


# EVALUATING THE LIMITS OF DOOR HEAT EXCHANGER SOLUTIONS OPTIMIZED FOR OPEN RACK V3

**AUTHORS:**

Jabari George, Mechanical Engineer

John Fernandes, Meta Platforms Inc.

Juan Carlos Cacho Alonso, Rittal

Kenneth Kiernan, Amphenol Corporation

Michael Thompson, nVent Schroff GmbH

Philippe Boisvert, Boyd

## Executive Summary

This whitepaper demonstrates the enhanced performance of a water-cooled rear door heat exchanger (Door HX) optimized for Open Rack V3 (ORV3) versus an equivalent off-the-shelf (OTS) counterpart. Three main Door HX solutions or implementations are evaluated: Traditional, Air-Assisted, and Hybrid. The major parameters of concern are airside approach temperature, water supply temperature, water-side delta T, percentage of liquid cooling load to total IT power, and approximate ITE fan power increase. For the Traditional Door HX implementation, a higher FWS temperature was achieved at the same cooling capacity and airflow rate. Similarly, the Hybrid solution data showed higher FWS temperatures with lower total IT power consumptions. Finally, reduced approach temperatures and lower water temperatures to cold plates were observed with the Air-Assisted Door HX.

# Table of Contents

1. License 4

2. Acknowledgements 4

3. Terminology 5

4. Introduction 6

Goals of the document 6

Door HX Technologies & Facility Applications 7

5. Boundary conditions and Parameters of Interest 10

Boundary Conditions and Assumptions 10

Parameters of interest 10

Comparison of ORV2 and ORV3 12

6. Two Different Door HX Solutions 13

Off-the-shelf (OTS) 14

Specific to ORV3 (Custom) 14

7. Performance Under Specific Applications 15

Air-assisted (liquid cooling in an air-cooled facility) 15

Traditional 17

Hybrid 18

8. Door HX Cooling Management 20

Traditional 21

Air Assisted 21

Hybrid 21

9. Summary of Benefits and Limitations 22

Key Takeaways 22

10. Next Steps 23

11. References 24

12. About Open Compute Foundation 24

## 1. License



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## 2. Acknowledgements

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## 3. Management Summary

This document explores the application of door heat exchangers (Door HX) in data center cooling. The technology has been around for some time and is used in high-performance computing and enterprise spaces. There are three main types of Door HX: Air-Assisted, Traditional, and Hybrid. Each category possesses distinct advantages and is suitable for specific situations.

Air-assisted: This solution focuses on enabling higher component power and rack density through the implementation of closed-loop liquid cooling with cold plates at the rack level of an air-cooled facility. Heat is rejected to the aisle via the rear-mounted Door HX. This solution is ideal for data centers that want to extend the capability or efficiency of air-cooled ITE and facilitate a smooth transition to liquid-cooled facilities. By being specific with the Door HX design, this solution can reduce fan power consumption by 55% among other benefits.

Traditional: This is the most widespread application of a door heat exchanger solution. Facility water is used to cool air leaving the rack to ambient temperature. Data center designs can therefore be simplified as aisle containment and dedicated CRAH units are not critical. This solution also enables the placement of higher power racks near low power counterparts. The traditional door HX is an option for small deployments, such as edge computing, and proper design can minimize the approach temperature, enabling 30°C ambient air with 27°C facility water supply.

Hybrid: The hybrid solution combines the AALC and traditional approaches by using cold plates to cool critical IT gear components, while also exhausting air at ambient temperature. This implementation simplifies the data center design while maximizing potential for white space footprint optimization by enabling higher rack powers compared to the previous solutions. For example, a 30kW rack could be cooled with 1500cfm of air (@ 32°C) and 30°C water supply, resulting in a total fan power of only 1.5% of the rack IT capacity, which is lower than AALC and traditional solutions.

Overall, the Door HX technology offers a unique opportunity to capitalize on the advantages of liquid-cooling to increase cooling efficiency and capability, reduce costs and IT refresh rate, and increase rack density. It is noteworthy that Door HX technologies are less disruptive to existing air-cooled hardware and ITE design compared to other advanced cooling solutions. The choice of solution depends on the specific needs and goals of the data center.

## 4. Terminology

The following is a list of terms or acronyms used frequently in this document.

- **Door HX**, Door Heat Exchanger assembly. A component typically mounted to the rear of an IT rack that can be used for liquid-to-air or air-to-liquid heat rejection.
- **CDU**, Coolant Distribution Unit. A component used to drive a closed loop of coolant that absorbs heat from IT racks or equipment and rejects it to the facility cooling (water) system. A liquid-to-liquid heat exchanger is used to keep the TCS and FWS separate. This component can be sized to mount within an IT rack or installed on the data center floor to support multiple IT racks.
- **RPU**, Reservoir and Pumping Unit. A component like the CDU, but without a heat liquid-to-liquid exchanger to reject heat to the facility cooling system. It is designed to drive a closed-loop of coolant within or across IT racks and, when combined with a liquid-to-air heat rejection device like a Door HX,

exhaust heat to facility air. Therefore, a cooling system employing an RPU can function in a facility designed for 100% air-cooling.

- **TCS**, Technology Cooling System, is the cooling system from the CDU to IT racks or equipment. This term is defined by ASHRAE to describe a type of liquid cooling implementation [1].
- **FWS**, Facilities Water Systems, is the facility cooling system. This term is defined by ASHRAE to describe a type of liquid cooling implementation [1].
- **W-Classes (ASHRAE)** indicate the temperature ranges of the FWS. For example, W17 indicates a FWS temperature range of 2°C - 17°C, W27 corresponds to a range of 2°C - 27°C.

# 5. Introduction

## Goals of the document

According to the Uptime Institute's Global Data Center Survey 2022, rack powers can approach 40-50 kW, but typical rack power is still under 20kW. Increases in air cooling density increase fan power and associated acoustical noise, while also decreasing overall cooling efficiency (i.e., fan power as a portion of total system power).

