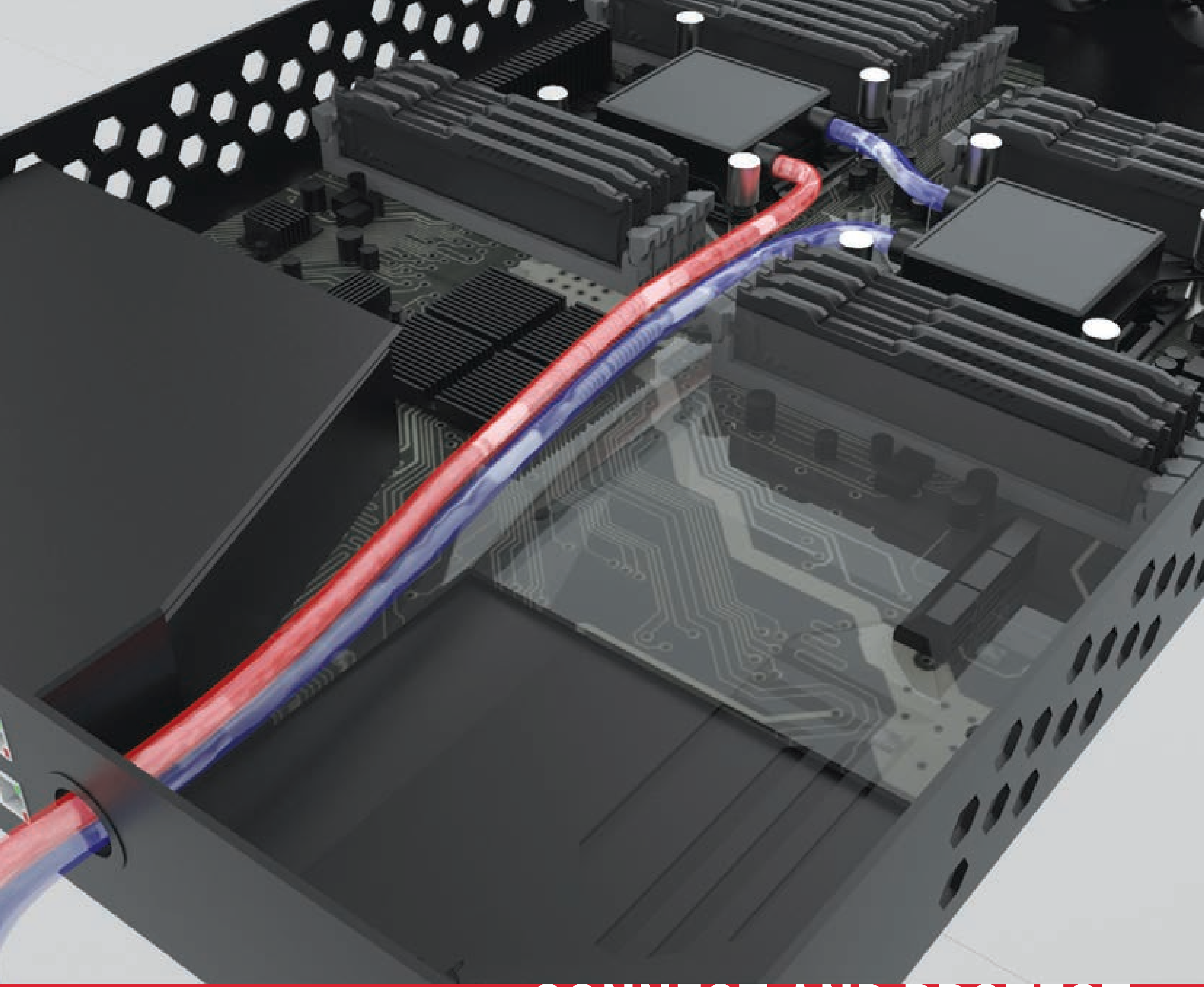


CONNECT AND PROTECT

Rack Level High Density Liquid Cooling

White Paper

ADVANCED RACK LEVEL INTEGRATED COOLING SOLUTION COMBINING LIQUID-ASSIST RACKCHILLER REAR DOOR AIR COOLING WITH DIRECT-CONTACT LIQUID COOLING. A MODULAR APPROACH TO MAXIMIZING LIQUID COOLING EFFICIENCIES.

Executive Summary

Increased heat densities of IT Equipment (ITE) in high performance data centers continues to drive the need for more efficient and effective cooling technologies. Traditional air cooling is not a sustainable solution in these settings. While liquid cooling offers far greater efficiencies than air cooling, many liquid cooling options require large capital expenditures, are difficult to integrate with existing infrastructure, and present complications when upgrades or added capacity are needed.

This paper presents a rack level Hybrid Liquid Cooling System (HLCS) that couples direct-contact liquid cooling with a rear door cooler air-to-water heat exchanger.

The rack-level Hybrid Liquid Cooling System presents a unique entry point to achieving much higher efficiencies of liquid cooling as well as built-in components that provide flexibility and scalability for attaining additional efficiencies long term.

