MAKING DATA CENTERS SUSTAINABLE

Data Center Rack Level Cooling Utilizing Water-Cooled, Passive Rear Door Heat Exchangers (RDHx) as a Cost Effective Alternative to CRAH Air Cooling

Joshua Grimshaw—Director of Engineering, Nova Corporation
Michael McSweeney —McSweeney Engineering
Shlomo Novotny —Vice President and Chief Technology Officer, Vette Corp.
Mike Gagnon —Director of Marketing, Coolcentric

December 2011

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Executive Summary

The increasing demand for energy conservation and the continued growth requirements of data center cooling reinforces the need to find ways to reduce energy consumption and at the same time realize cost savings.

This white paper discusses CAPEX and OPEX costs of cooling a data center. The paper compares the traditional CRAH air cooling method utilizing chilled water to passive Rear Door Heat Exchanger (RDHx) solutions. Our study concludes that in terms of CAPEX, the RDHx cooling is roughly equivalent to CRAH cooling at approximately 5kW per rack power dissipation. However, OPEX for RDHx cooling, is better at reducing today's energy costs. As we look to the future and the expectation that energy costs will continue to rise, OPEX savings from an RDHx cooling solution are likely to be even more significant.

Guidelines by ASHRAE have led to the practice of raising supply air temperatures in conjunction with the cold aisle – hot aisle arrangement. These high-supply air temperatures can range from the high 60 degrees F to the high 70 degrees F or more. While the increase in supply air temperature has had a positive impact on energy efficiency, the corresponding rise in air temperature in the hot aisle of 20°F to 30°F above the cold aisle air temperatures does not eliminate the significant amount of energy needed to run the air-movers and creates difficulties for service personnel who work in the hot aisles. Additionally, the elevated hot and cold aisle air temperatures create thermal management design complexities because of a decrease in the cooling margins. As a result, precise placement of the IT racks and better containment is required for proper cooling distribution.

As discussed in other white papers, rack-based cooling is an effective, energy efficient alternative to air- based systems as a way to provide cooling to high densities loads. The question has yet to be asked, "When does it become cost effective, for both construction costs and energy usage, to deliver a rack based liquid cooling solution?"

Introduction: Benefits of the Water-Cooled Passive Rear Door Heat Exchanger

The passive Rear Door Heat Exchanger (RDHx) uses a high performance air-to-water heat exchanger (coil) in lieu of an open cabinet or ventilated door.

By close coupling the RDHx to the rack, two obvious benefits can be realized: first, the hot aisle containment is moved closer to the heat source, thereby confining the hot aisle to the interstitial space between the servers; and second, the coil provides a medium (water) for heat transfer at a rate that is approximately 3,400 times that of air. By treating the heat load in this manner, the air in the hot aisle is now at the same temperature as the discharge temperature of the RDHx which is typically in the mid-70°F range. ASHRAE has recommended that the inlet temperature to the racks be set between 64.4°F and 85°F.

Lawrence Berkeley National Labs has determined that at higher rack inlet temperatures, the energy savings of the raised temperatures may not be significant since the server fans speed up to deal with the higher temperatures. Therefore, limiting the supply air temperature to a maximum of 74°F to 78°F should be acceptable for energy savings. This temperature range conserves energy since mechanical cooling is limited and will prevent the servers' own circulation fans from speeding up to attain the proper chip cooling.

A major benefit of the RDHx, beyond effectively controlling the entire ambient air temperature in the data center, is the significant reduction in the fan energy required in a typical air handler cooling system (or CRAH) cooling scheme. In a CRAH, the temperature exchange of the cooling air occurs at the CRAH, which is positioned remotely from heat generating servers. Due to the distance between the cooling device and the heat source, the CRAH requires a fan in order to move the cool air to the inlet of the racks as well as to pressurize the air plenum, and after discharge from the racks, bring the hot air back to the CRAH for cooling. In comparison, the RDHx does not require a fan since it neutralizes the hot air discharge from the servers directly at the rear of the rack.

Current design concepts and implementation for RDHx typically involve a secondzary cooling loop—a Coolant Distribution Unit (CDU) with an associated heat exchanger and pump package. The secondary loop primarily limits the racks' exposure to water in the event of a heat exchanger or hose failure and controls coil water condensation (see Design Alternative 3). However, there are other water distribution methods that do not require the utilization of a CDU. One such method is to employ prefabricated manifold and valve systems for cutting down CAPEX cost (see Design Alternative 2).