According to ASHRAE TC 9.9 whitepapers [2, 3], over the last decade, IT manufacturers have managed to significantly reduce fan power as a percentage of server power with complex fan control algorithms acting on feedback from a variety of sensors. Since 2018 however, the advantages of multicore technologies seem to have reached their limits, and further performance increases have required more power. This problem is exacerbated by multithread processing using more socket thermal design power (TDP) and decreases in allowable case temperatures, both of which are characteristic of several next-generation processors. In response, server fan power has been increasing in recent years, with percentages of 10% - 20% common for denser servers, not to mention the impact on fan efficiency at the facility level. Additionally, since server fans rely on the same uninterruptible power supply (UPS) source as the server itself, an increase in server fan power from 2% to 10% of the total server power equates to a reduction in UPS capacity by 8%.

The case for liquid-cooling is strengthened as these trends continue. The adoption of liquid cooling technologies can break the trend of ramping cooling power costs associated with higher ITE power within a rack. It should be acknowledged that these technologies are unfamiliar to many in the datacenter industry. While many efforts are underway within organizations like OCP to formalize the adoption of liquid-cooling technologies, the fact is that their use is currently far less widespread than traditional air-cooling in the datacenter industry.

A variety of methods of liquid cooling exist. Within the broad categories of single-phase and two-phase cooling, technologies can involve full immersion, cold plates, rear-door heat exchangers (Door HX), or combinations of each. In addition, introduction of liquid-cooling infrastructure advances innovation in thermal designs of ITE components, such as boiling enhancement coatings, and fluidic and microfluidic channels for enhanced heat transfer from heat sources. These combinations and innovations may even eventually extend to other traditionally air-cooled ITE components, such as cold plates for power components. Today, however, the Door HX offers a unique opportunity to capitalize on the advantages of liquid-cooling, while continuing to use existing air-cooled equipment and infrastructure. This whitepaper investigates the expected performance of different Door HX technologies optimized for ORV3.

## Door HX Technologies & Facility Applications

Rear Door Heat Exchanger technologies fall into three categories: Traditional, Air-Assisted, and Hybrid [4]. As illustrated in the Figures below, each category possesses a few defining characteristics:

**Traditional** - The most widespread application of a door heat exchanger is where the solution replaces the rear door of a rack and relies on the facility-provided coolant to make the rack thermally neutral to the room.

**Air Assisted** - Heat exchanged in an internal (closed) coolant loop is exhausted to facility air using a door heat exchanger. Rack-level liquid cooling infrastructure such as cold plates, manifolds, and RPU are used to cool high-power IT components such as CPUs, GPUs, etc.

**Hybrid** - This solution is an extension of the traditional approach with the added feature of liquid-cooling IT hardware components in the rack. Availability of facility coolant at the rack is leveraged to liquid-cool high-power components in IT chassis.

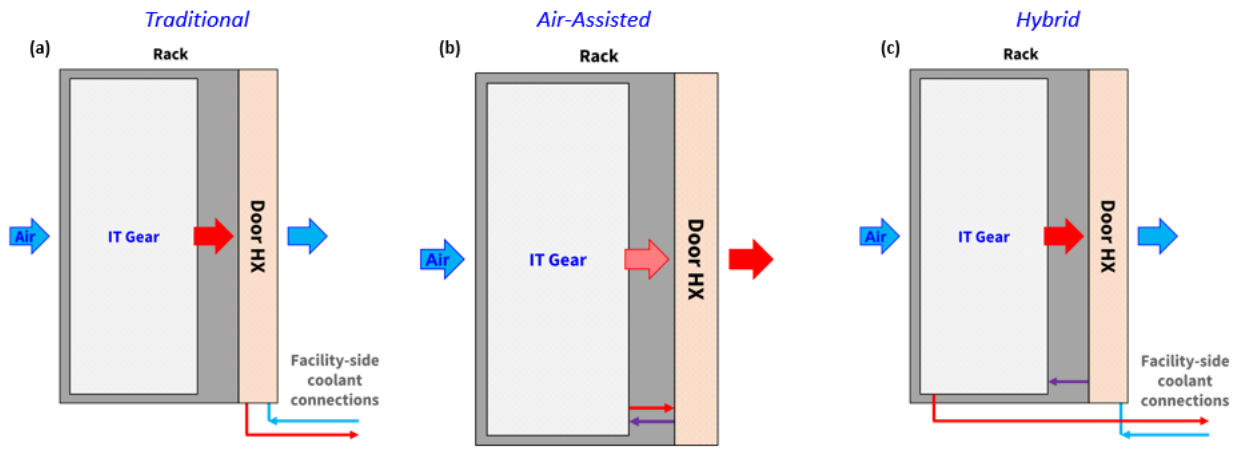



**Figure 1: Different applications of Door HX – (a)traditional, (b) air-assisted and (c) hybrid**

The characteristics of each Door HX technology determine its suitability for the various data center facility types. Below is a high-level summary of the operational issues associated with different types of data center facilities, along with the best-fit Door HX technology solutions based on their advantages.

**Table 1: Advantages of Door HX applications in air-economized data centers (no water loops at the facility)**

| | Door HX Advantages | | |
|---|---|---|---|
| Air Economized (100% Evaporative Cooling) Facility Limitations* | Traditional | Hybrid | Air-Assisted |
| High Fan Power | *Traditional and Hybrid Door HX require a Facility Water System with chilled water supplied to the rack.* | | Improved cooling of high-power IT equipment, which decreases fan bank power required to supply cool air. Additional fan power optimization and rack power density can be achieved by reducing the rack inlet air temperature or increasing rack outlet temperature. |
| Mechanical Vibration & Acoustic Noise | | | Reduction in fan power at the rack level reduces the associated mechanical vibration and acoustic noise, creating a safer work environment. |

| | | |
|---|---|---|
| High Water Usage | | Improved efficiency of heat removal increases heat transfer rate to air, reducing overall load. |
| Slow system response time to increase in IT load | | Door HX RPU/CDU can respond rapidly at-source to improve cooling. |
| Humidity / Dew Point Control | | Door HX provides additional cooling capacity without additional humidification. |