Introduction

Content streaming, online banking, cloud computing, sophisticated smart phone apps, eCommerce. These are just a few examples of applications that are fueling data processing and traffic demand in data centers throughout the world. Emerging technologies, such as Artificial Intelligence (AI), telemedicine, machine learning, autonomous (driverless) vehicles and other real time modeling applications will accelerate demand further. The International Data Corp. (IDC) predicts that by 2025 we will generate 175 Zettabytes of data annually.

Forecasts suggest that the total electricity demand of information and communications technology will accelerate exponentially in the 2020s, and data centers will continue to grow in their share of power consumption (Nature, 13 Sept. 2018 Vol 561).

Inside the data center, High Performance Computing servers are energy intensive and densely configured, producing more heat in smaller spaces.

Power Density Trends

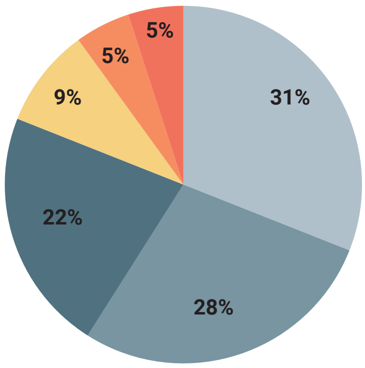
Power density – the amount of electricity used by servers and storage in a given rack – has been monitored since the early 2000s. Surveys from the Uptime Institute tracked steady rates of 3 to 5 kW per rack for many years. Then, in 2018, they reported a jump to 6 to 7 kW averages, with 40 percent of respondents reporting over 20 kW per rack power densities (Uptime Institute 8th Annual Global Data Center Survey).

Rack Level High Density Liquid Cooling

What is the HIGHEST server density deployed in your site?

Above 50 kW per rack
40-49 kW per rack
30-39 kW per rack
20-29 kW per rack
10-19 kW per rack
Less than 10 kW per rack

Source: Uptime Institute 2018 n=272



Heat Generation And Cooling Costs

The byproduct of energy use by electronics is heat. Data center heat must be managed to assure optimum function and lifespan of key components. As a traditional rule of thumb, every 10 degrees Celsius (18 °F) rise in temperature, reduces the life of the electronics by half. Heat stress can reduce response time of electronics; result in loss of data and component failure.

Cooling costs have become a significant portion of operating expenses. Costs to cool a data center by traditional means can often be as much as the cost to power the IT Equipment it houses. Therefore, finding the best, most efficient cooling methods for high density data center environments is critical.

Cooling Methodologies

Four approaches for dissipating ITE heat loads include — air-cooled, direct liquid-cooled, indirect water-cooled and hybrid direct-and-indirect water-cooled.

- Air cooled - heat is transferred directly to the room air and cooled via traditional data center cooling
- Indirect water-cooled - heat is transferred indirectly to water through an air-to-water heat exchanger located within the rack row or single rack
- Direct liquid-cooled - heat is transferred directly to an attached heat transfer component such as a cold plate
- Hybrid direct and indirect water-cooled - selective cooling of highest energy-consuming components with direct-contact liquid cooling and the balance of the rack is cooled via secondary air-to-water cooling device, such as a Rear Door Cooler (RDC).

Considering Facility Water Inlet Temperature

To avoid condensation, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends facility water inlet temperature of at least 18 °C/ 64.4 °F. Using facility water at this relatively warm temperature also saves energy as facility chillers do not have to cool the water to lower temperatures.

The water inlet temperature directly correlates with cooling requirements. Generally speaking, an air-to-water heat exchanger needs a minimum of 2 Kelvin temperature difference between water inlet temperature and cold air temperature to achieve a minimum of cooling.

Depending on the cooling setup, the operator may have an opportunity for energy savings by increasing the water inlet temperature.

Facility water supply temperatures for various cooling systems are defined in classifications W1 through W5 by ASHRAE.

W1 W1, facility water-supply temperature of 2 °C to 17 °C

W2 W2, facility water-supply temperature of 2 °C to 27 °C
Class W1 and W2 typically apply to a data center that is traditionally cooled using chillers and a cooling tower but with an optional waterside economizer to improve energy efficiency depending on the location of the data center.

W3 W3, facility water-supply temperature of 2 °C to 32 °C
For most locations, these data centers may be operated without chillers in a waterside economizer mode. Some locations may still require chillers to meet facility water supply temperature guidelines during peak ambient conditions for relatively short periods of time.

W4 W4, facility water-supply temperature of 2 °C to 45 °C
To take advantage of energy efficiency and reduce capital expense, these data centers are operated in a waterside economizer mode without chillers. Heat rejection to the atmosphere can be accomplished by either a cooling tower or a dry (closed-loop liquid-to-air) cooler.

W5 W5, facility water-supply temperature greater than 45 °C
W5 facilities take advantage of energy efficiency, reducing capital and operational expense with chillerless operation, and by making use of the waste energy. The facility water temperature is high enough to make use of the water exiting the IT equipment for heating local buildings.