The Study: Comparing 3 cooling designs and resulting cost factors

The study compares 3 design alternatives and includes all aspects of deploying each cooling solution in a 1mW data center module, including the furnishing and installation of the data center cooling system, valves, piping, building monitoring integration system, leak detection, smoke/fire detection, condensate removal and electrical connections. The designs presented in this paper are:

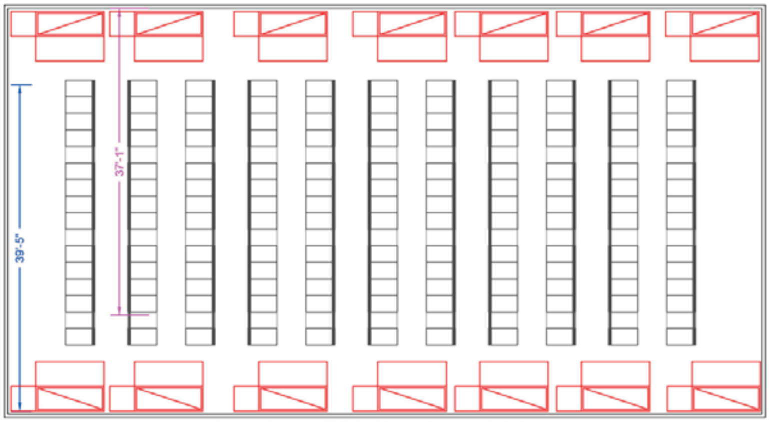
1. Traditional 30-ton CRAH units (benchmark)
2. Rear Door Heat Exchangers with a primary piping manifold system
3. Rear Door Heat Exchangers with Coolant Distribution Units and a secondary loop

Data Center Configuration

The study looks at a proposed data center module based on the following configuration:

- Consumes 1mW of IT power in a raised floor environment.
- Consists of a 5,000 square foot white space with a planned deployment of 177 IT enclosures.
- The infrastructure is designed for a space loading of 200 watts per square foot or 28 square feet per IT enclosure, assuming a rack power dissipation of approximately 5kW.
- The benchmark air cooling system is designed for using chilled water Computer Room Air Handlers (CRAHs). The 1mW planned load requires twelve 30-ton operating units distributed around the perimeter of the white space and discharges cold air under an 18 inch raised floor. Two additional CRAH units are installed for redundancy. Power consumption per CRAH is assumed to be 4.6kW since the units will be running at reduced load of approximately 80%.
- Chilled water piping for the CRAHs is branch connected from a main chilled water loop running external to the white space, using 100% water (no glycol).
- Utilizing a hot aisle-cold aisle arrangement, the CRAH unit air discharge temperature is in the 68°F to 70°F range.
- The chiller and water supply costs and energy consumption are not included in any of the alternatives.

Design Alternative 1 - Traditional CRAH units



UNDER-FLOOR COOLING AIR DISTRIBUTION - CRAH UNITS
5.5 kW per Rack. 5000 sq-ft ~ 1MW Power

Cost Description	Design Alternative 1 CRAH
Install Cost (CAPEX)	$942,390.00
Data Center Footprint Cost	$102,375.00
Total COST	$1,044,765.00
Cost per kW	$1,044.77
Possible Savings in Greenfield Building	$87,750.00
Annual Energy Cost (OPEX)	$60,444.00
1-Year TCO (CAPEX & OPEX)	$1,105,209.00
5-Year TCO (CAPEX & OPEX)	$1,346,985.00

Inefficiencies are common in this cooling system as airflow over a large area is unpredictable and obstructions like columns or cable runs can alter airflow paths. In a raised floor environment, openings in the tiles that don't provide direct access to the intakes of IT equipment become wasted air. This study assumes a 25% reduction in CRAH performance.

For this data center, fifteen 30-ton CRAH units are used, of which twelve are active and three are standby units. This comparison also factors in the white space that is consumed by the CRAH units and their required servicing clearance. The footprint required by a CRAH system far exceeds that required by the RDHx solution, which could prevent or complicate future expansion of IT enclosures.

Alternative 1 Summary

The CRAH design alternative represents the typical cooling topology used in data centers. The cost includes all the electrical, mechanical and plumbing systems for a fully functional unit. The cost also includes BMS monitoring as well as the fit-out space and fire protection/suppression systems required for access and CRAH footprint. Derating the published sensible cooling capacity by 25% is considered a conservative discount for the built-in inefficiencies of the CRAH based air cooling systems. The power consumption of the CRAH system is much higher than the RDHx alternatives due to the fan utilization, humidification and reheat functions. Furthermore, any increase in rack power dissipation will force a change in the cooling infrastructure through the addition of more CRAHs, use of supplemental cooling devices or some form of containment.