* Facility air-side limitations include:

- Limited to (<20 kW/rack)
- Class A1-A4 Recommended (18°C-27°C air, -9—15°C max Dew Point, 60% RH)
- Server air △T of 15-23°C @ 35°C inlet T

**Table 2: Advantages of Door HX applications in chilled water-based facilities (with water piped to IT racks)**

| | Door HX Advantages | | |
|---|---|---|---|
| Chilled Water Based Facilities Configurations and Limitations* | Traditional | Hybrid | Air-Assisted |
| Room CRAH + No Aisles<br>• High vibration & noise<br>• High fan power losses<br>• CRAH demand fighting<br>• Short cycling at rack level | • Approximately 10 kW/rack additional cooling capacity.<br>• Reduced rack leaving air temperature.<br>• Ability to position high-power racks next to lower-power, air-cooled racks.<br>• N+1 or 2N redundancy possible for lower-power racks<br>• Mitigated impact of demand fighting<br>• Reduced air bypass / short cycling | •All advantages of Traditional RDHx<br>• Reduced ITE fan power along with vibration and noise.<br>•Direct liquid cooling of ITE components rated at 300W and higher. [3] | *Not required with water supply to IT racks.* |
| In-row CRAH<br>• Logistically challenging to service/upgrade cooling units due to streamlined airflow.<br>• Heavy equipment relative to ITE density | | | |

* Facility air-side limitations include:

- Limited to <20 kW/rack
- 4°C - 16°C chilled water supply with optimized facilities (free air cooling + chiller trim)
- Class A4 (5°C-45°C air, 24°C max Dew Point, 8%-90% RH)

# 6. Boundary conditions and Parameters of Interest

The performance of the Door HX is demonstrated by comparing the performances of an Off-The-Shelf (OTS) version versus a Custom design optimized for ORv3. The boundary conditions along with the measured parameters forming the basis of the performance analyses are explained below. This is followed by a brief comparison of the features of ORV2 vs ORV3.

## Boundary Conditions and Assumptions

- Air-side operating conditions: 30°C ambient; sea-level operation; target delta-T of 12°C - 15°C across either IT gear or the rack depending on the Door HX solution/application. The 30°C temperature was selected as an upper limit for datacenter cold aisle operation but would be subject to OSHA Heat Hazard Assessments for each facility [5] as well as power components thermal performance limits. In addition, air-economized data centers are designed and operated with an upper limit of supply air temperature in the range of 30 to 35°C. Hardware deployed in such facilities are found to have adequate reliability or life expectance at the aforementioned elevated air temperatures. The target delta-T of 12°C - 15°C is based on preliminary calculations of a model Door HX with ORV3 specifications.
- Liquid-side operating conditions: Treated water; W27 facility water system [1]. Typically, door heat exchangers require colder FWS operating temperatures of W17/W27. These liquid-side operating conditions were selected to demonstrate improved performance at warmer FWS temperatures.
- ORv3 server rack is capable of supporting 30kW of ITE with two power shelves (fully populated with 3kW PSUs or rectifiers). Unlike ORV2, which contains one power shelf, these power shelves are not confined to specific power zones or locations and can be positioned within the rack as required.

## Parameters of interest

Many metrics exist to monitor the condition of IT hardware and associated temperature management. The complexity of any analysis grows linearly with the number of metrics involved, so a balance between simplicity and insight was sought. The following criteria were selected as the metrics that would best demonstrate the

performance of each component of a Door HX solution, while also allowing for comparisons among different solution implementations. Door HX design parameters of interest are in alignment with those listed in the ACS Door Heat Exchanger Requirements for Open Rack [4]. Due to the increased static pressure associated with multiple rows of coolant-carrying tubes in Door HX coils, as well as the heat transfer impact of higher inlet air temperatures, server fan power is also assessed.

Parameters of interest and their definition in relation to the Door HX solution on an ORV3 rack have been outlined in the following visual and table.

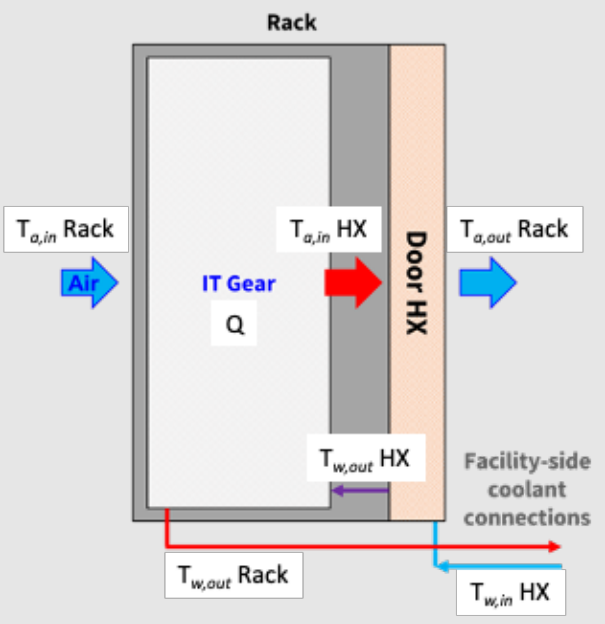



**Figure 2: Air-side and water-side temperature definitions for a Door HX solution and supporting rack/IT gear**

**Table 3: Relevant parameters to evaluate operation of Door HX designs**

| Parameter | Unit | Description |
|---|---|---|
| $T_{a,in}$ Rack | °C | Temperature of air entering the rack and ITE |
| $T_{a,in}$ HX | °C | Temperature of air entering the (Door) HX, having absorbed heat from the ITE |
| $T_{a,out}$ Rack | °C | Temperature of air exiting the Rack (or Door HX). In the case of 'Traditional' and 'Hybrid' solutions in this document, we assume this value is equal to Ta,in Rack. In the case of the 'Air-Assisted' solution, this parameter captures the entire ITE heat exhausted to the rack air stream. |
| $T_{w,in}$ HX | °C | Temperature of water entering the (Door HX). Water could be either supplied directly from the facility loop (FWS) or by a CDU (TCS loop). |
| $T_{w,out}$ HX | °C | Temperature of water exiting the (Door) HX. In the case of 'Traditional' and 'Hybrid' solutions in this document, the water has absorbed heat from the rack air stream. In |