*ASHRAE “Liquid Cooling Guidelines for Datacom Equipment Centers Second Edition, Datacom Series 4”

Rack Level High Density Liquid Cooling

A Range Of Data Center Cooling

Legacy cooling in data centers uses technology based on traditional air conditioning systems. Entire rooms, sometimes complete buildings, are cooled with a single system. These Computer Room Air Conditioning units (CRAC) or Computer Room Air Handler (CRAH) worked well for a number of years because data rooms were smaller, IT racks were not densely packed, and less heat was generated in a given space. While still popular today, whole room cooling can be inefficient and expensive.

More current cooling designs include aisle containment and rack-based cooling. These models increase efficiency and often incorporate an air-to-liquid heat transfer to leverage the higher heat transfer qualities of liquids.

Direct-contact liquid cooling (direct-to-chip) presents the highest efficiencies. A coldplate is placed directly on processors inside the server. The coldplate has internal micro channels and an inlet and outlet through which liquid is circulated to carry away heat.

Liquid Cooling Efficiencies

Air cooling is becoming less feasible in high density data centers, as heat loads increase and server racks become so densely configured that air circulation is impeded. Data centers that try to cope by increasing air velocity can quickly become a wind-tunnel like environment that is difficult to work in.

Water has a heat carrying **capacity 3,500 times higher** than that of air.

Liquid cooling systems, however offer effective solutions for achieving required temperature parameters and lowering energy consumption of the cooling system, thus lowering operating costs. Because liquid is denser than air, it has much greater heat transfer capacity. The heat carrying capacity of water is 3,500 times higher than that of air.

Low-profile coldplates used in direct-contact liquid cooling also have the advantage of taking up much less rack space than traditional heat sinks.

While liquid cooling offers huge advantages in moving heat, managing the entire heat load of the rack with liquid cooling methods can be overly complex and cost prohibitive.

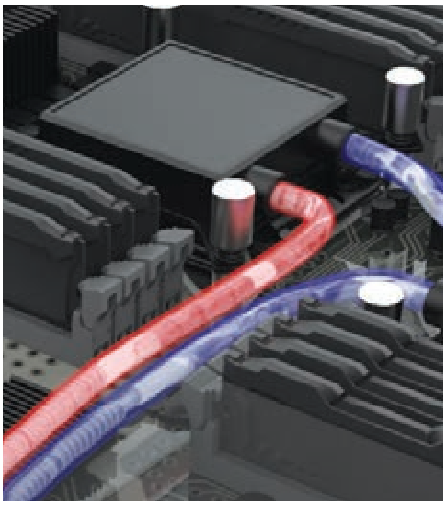
Continuum Of Cooling

Rack Level High Density Liquid Cooling

Hybrid High Density Cooling

A hybrid solution – combining both liquid and air cooling – is a more accessible and scalable deployment option, that effectively leverages the highly efficient heat transfer of liquids.

To understand the full advantage of the hybrid cooling system, first we must note that a typical server houses a variety of hardware. A few of those components, including the CPU, GPU, memory, power supply, and some older hard drives, consume the most energy and create the most heat. Many other components such as switches, routers, and network hardware, consume only small amounts of energy and generate small amounts of heat.



Direct-to-chip cooling

To remove all of the rack heat with direct-contact liquid cooling is complex and expensive requiring a configuration in which every heat source in the rack – large or small – has a separate coldplate and connection to the chilled coolant system.

Configuration Of The Hybrid System

In the hybrid system, the highest energy-consuming components are selectively cooled with direct-contact liquid cooling, and the balance of the rack is cooled with air cooling via a Rear Door Cooler (RDC).

For the direct-contact liquid cooling, low-profile coldplates are placed directly on high-heat-generating components; conditioned coolant is circulated through micro channels in the plates, sometimes in series, to provide concentrated cooling directly to the components.

A Coolant Distribution Unit (CDU) is mounted in the bottom of the rack and includes a liquid-to-liquid heat exchanger, pump and control system. It constantly monitors pressures, flow, and filtration of the unit. A rack manifold manages liquid distribution between the CDU and any number of coldplate loops. The manifold puts architecture in place to accommodate additional direct-contact liquid cooling in the future without additional facility plumbing requirements.

Managing the major heat-producing components with direct-contact liquid cooling can often achieve 70 to 80 percent of the cooling requirement.

The balance of the heat load – the remaining 20 to 30 percent – is the sum of the many low-heat-producing components. This remaining heat is air cooled with a self-contained RDC unit mounted to the back of the rack and utilizing an integrated air-to-water heat exchanger.

The RDC unit is an active solution with fans that pull the warm air out of the rack and through the heat exchanger. An integrated differential pressure sensor is used to control the air flow to the cooling needs and thus minimize the energy consumption of the unit. A water control kit allows water flow regulation according to the current heat load.