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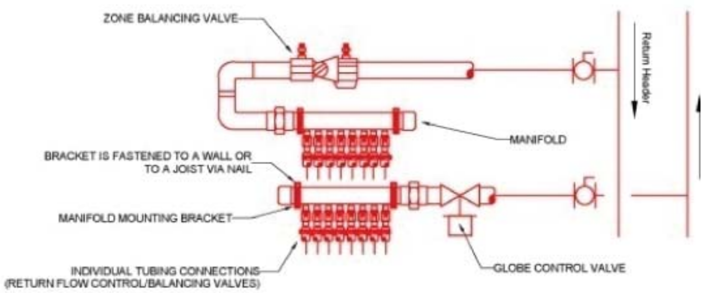
Design Alternative 2 – RDHxs with a primary piping manifold system

In this design alternative, cooling is handled by RDHxs with chilled water coming from a prefabricated manifold and valving system. Two CRAH units remain for the purpose of humidification control and as a room cooling backup.

Note: Standard practice when deploying RDHxs is to use Coolant Distribution Units (CDUs), which provides a separate secondary cooling loop (see Design Alternative 3). In the RDHx with piping manifold design, the RDHx system is analyzed without CDUs.

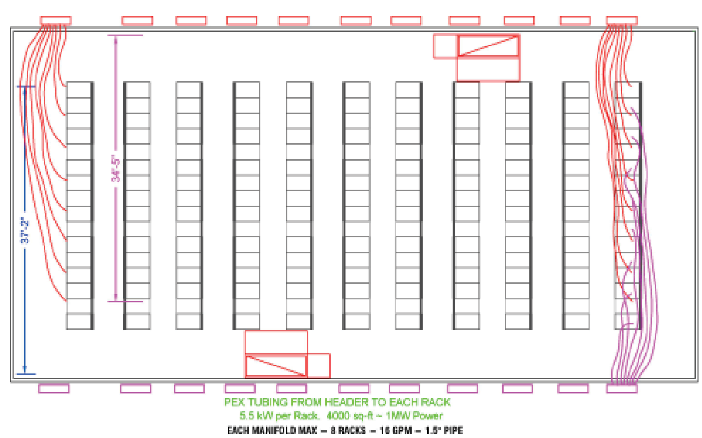


When eliminating the CDU entirely, the system relies on a piping manifold for the interface between the building's chilled water system and the RDHx. By removing the CDU and using a radiant piping system, the implementation does not require additional pumps or heat exchangers, thus reducing overall CAPEX cost but at the same time increasing energy efficiency.

The piping manifold design examines cooling systems more holistically and looks at other industries' methods of water distribution for possible application. This simpler method considers systems used by the radiant piping industry. Industry-standard radiant systems primarily connect flexible tubing to a copper piping assembly. There are multiple methods for generating the correct temperature water for the radiant systems. The radiant system configurations use a pre-manufactured manifold assembly to distribute the water to a floor or a radiant panel. One could compare the RDHx system to a radiant heating system even though their functions are the opposite of each other, that is, one cools while the other heats. By leveraging the use of readily available radiant heat manifolds over custom built manifolds, material cost can be reduced.

Piping Manifold Alternatives:

The connection between the building's chilled water system and the RDHx is a piping manifold that can be configured in various ways.



1. The piping manifold consists of a very simple branch connection with an isolation and balancing valve on the return and a number of tubing connections on both supply and return sides. This type of connection requires the chilled water system to operate at higher supply water temperatures so as not to create condensation in the data center space. The tubing connections would have isolation and/or balancing valves.

2. Another configuration, which has become more common in radiant systems, is for the piping manifold to use a small pump that connects to a bypass/mixing line. The small pump draws water from the bypass line and sends it to the radiant system to maintain the space thermostat and chilled water temperatures. The return water then discharges back into the bypass line. This piping arrangement is very typical of a tertiary pump system used on large campus piping systems.

3. Finally, a manifold that incorporates a mixing three-way valve along with the balancing valve manifold can be installed to achieve the high supply water temperatures while still achieving the individual balance for each tubing run without the need for pumps.

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Any one of these three commercially available manifold systems could efficiently leverage the already existing infrastructure by directly connecting to the building's chilled water system and to the RDHx, thus eliminating the need for a CDU unit.