| | | |
|---|---|---|
| | | the case of the 'Air-Assisted' solution, the water is returning to the cold plate loops in ITE having exhausted heat to the rack air stream exiting the Door HX. |
| $T_{w,out}$ Rack | °C | The temperature of water exiting the rack. In the case of the 'Traditional' solution in this document, this is synonymous with Tw,out HX. For the 'Hybrid' solution, the water has absorbed heat from the cold plate loops (either directly or through an in-rack CDU) and exits the rack at a higher temperature than Tw,out HX. For the 'Air-Assisted' solution, this parameter does not apply as the water loop is closed or contained within the rack boundary. |
| Q | W or kW | Total heat or power load of the ITE |
| $T_{approach}$ | K | Temperature difference between secondary fluid return and primary fluid supply. For the 'Traditional' and 'Hybrid' Door HX, this is the difference between Ta,out Rack and Tw,in HX. For the 'Air-Assisted' Door HX, this is the difference between Tw,out HX and Ta,in HX. For CDUs, this is the difference between secondary outlet (TCS) and primary inlet (FWS) water temperatures. |
| ITD | K | Referred to as 'Initial Temperature Difference'. For the 'Traditional' and 'Hybrid' Door HX, this is the difference between Ta,in HX and Tw,in HX. For the 'Air-Assisted' Door HX, this is the difference between Tw,in HX and Ta,in HX. |
| Q/ITD | W/K | Parameter used to define HX performance at different air and water flow rates |
| $\dot{V}_a$ | cfm | Volumetric airflow rate through the Rack |
| $\dot{V}_w$ | lpm | Volumetric water flow rate through the Rack |
| $P_{fan}$ ITE | W | Total fan power consumption for all ITE |
| $P_{fan}$ HX | W | Fan power consumption for the Door HX |

## Comparison of ORV2 and ORV3

**Table 5: High-level comparison between Open Rack versions 2 and 3**

| | ORV2 | ORV3 |
|---|---|---|
| Height | 2210 mm | 2295 mm |
| # of U's | 41OU | 44OU or 48RU |
| Location of PSU/BBU shelves | Fixed | Anywhere in rack |
| Liquid cooling support enabled | No | Yes |
| Horizontal frame support movable | No | Yes |

ORv3 liquid cooling implementations:

- Rack-level, blind-mate manifolds
- Blind-mate quick connects to interface with liquid-cooled chassis
- Reservoir and pumping unit (RPU) for air-assisted liquid cooling support. Off-the-shelf, in-rack CDUs could be modified to support hybrid cooling.
- Ability to support higher power/density rack configurations with flexible PSU/BBU shelves (quantity and location)

To outline the impact of different Door HX applications on overall/rack efficiency, fan power consumption is estimated at both ITE and Door HX solutions. Fan power consumption of the Door HX will be addressed in the following section. For the ITE, since our focus is on Open Rack V3, we assume blind-mate interfaces being developed through OCP to support liquid-cooling of individual servers/ITE chassis. In total, up to 36OU of ITE could be liquid cooled of the 44OU positions available in the rack. We assume the non-ITE positions are either blanked off (using pizza boxes or equivalent) or contain supporting hardware such as top-of-the rack switches and power infrastructure devices (such as Power Supply Unit and Battery Backup Unit shelves) that consume minimal airflow and thus do not need to be accounted for as part of ITE fan power consumption. The following curve is used to estimate ITE fan power per OU (not including the Door HX). It is estimated based on a nominal-to-high chassis flow impedance and maximum number of fans feasible (at the rear of the chassis) while accounting for space required to accommodate busbar and blind-mate manifold connections. In general, this ITE fan power curve estimates in the range of 2%~10% of ITE load, which is found to be reasonable considering latest chassis design/performance trends [3].

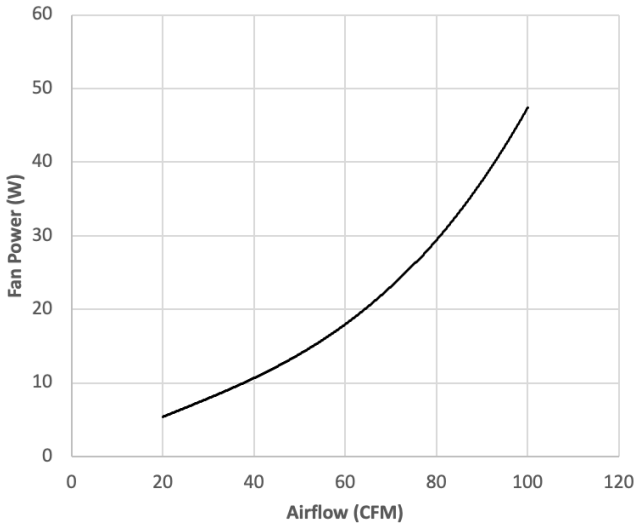



**Figure 3: ITE fan power consumption per OU as a function of airflow rate**

## 7. Two Different Door HX Solutions

To highlight the impact of Door HX selection (or design) on performance in-application, this study has defined two different Door HX solutions – (a) Off-the-shelf; (b) Custom sized for ORV3. Refer to Table 3 in Section 6 above for definitions of all parameters listed.

## Off-the-shelf (OTS)

The off-the-shelf or OTS solution is meant to represent a Door HX solution that dimensionally fits (and could be mounted to) an ORV3 rack without paying specific attention to performance characteristics (beyond minimal requirements). The following HX performance and fan power consumption data are used as reference for the "OTS" solution in subsequent sections.