Rack manifold to manage liquid distribution

RackChiller Rear Door without fans

RackChiller Rear Door with fans

Example Hybrid Cooling Application Two technologies combine to cool high density rack	
80% Direct-contact liquid cooling	High energy/high heat components selectively managed with Direct-contact liquid cooling. Up to 80 kW per rack
20% Air with indirect liquid cooling	Remainder of the heat, is managed by a RackChiller Rear Door air-to-water heat exchanger. Air cooling with liquid assist. Up to 55 kW per rack.

Rack Level High Density Liquid Cooling

The RDC system is housed within a framed, perforated door with protective covers that isolate the air-to-water heat exchanger from the rack-mounted equipment. Because the RDC is installed directly onto the equipment rack as a separate, complete rear door, it is also possible to be retrofitted to existing racks.

The hybrid cooling system assembles two different cooling technologies into the same rack and captures 100 percent of the heat.

Primary And Secondary Loops

Designing the system with primary and secondary loops facilitates two distinct water paths – one for “raw” facility water, and a second to carry specially conditioned water for the direct-contact coldplates, manifolds and connecting elements.

The primary loop carries chilled facility water to the Rear Door Cooler. The chilled water system in the rear door removes heat from the rack by circulating cooled air through the rack and an air-to-water heat exchanger. This slightly warmed exhaust water is routed into the Coolant Distribution Unit (CDU) locally positioned at the bottom of the rack.

Within the CDU, a heat transfer takes place, from the secondary loop to the primary loop without the two fluids ever touching. This heat transfer effectively cools the water in the secondary loop to an acceptable temperature and pumps it to the coldplates in the direct-contact liquid cooling system. The strategically positioned coldplates are able to remove a large portion of the rack heat load.

Synergistic Benefit Of This Hybrid Configuration

This hybrid solution effectively uses preheated return coolant from the air-cooled loop to cool the hot return coolant coming out of the liquid-cooled loop. This is possible because the liquid cooling system can be effective at much warmer coolant temperatures than the air-cooled system.

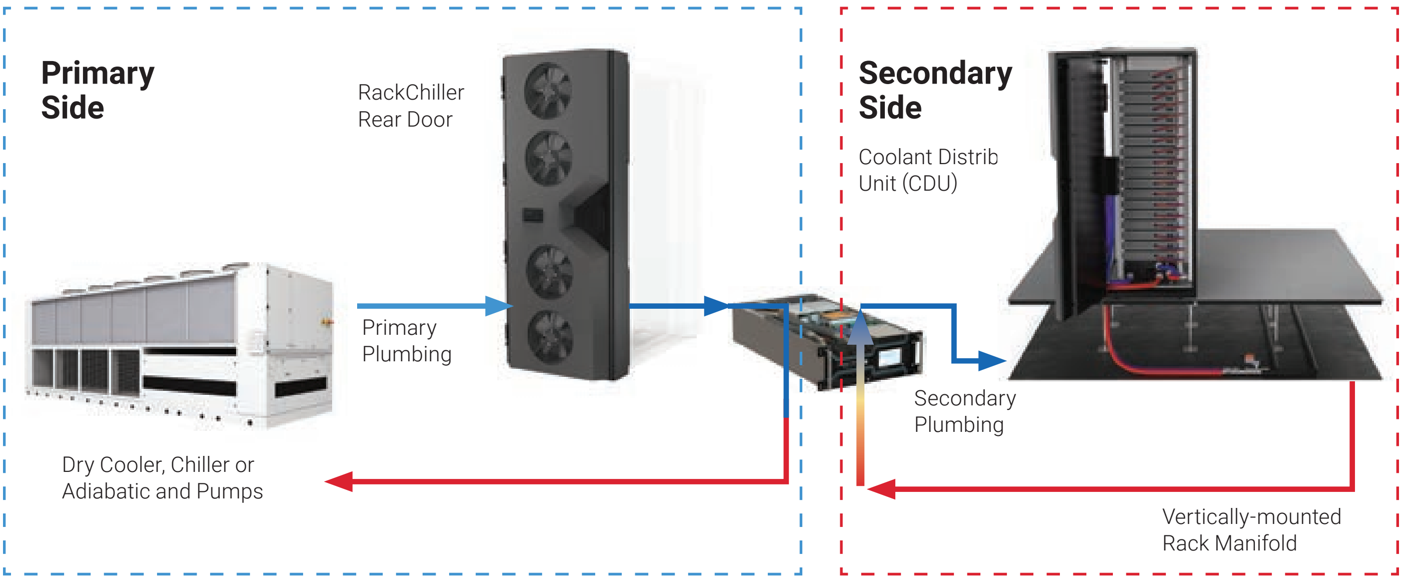
In layman’s terms, one side of the system is happy to use the cast-off coolant of the other side of the system. Liquid that has done its job and is now ‘too hot’ to be of further use in the air-cooled side, is ‘just right’ to remove heat in the liquid-cooled side.

