exchangers located close to the heat source.	★★ Pumping water to the heat exchangers, located close to the heat source, yields good energy efficiency.
Provide Thermal Ride Through in Case of a Failure	★★★★ Due to the phase changing of the fluid contained in the piping circuit, extended thermal ride through time can be achieved.	★★ The water (one-phase fluid) contained in the piping circuit, can yield some thermal ride through time.
Low Complexity of Cooling Redundancy	★ Heat exchangers close to the heat source increase complexity of cooling redundancy.	★ Heat exchangers close to the heat source increases complexity of cooling redundancy.
Avoid Possibility for Water Leaks in the Data Center	★★★★ No water introduced in the middle of the data center.	★ Requires very careful piping layout, piping containment/trays, detection and isolation to minimize the possibility of a water leak.
Easy to Implement as Retrofit	★ Requires space for distribution piping (and heat exchangers) to implement.	★ Requires space for distribution piping (and heat exchangers) to implement.
Fast and Easy Installation	★★ Hard piping includes pressure testing, vacuum purging and charging. Pre-fabricated piping and quick connects can shorten installation time.	★★ Hard piping includes pressure testing, filling and air bleeding. Pre-fabricated piping and quick connects can shorten installation time.
Known Technology with which Users are Comfortable	★★★ The pumped refrigerant is known technology but in a relatively new (since 2003) application when used for data center high heat density cooling. Currently more than 10,000 racks are cooled by the pumped refrigerant technology.	★★★ Water based cooling was more common 20 years ago. The technology is slowly becoming used again because of increasing heat densities.

★ Fair ★★ Good ★★★ Excellent

Appendix B

Comparison of cooling system architectures based on cooling solution requirements.

Cooling Solution Requirement	Open Architecture	Closed Architecture
Flexibility to Equipment Reconfiguration and Changed Room Layout	★★★★ Open cold and hot aisle architecture increases flexibility.	★ Closed racks limit flexibility due to cooling (duct/pipe) and power connections and size/weight of the rack.
Capacity to Cool High Heat Densities	★★★★ More than 30kW per rack.	★★★★ More than 30kW per rack. Closed architecture has potential to cool considerably higher heat loads than 30kW per rack, if required.
Minimum Floor Space Usage	★★★★ Available overhead modules and piping requires no floor space.	★ Cooling coils/ducts/fans in a closed architecture rack typically use premium floor space.
Energy Efficiency	★★★★ Supplemental cooling with distributed fan coil modules yields very good energy efficiency for the cooling system.	★★★★ Closed racks with integrated fan coils yield very good energy efficiency for the cooling system.
Provide Thermal Ride Through in Case of a Failure	★★★★ Due to the open architecture of both cold and hot aisle, the room can be utilized as a heat sink. Ride through time depends on many factors but is typically several minutes. At low heat densities, the time can be much higher.	★ For a closed rack (without automatic door opening or similar) the thermal ride through time is very limited, typically only a few minutes or less.
Low Complexity of Cooling Redundancy	★★★ One redundant cooling unit can serve many racks.	★ Requires one redundant unit/heat exchanger per section of contained racks or for each closed rack.
Flexibility Regarding Rack Types and Manufacturer	★★★★ Open architecture allows most racks to be used.	★ Closed rack limits flexibility.
Comfortable Environment for Operation/Maintenance of Rack Equipment	★★★ Typically yields acceptable sound levels, air velocities and temperatures.	★★★ Can yield uncomfortable air velocities, air temperatures and noise levels when closed rack has to be opened for maintenance work.
Good Accessibility for Operation/Maintenance of Rack Equipment	★★★★ Open architecture allows access to racks front and rear.	★ Closed cooling architecture racks can limit access for operation/maintenance work.
Easy to Implement as Retrofit	★★★ Most existing data centers already have the open architecture.	★ Requires space to implement.
Known Technology with which Users are Comfortable	★★★★ Most existing data centers already have the open architecture.	★★★ The use of closed architecture is increasing, especially for small and medium size data centers.

★ Fair ★★★ Good ★★★★★ Excellent

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