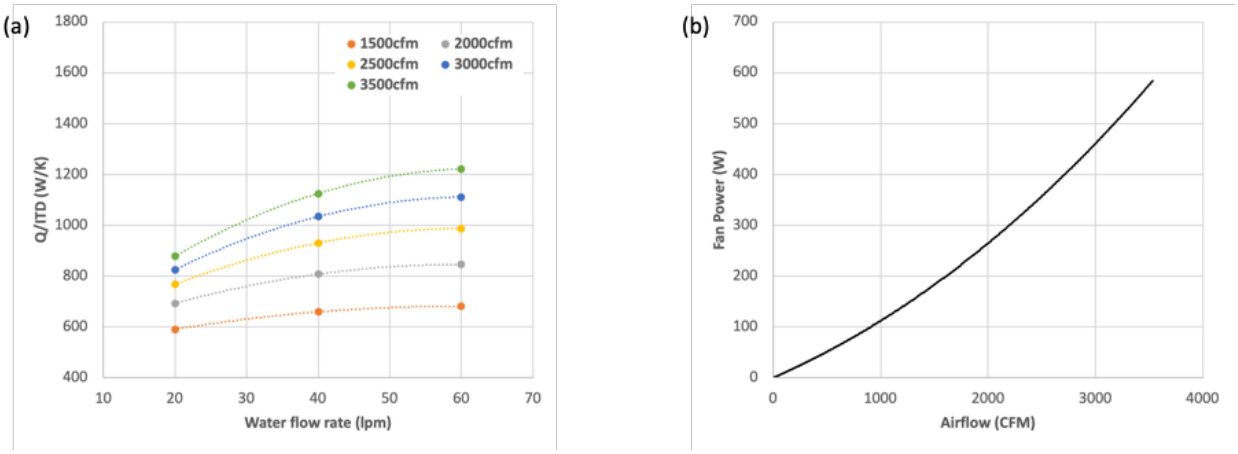



**Figure 4: (a) Performance of the OTS solution under different air- and water-side flow rates; (b) Door HX fan power consumption as a function of rack airflow rate**

## Specific to ORV3 (Custom)

The Custom solution is meant to represent a Door HX solution that maximizes coil footprint as well as thermal performance in relation to the rack being supported (ORV3). This is in-line with the 'metrology of performance' tenets highlighted in the ACS Door HX Requirements for Open Rack [4]. In relation to the OTS solution, the custom design has a larger coil footprint as well as a larger number of rows/tubes in the assembly. This manifests as superior performance as well as slightly lower fan power consumption compared to the OTS counterpart. The latter is not always necessarily true as increasing the number of tubes in a row result in a deeper coil that generally increases pressure drop (and, in turn, fan power consumption). In this specific case, the increased (frontal) footprint of the coil compensates for the increased depth to provide fan power characteristics that are superior to the OTS solution. The following HX performance and fan power consumption data are used as reference for the "Custom" solution in subsequent sections.

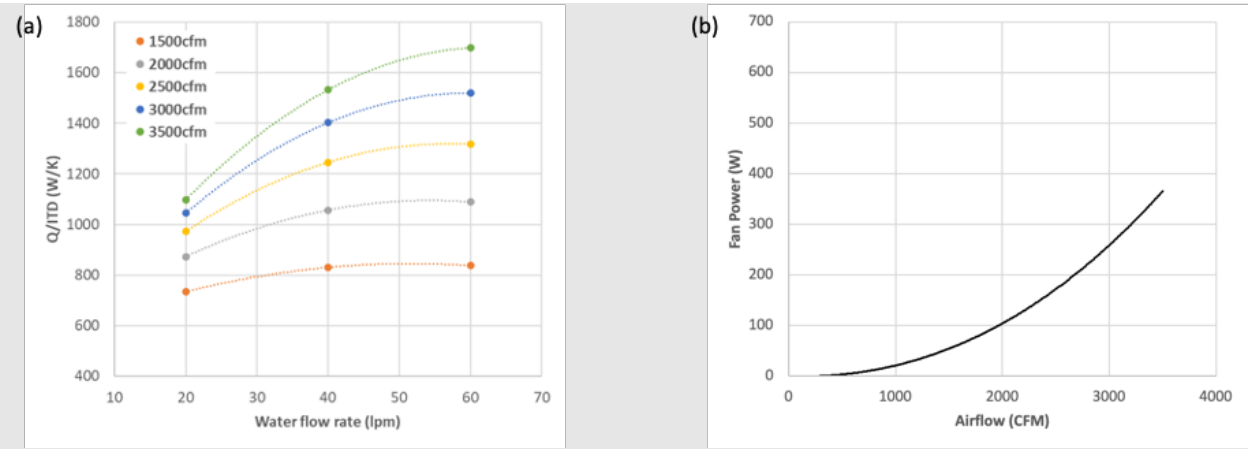



**Figure 5: (a) Performance of the Custom solution under different air- and water-side flow rates; (b) Door HX fan power consumption as a function of rack airflow rate**

## 8. Performance Under Specific Applications

This section will compare the OTS and Custom solutions based on different Door HX applications (highlighted in section 4) and help outline why purposeful design/selection of the Door HX for your application is important to realize rack- as well as facility-level performance and efficiency goals. Unless explicitly outlined, the following analyses assume 30kW of ITE load in a rack as well as an operating ambient temperature of 30°C and sea-level altitude.

### Air-assisted (liquid cooling in an air-cooled facility)

The air-assisted liquid cooling or AALC solution focuses on enabling higher power/density racks as well as the thermal performance benefits of a direct-to-component liquid cooling solution (cold plate loops) in an air-cooled facility. This is realized by running a closed, water loop within the rack, with the rear mounted Door HX responsible for rejecting heat to rack airflow. As such, performance is maximized when the water is delivered to cold plates in ITE chassis at a temperature closest to rack inlet or facility supply air. The difference in the water and air temperature values is referred to as the approach temperature. The following plots highlight performance for both OTS and Custom solutions under similar operating conditions/parameters.