A single server, or several servers in a rack can be cooled with direct-contact liquid cooling. The modular structure of the system with dry-break water connections simplifies the process of adding direct-contact applications at a later date. With the infrastructure already in place within the rack, it is a simple process of plugging in the direct-contact server, and making the connections to the manifold. Facility water is already plumbed in.

The complete hybrid system will more feasibly integrate into an existing architecture, is modular and is scalable. These qualities allow for simple upgrades and ease of maintenance. It is managed with a controller interface with local displays and Modbus/Ethernet interfaces to allow remote management of the cooling devices. All components are contained in a cabinet enclosure creating a net neutral environment, independent of the ambient air.

Benefits of Hybrid Cooling
Reduces energy consumption
Enables higher rack density
Decreases total cost of ownership
Quick and easy installation
Modular design for easy future upgrades

HYBRID COOLING LAYOUTS WITH TEMPERATURES



Rack Level High Density Liquid Cooling

Cooling Performance For The Hybrid Solution

Different operating points for a rear door solution at comparable water flow rates

The rear door setup is designed to isolate warmer air temperatures in a contained area at the back of the rack. Additional equipment mounted in that area, for example PDUs, are released for operating temperatures 50 °C and higher. Of course higher temperatures have an impact on the lifespan of electronics and must be considered alongside potential energy savings.

By increasing the coolant supply temperature, we reduce the cooling performance of the RDC.

In this example the primary side coolant supply temperature ($T_{water, in}$) is varied with Operating Point 1 at 15 °C, Operating Point 2 at 20 °C, Operating Point 3 at 30 °C and Operating Point 4 at 40 °C.

This demonstrates the relationship between temperature of the water going into the system and the air temperatures in the data center: higher water supply temperature, result in generally higher air temperatures in the data center.

We also look at cooling capacity in the rear door cooler – this is the thermal power which the rear door cooler would remove in those points. Calculations for the CDU and the rear door cooler are both in the primary loop and must be done in tandem.

Hence ($T_{water, out}$) is also an important parameter as this is considered the boundary temperature for the CDU.

All points have been calculated at roughly 65 liters per minute of water flow – the maximum water flow rate for this CDU.

RACKCHILLER REAR DOOR OPERATING PARAMETERS

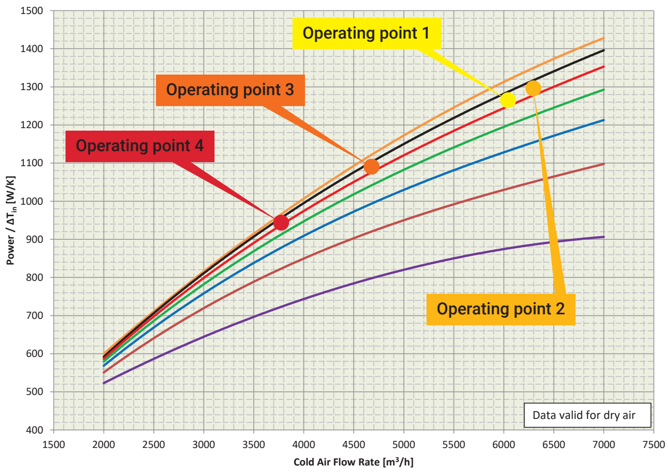
RackChiller Rear Door Operating Parameters

Parameters		Operating point 1	Operating point 2	Operating point 3	Operating point 4
P	[W]	25500	17000	11000	5700
$T_{water, in}$	[°C]	15	20	30	40
$T_{air, in}$	[°C]	35	33	40	46
$T_{air, out}$	[°C]	23	25	33	42

Result		Operating point 1	Operating point 2	Operating point 3	Operating point 4
P / ΔT	[W/K]	1275	1308	1100	950
V'_{air} (projection)	[m3/h]	6120	6375	4714	3800
V'_{water} (projection)	[l/min]	64	65	66	64
Feasibility		feasible	feasible	feasible	feasible
$T_{water, out}$	[°C]	21	24	32	41
Δp_{air}	[Pa]	24	26	15	10
Δp_{water} (no valve)	[kPa]	15	15	15	15
Δp_{water} (with valve)	[kPa]	59	61	62	59

$T_{air, in}$: Rear Door Cooler air intake temperature equals the server return air temperature

$T_{air, out}$: Rear Door Cooler air out temperature equals the server supply air temperature equals the data center room temperature