The controls for the proposed system rely on supply air temperature sensors for eight racks that are served by the manifold and the eight corresponding RDHx units and modulating temperature control valve or mixing valve at the piping manifold. CRAH units monitor overall room temperature and humidity and adjust their own cooling to meet the room load as necessary. Leak detection is placed under the raised floor, where the piping runs in a manner such that an offending manifold system is isolated. Isolation can be done with isolation control valves or solenoid valves.

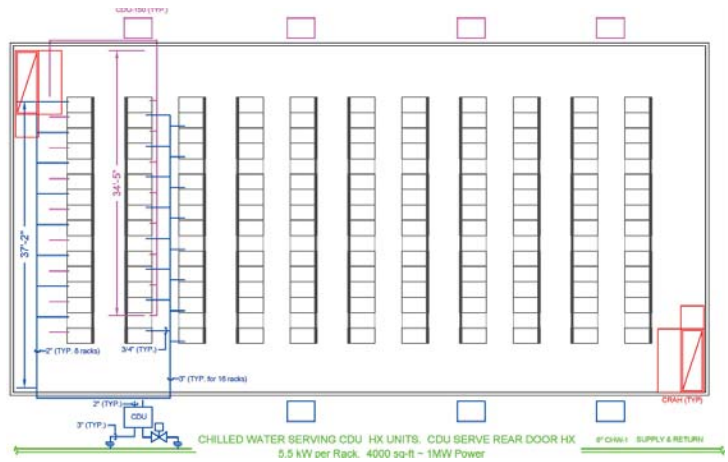
Cost Description	Design Alternative 1 CRAH	Design Alternative 2 Coolcentric RDHx w/ Primary Manifold
Install Cost (CAPEX)	$942,390.00	$1,003,929.00
Data Center Footprint Cost	$102,375.00	$0.00
Total COST	$1,044,765.00	$1,003,929.00
Cost per kW	$1,044.77	$1,003.93
Possible Savings in Greenfield Building	$87,750.00	$0.00
Annual Energy Cost (OPEX)	$60,444.00	$1,927.20
1-Year TCO (CAPEX & OPEX)	$1,105,209.00	$1,005,856.20
5-Year TCO (CAPEX & OPEX)	$1,346,985.00	$1,013,565.00

Alternative 2 Summary

In terms of CAPEX, the RDHx with prefabricated manifold system is comparable to the CRAH alternative. Since the RDHx units are a passive system, power consumption is insignificant – about 3% of the power consumed by the CRAH units. The result is major OPEX savings. The fact that RDHxs consume very little white space footprint means that the space allocated for the CRAHs in Design Alternative 1 can be freed up for adding IT equipment or result in construction savings. Data center construction cost could be reduced by the removal of CRAH units, because less space is required. Additionally, this footprint reduction can translate to further savings in 'greenfield' projects by reducing the overall building footprint. Payback for an RDHx with manifold piping takes place within the first year of operation.

This design alternative offers several other benefits beyond CAPEX and OPEX. While the current rack power density is approximately 5kW, the cooling capacity of the lowest rated RDHx is 18kW nominally. The ability of the data center operator to increase the rack power density to 18kW with minimal changes provides a "future proofing" not possible with the CRAH configuration. The fact that the RDHxs consume very little white space footprint means that the space allocated for the CRAHs in Design Alternative 1 could be freed up for adding IT equipment.

Design Alternative 3 – RDHxs with CDUs and a secondary loop



In this design, cooling is handled by RDHxs mounted to all 177 IT enclosures with the chilled water supplied by 4 Coolant Distribution Units (CDUs), which is the typical implementation of an RDHx design.

The CDU is a floor-mounted device that consists of a heat exchanger, pumps, controls and a piping distribution manifold. The CDU provides closely controlled cooling water to the RDHxs. The CDU creates an isolated secondary loop separate from the primary chilled water system loop, enabling strict containment and control of the liquid cooling system. The CDU automatically prevents condensation and ensures 100% sensible cooling by maintaining the secondary loop supply temperature above the dew point of the data center. Because of the isolated loops, the CDU can accept chilled water temperatures that are lower than the secondary water temperature. Heat removed by the RDHxs is then returned to the chilled water supply by means of the CDU heat exchanger.

In this configuration all 177 IT enclosures have an RDHx attached neutralizing 100% of the 5.6kW rack heat load. The RDHx in this design is underutilized as the heat load is well below its 18kW nominal rating. A total of four CDUs, each rated at 260kW, provide the secondary loop water to a series of external under floor manifolds which are attached to the RDHxs. Power consumption of the CDUs is 3.7kW each.