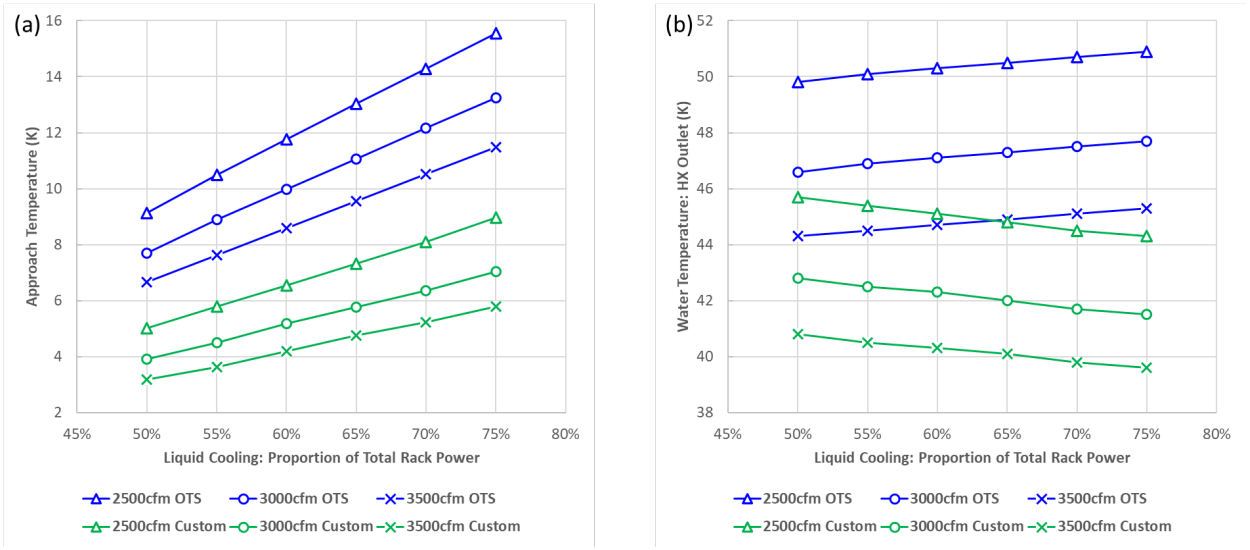



**Figure 6: Operating parameters as a function of rack airflow and proportion of 30kW ITE load that is liquid cooled for (a) OTS and (b) Custom Door HX solutions**

Both plots assume airside and water-side deltaT of 15~20°C and 10°C correspondingly across the ITE gear. The custom solution can provide lower approach temperatures and, as a result, lower HX outlet water temperatures (or water supply temperature to ITE cold plates) for a given amount of rack airflow. The performance of the custom solution is so visibly superior that supplying water to cold plates in the range of 44~46°C is possible with 2500cfm of rack airflow. The corresponding requirement for the OTS counterpart is 3500cfm, or with 1000cfm of additional rack airflow. The impact of these savings manifests as 990W of total fan power for the custom solution as compared to 2180W for the OTS counterpart. Beyond rack energy-efficiency to support 30kW of ITE load, the custom solution also helps reduce airflow requirements from the facility that could manifest as lower aggregated PUE and WUE values. In general, the AALC application helps enable higher power components/ITE racks in an air-cooled facility without significantly impacting operating efficiency (as compared to traditional heat sink solutions). The following bulleted list highlights further observations made based on the plots in Fig. 6.

- In both cases, the approach temperature increases as the proportion of ITE load rejected to the water loop is increased. However, the slope of approach temperature increase is more pronounced for the OTS solution due to inferior performance for a given amount of water- and air-side flow rates.
- The HX outlet or cold plate water supply temperature is calculated by adding the rack inlet air, ITE airside deltaT and approach temperatures. Depending on the solution, this parameter either increases or decreases as the proportion of ITE load rejected to the water loop is increased. This has to do with the rate at which ITE airside deltaT and approach temperature decrease/increase in opposition to each

other. For the custom solution, the ITE airside deltaT decreases at a greater rate compared to increase in approach temperature resulting in HX outlet water temperature decreasing as proportion of ITE load rejected to the water loop increases.

- For a desired component case temperature, a lower HX outlet water temperature enables support for higher component powers. Therefore, selecting a Door HX with superior performance may be necessary to enable higher rack power as well as energy-efficient operation.

## Traditional

The traditional Door HX application involves using a rack-mounted solution with facility water (FWS) supply to either minimize the air-cooled load added to the room/facility or eliminate it (make the rack exhaust thermally neutral to the room). In this case, performance of the Door HX solution impacts both cooling capacity and FWS supply temperature for a given amount of rack airflow. The following plots highlight performance for both OTS and Custom solutions under similar operating conditions/parameters.