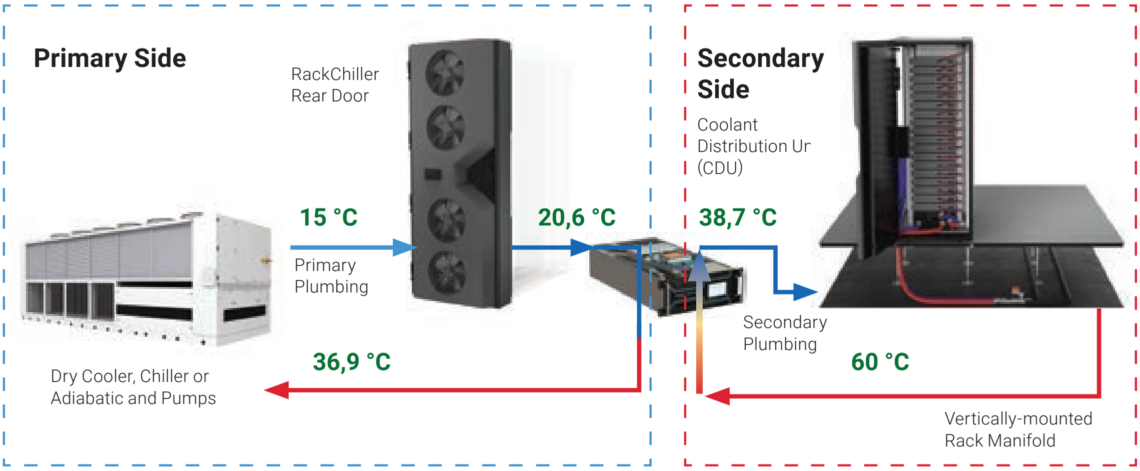
$\Delta T_{in} = T_{air, in} - T_{water, in}$

- water flow: 80 l/min.
- water flow: 70 l/min.
- water flow: 70 l/min.
- water flow: 50 l/min.
- water flow: 40 l/min.
- water flow: 30 l/min.
- water flow: 20 l/min.