Cost Description	Design Alternative 1 CRAH	Design Alternative 2 Coolcentric RDHx w/ Primary Manifold	Design Alternative 3 Coolcentric RDHx w/ CDU +Secondary Manifold
Install Cost (CAPEX)	$942,390.00	$1,003,929.00	$1,236,397.00
Data Center Footprint Cost	$102,375.00	$0.00	$0.00
Total COST	$1,044,765.00	$1,003,929.00	$1,236,397.00
Cost per kW	$1,044.77	$1,003.93	$1,236.40
Possible Savings in Greenfield Building	$87,750.00	$0.00	$0.00
Annual Energy Cost (OPEX)	$60,444.00	$1,927.20	$12,964.80
1-Year TCO (CAPEX & OPEX)	$1,105,209.00	$1,005,856.20	$1,249,361.80
5-Year TCO (CAPEX & OPEX)	$1,346,985.00	$1,013,565.00	$1,301,221.00

Alternative 3 Summary

The use of CDUs in this alternative increases the CAPEX, but reduces OPEX. Although the RDHx units are passive devices, the pumps in each of the four CDUs consume approximately 3.7kW of power each. However, power consumption by the CDU pumps is only about 15% of the power consumed by the CRAH units – resulting in major OPEX savings. Factoring in both CAPEX and OPEX, the breakeven point takes place in Year 3. The current rack power dissipation is 5.6kW, thus enabling the data center operator to increase the rack power dissipation to 18kW with minimal changes, providing a “future proofing” not possible with the CRAH design. Although a CDU consumes the white space footprint of a single IT enclosure, there still are space savings in this concept over the CRAH alternative.

Summary of the Three Design Alternatives

The study shows that, at approximately 5kW per rack power dissipation, there are cooling alternatives using RDHxs that have about the same CAPEX as CRAH air cooling utilizing chilled water. In addition to the designs discussed here, CAPEX could be further reduced by implementing a design with alternating RDHxs. Such a design is feasible because the cooling capacity of the RDHx is more than twice the per-rack power dissipation requirement. CAPEX savings could be as high as 25% compared to populating each rack with an RDHx.

Another alternative is for the data center operator to densify, i.e., increase the power dissipation per rack to 18kW. By doing so, infrastructure space is minimized as is the number of racks needed, resulting in significant CAPEX savings that could be as high as 30-40%. The CAPEX in this high density design will be significantly lower than that CAPEX of CRAH based air cooling. OPEX savings would be approximately the same as in the alternatives described in this paper.
The benefits of using an RDHx for data center cooling can be summarized as follows:

- The CAPEX with an RDHx at 5kW per rack is approximately the same as the CAPEX of CRAH cooling, enabling significant energy savings or a significant reduction in OPEX.
- With power dissipation higher than 5kW per rack, CAPEX and OPEX savings would be even more significant, enabling future data center power dissipation growth without new construction for the additional cooling. The RDHx can neutralize approximately 20 kW per rack.
- The RDHx performs well with elevated water temperature, thus minimizing the energy used by the chiller.
- Further energy-OPEX saving could be obtained by using waterside economizers in conjunction with the rear doors. The RDHx neutralizes 8-10kW power dissipation per rack with 70°F water.
- A hybrid system that includes a few CRAH air cooling units along with RDHxs adds significant redundancy for system availability.
- A hybrid system as described above with rear doors removing 8-15kW per rack is significantly lower cost in CAPEX and OPEX than an equivalent CRAH air cooling system.

Conclusion

A common misconception in the industry is that liquid cooling is too expensive to deploy until the rack dissipation exceed 6-8kW. This study demonstrates that 5kW per rack may be the point where CAPEX of liquid cooling is approximately the same as traditional air cooling.

An increase in the cost of energy, which is likely, should drive data center customers to consider liquid cooling as the ultimate data center cooling solution because of its lower energy consumption. Even less than 5kW per rack power dissipation justifies an investment in liquid cooling that could be recovered in a short period of operation.

Passive liquid cooling enables expansion and flexibility in data center configuration at a lower capital expenditure. Raised floors and pre-configured data centers now commonly in use could be replaced with modular low-cost liquid cooled data center designs.

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Coolcentric • 201 Boston Post Road West • Marlborough, MA 01752 USA
Phone: +1 508.203.4690 • Fax: +1 508.203.5905 • Web: www.coolcentric.com