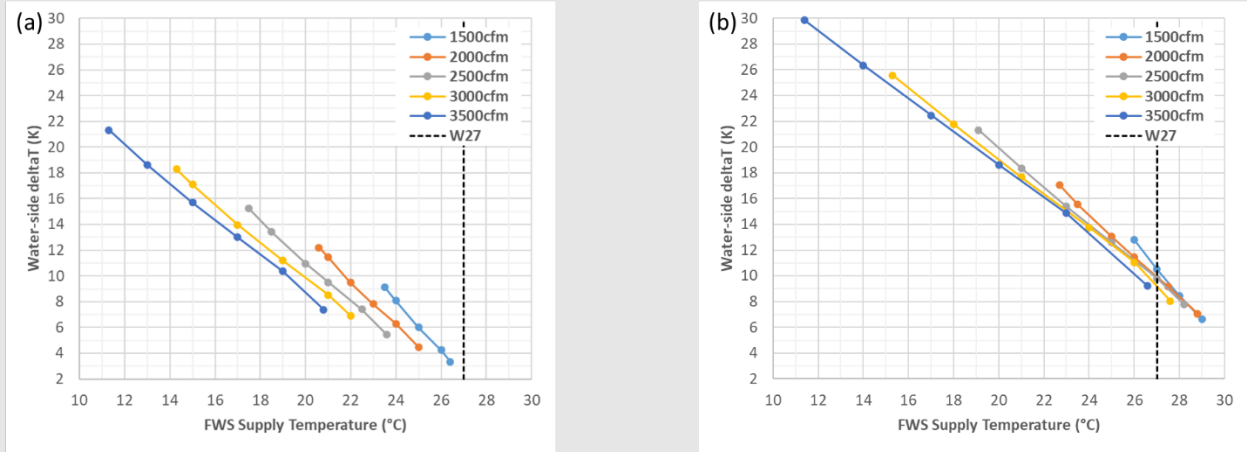



**Figure 7: Operating parameters as a function of rack airflow for (a) OTS and (b) Custom Door HX solutions**

Both plots assume ITE airside deltaT of 15°C for different rack airflow values. As a result, the total ITE load is 12.6, 16.9, 21.1, 25.3 and 29.5kW for corresponding rack airflow rates of 1500, 2000, 2500, 3000 and 3500cfm. The individual data points of water-side deltaT (across the HX coil) for a given FWS supply temperature are generated by varying FWS flow rates while targeting an HX outlet air temperature of 30°C. Once again, the custom solution manifests superior performance in the form of higher FWS supply temperatures along with higher water-side deltaT across the HX coil. Both parameters have a direct influence on facility efficiency (PUE and WUE) as the

former determines the method of heat rejection (chiller as primary or trim; dependent on-site location) while the latter influences FWS pump power consumption. To help further illustrate this, let us assume an ITE load of 29.5kW and a rack airflow of 3500cfm. For the OTS solution and a water-side deltaT target of 10°C, the FWS loop would need to be operated at 19°C (supply temperature). The corresponding Custom solution could raise the FWS operating point by 7°C to 26°C. In general, facility operators would acknowledge that this is not a small improvement. This application of the Door HX solution once again highlights the importance of sizing for the use-case to maximize performance and efficiency.

## Hybrid

The hybrid application is an evolution of the traditional counterpart where facility water is not only used to make the ITE rack neutral to the room with a rear-mounted Door HX but also use the cooling resource for thermal management of critical components in the ITE chassis using direct-to-component liquid cooling solutions (cold plate loops). Since cold plate loops have more stringent water quality requirements compared to a Door HX, a Coolant Distribution Unit or CDU is required to separate the FWS and cold plate/TCS loops. As a result, the CDU can either be placed upstream or downstream in relation to the Door HX. Placing the CDU upstream to the Door HX saves space/power in the rack at the cost of higher water supply temperature to the HX coil due to the approach penalty being paid upstream. On the other hand, placing the CDU in the rack and downstream to the Door HX provides the benefit of using FWS supply temperature at the HX coil and paying the penalty of CDU approach (in this case, in-rack) with the cold plate loops only. It should be noted that an elevated (temperature) TCS loop within the rack can support a wide range of existing, high-power components such as CPUs, GPUs, etc. This is illustrated with the visual below.

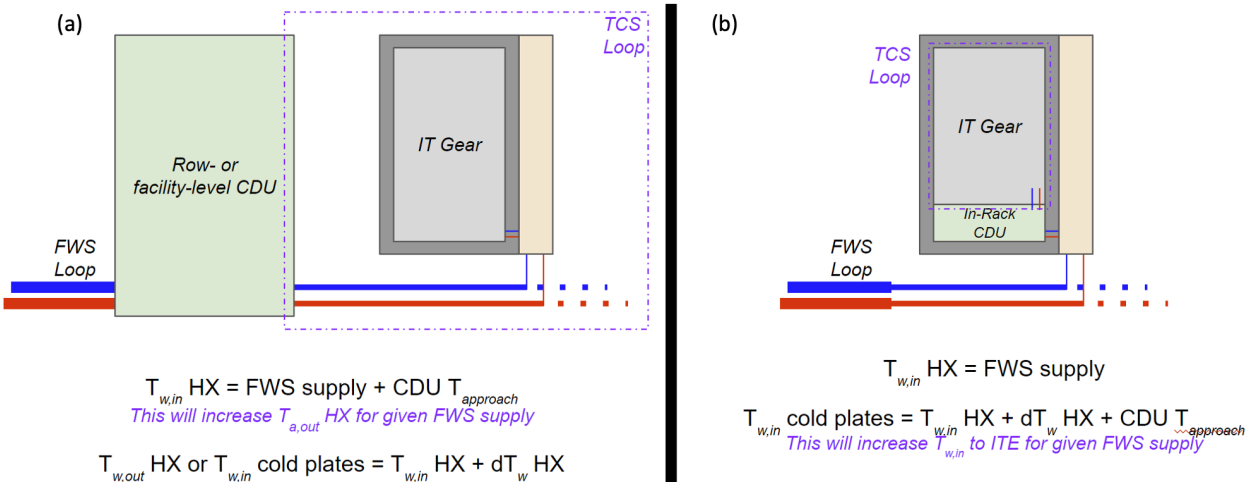


**Figure 8: Location of CDU and impact to hybrid solution performance or operating parameters**

To compare the OTS and Custom solutions in a hybrid application, let us assume the CDU is located upstream to the Door HX and the TCS loop encompasses entire rack-level assemblies. To aid our analysis, we assume row-level or facility-level CDUs can comfortably achieve an approach temperature of 3°C at or close to their designed capacities. Thus, for HX outlet or rack ambient air temperatures of 32°C and total ITE load of 30kW, the following plots highlight performance for both OTS and Custom solutions.