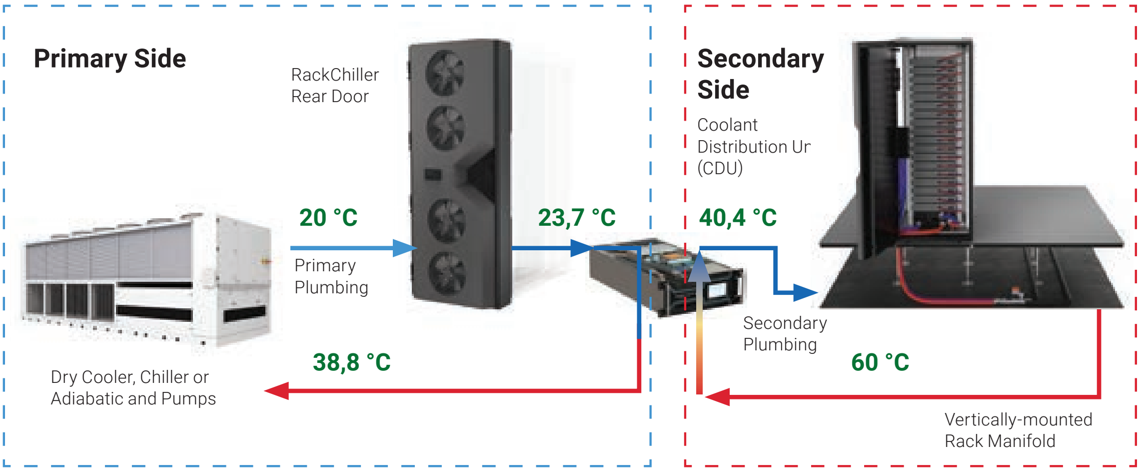
*RackChiller Rear Door 800 mm x 2000 mm

Rack Level High Density Liquid Cooling

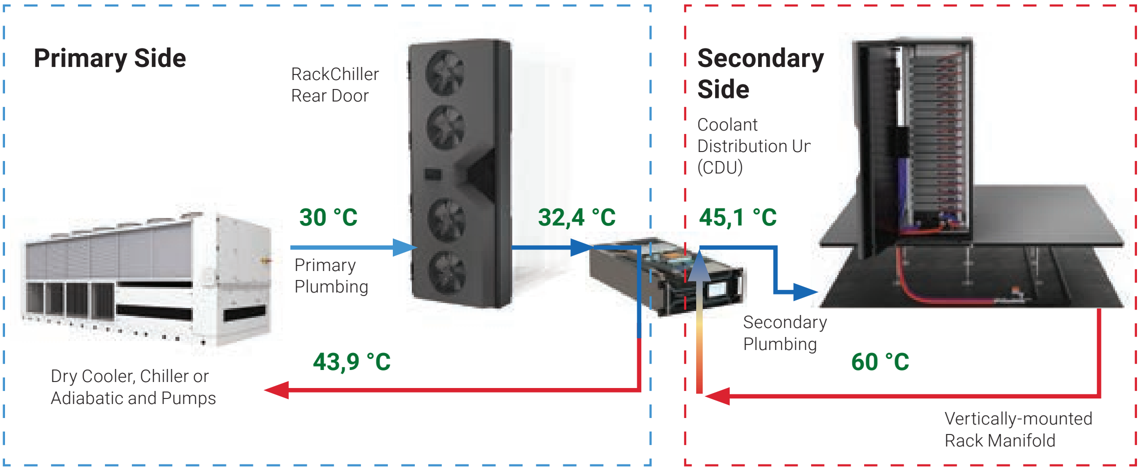
Operating point 1



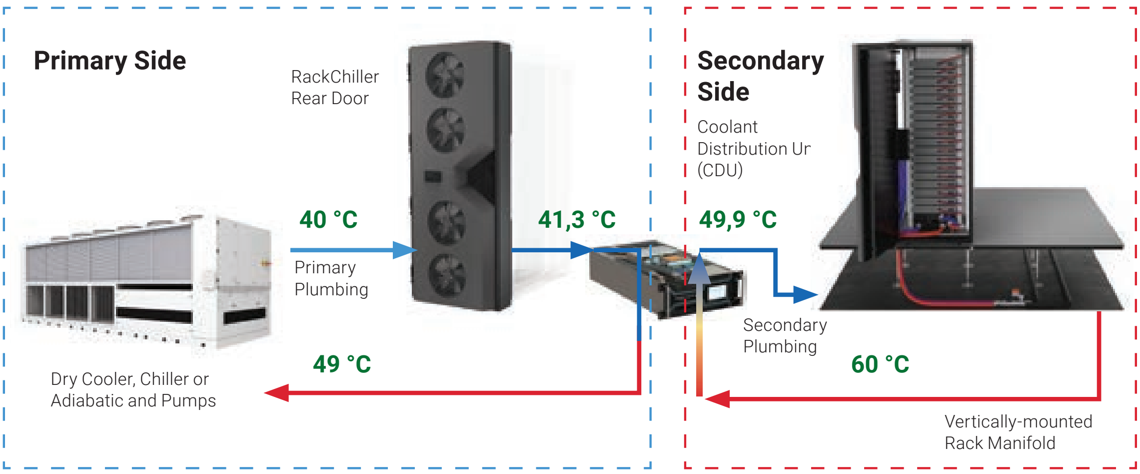
Operating point 2



Operating point 3



Operating point 4



Rack Level High Density Liquid Cooling

As a next step we take the operating parameters of the Rear Door and combine it with the CDU and Direct to Chip setup.

The water outlet temperature of the RDC gives us the water inlet for the CDU.

The operating range of the system is visualized below. Note that with warmer facility water ($T_{water, in}$) less heat is being removed by the rear door cooler, and more power is shifted to the direct to chip water cooling side. With a higher percentage heat capacity on the water cooling system, the warmer the primary loop water cycle can be.

The approach temperature is the temperature difference at the CDU (In operating point 1: 38.7-21.6 = 18.1)

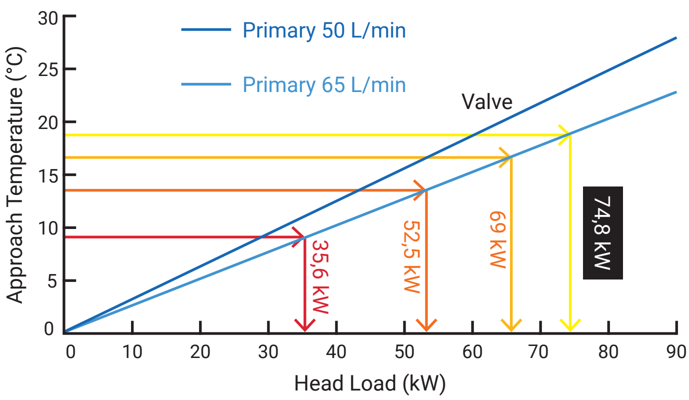
CHX80 OPERATING PARAMETERS BASED ON REAR DOOR OPERATING POINTS

Result	Operating point 1	Operating point 2
RDC Return [°C]	21	24
Server Supply [°C]	39	40
Server Return [°C]	60	60
Approach dT [°C]	18	17
Capacity from		
Approach curve [kW]	75	69

Result	Operating point 3	Operating point 4
RDC Return [°C]	32	41
Server Supply [°C]	45	50
Server Return [°C]	60	60
Approach dT [°C]	13	9
Capacity from		
Approach curve [kW]	53	36

CHx80 Performance

ASHRAE W4 (45 °C); 25 % PG Secondary



SUMMARY: OPERATING POINTS

Combining the working parameters leads us to the following table. Based on the required cooling capacity the operator can now compare different designs.

Below you can see the shifting relationship between the percentage air cooled and percentage liquid cooled. With cooler facility water, a greater percentage of the heat load can be managed with air cooling. With warmer facility water, a greater percentage of the heat load must be shifted to direct-to-chip liquid cooling.

To achieve energy efficiency and reduce capital expense operator can consider increasing the water temperatures. However, it will also have an impact on the room conditions as well as MTBF of electronics.

Parameter	Unit	Operating point 1	Operating point 2	Operating point 3	Operating point 4
Server return water temp.	[°C]	60	60	60	60
Facilty supply water temp.	[°C]	15	20	30	40
Room temp.	[°C]	23	25	33	42
Rear Door Cooler capacity	[kW]	26	17	11	6
RackChiller Rear Door return / CHx80 primary supply temp.	[°C]	21	24	32	41
CHx80 approach temp. diff.	[°C]	18	17	13	9
CHx80 capacity	[kW]	75	69	53	36
Combined capacity	**[kW]**	**100**	**86**	**64**	**41**
Percentage air-cooled	[%]	25	20	17	14
Size cooled	[%]	75	80	83	86

Rack Level High Density Liquid Cooling

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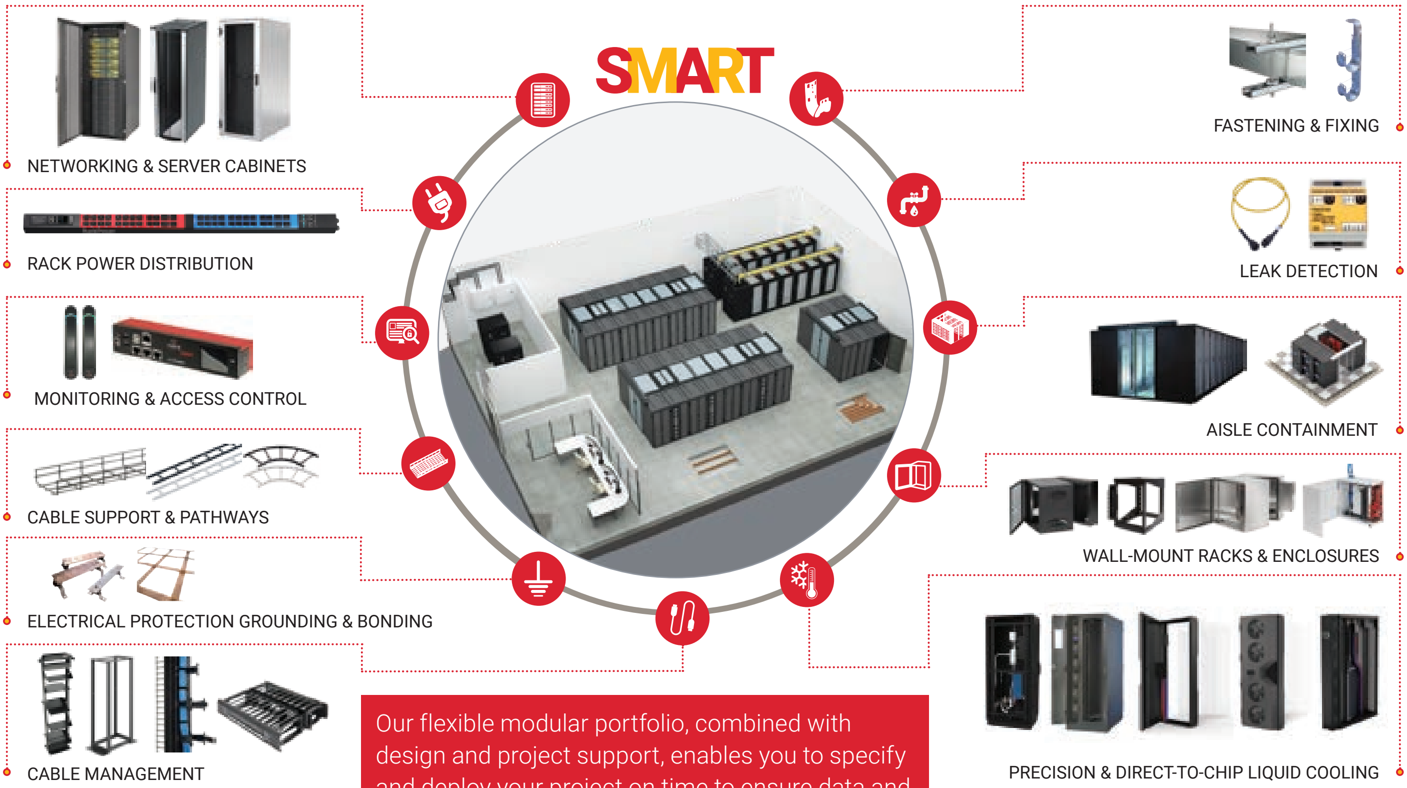

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Conclusion

Data center density is increasing and cooling technology is facing steep challenges. Traditional air cooling is no longer sufficient, while using all liquid cooling is too costly and inflexible for most operations. Hybrid cooling combines direct-contact liquid cooling with air cooling to deliver significant benefits in the near term,
and flexibility to scale up in the future.

Selecting the right cooling model is crucial to avoid thermally-related faults and equipment failures. With energy consumption for cooling being a substantial part of the total energy consumption in a data center, improvements in cooling efficiencies can also provide significant operational cost savings. The hybrid system discussed in this paper addresses emerging cooling challenges with benefits that can be realized immediately and scaled up in the future.

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nVent's experts consult with customers in the specification of datacenter cooling concepts by assessing individual server configurations, specific environmental parameters, required redundancy, uptime levels and other data points. The team then recommends the most suitable, energy-efficient solutions for a single data center or a portfolio of global data centers. nVent deploys its broad portfolio of products, and global experience to a variety of customers throughout the world.

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