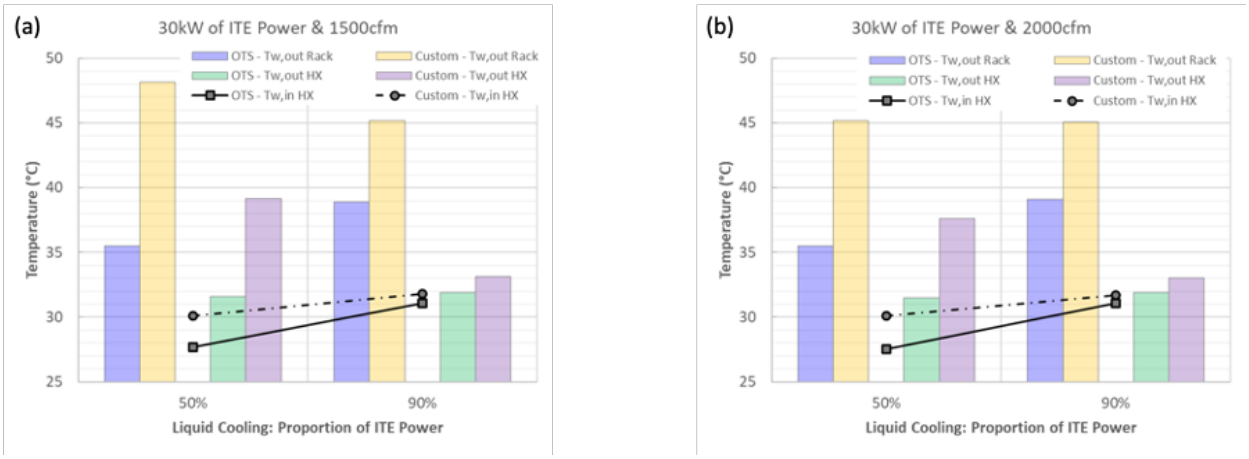



**Figure 9: Comparison of operating parameters for OTS and Custom solutions under varying ITE liquid cooled loads and for given rack airflows of (a) 1500cfm and (b) 2000cfm**

Observations based on the above plots are highlighted in the following bulleted list:

- The custom solution can support FWS supply temperatures ≥ 27°C to the row-level CDU to maintain ambient air temperatures of 32°C with rack ITE loads of 30kW. This is true when the proportion of total ITE load that is liquid cooled is ≥ 50%. For the OTS counterpart, the FWS supply water setpoint is visibly lower when the 30kW ITE load is equally split between air- and liquid-cooling at the server/chassis.
- Independent of the rack airflow setpoint, the custom solution enables higher HX and rack water outlet temperatures in comparison to the OTS counterpart. Maximizing the rack water outlet temperature helps with entertaining the feasibility of low-grade waste heat recovery for potential district heating, etc. The reason the OTS solution has lower water-side deltaT values is because comparatively higher water flow rates are required to hit the cooling capacity/performance targets of rack-level air-side heat capture.

- Understandably the gap between the OTS and custom Door HX solutions shrinks as the proportion of ITE power/load that is liquid cooled is increased. This is because the proportion of rack ITE load exhausted to/captured from rack airflow is reduced, making the Door HX performance less of a concern.

As previously highlighted, the hybrid solution has the greatest potential for maximizing ITE power while enabling 100% liquid cooling at the rack (without fundamentally changing how ITE gear is designed). To illustrate this, we assume the Custom Door HX solution mounted to an ORV3 frame with an in-rack CDU for TCS loop support. For a rack airflow of 3500cfm, the Door HX is capable of rejecting 30kW of heat dumped to air flowing through the ITE gear assuming an FWS setpoint of 27°C and HX outlet or ambient air temperatures of 30°C. The maximum amount of ITE load rejected to the TCS loop is a function of the CDU performance and TCS loop component sizing (manifolds, QCs, etc.). However, the authors believe an in-rack CDU with a form-factor of 4U and cooling capacity of 50kW is entirely feasible with an approach temperature of 5°C or under. Thus, a total/rack ITE power of 80kW is considered feasible for a hybrid cooling solution with an FWS water supply temperature of 27°C and a rack inlet air temperature of 30°C. The corresponding parameters of interest are listed below.

- Total fan power consumption of 1.97kW (Custom Door HX + ITE chassis). This corresponds to ~2.5% of the rack ITE capacity of 80kW.
- Rack and Door HX footprints add to 8.87 square feet (service or accessibility space not included). Thus, the corresponding power density is 9.02kW per square foot.
- Water supply temperature to cold plates is ≤ 40°C which should be adequate to cover a reasonable number of SKUs of current/future CPUs, GPUs, and ASICs.
- When operating at capacity, the rack outlet water temperature is 43°C, which may be high enough to support low-grade waste heat reuse at the facility.

## 9. Door HX Cooling Management

All three implementations of a Door HX require some form of management. The device manager could be a simple microprocessor, or something more complex with a network interface that supports the DMTF's Redfish API. The ITE, and possibly the RPU or CDU will have a BMC (Baseboard Management Controller) that implements Redfish. Sensors, controls, device descriptions, and telemetry data that are exposed by Redfish can be utilized by the facility management system to get a detailed view of the power and cooling requirements for the facility, for predictive failure analysis, asset inventory management, etc.

### Traditional

When a Door HX is added to a rack, the heat exchanger coil impedes the ITE's cooling air flow. A Door HX can be equipped with fans to compensate for the additional air impedance. The Door HX fan speed is typically managed by measuring the differential air pressure between the rack interior and the ambient air pressure. By adjusting the Door HX fan speed so that the air pressure inside of the rack is at ambient pressure, the Door HX will not impede the ITE's air flow. Fan speed control will also minimize fan power consumption and noise.

It is possible to manage the coolant flow through the Door HX by controlling a FWS coolant flow valve. There are many management methods that can be used to minimize FWS coolant flow including; return air temperature, differential air temperature, return coolant temperature, differential coolant temperature, minimum coil temperature to avoid condensation, etc.

### Air Assisted

Fan speed control is typically the same as with a Traditional Door HX.

This implementation includes an RPU to circulate the coolant between the Door HX and the ITE. The coolant flow is managed by controlling the pump speed. There are many methods that can be used to manage the pump speed; simple fixed speed, coolant pressure, coolant supply temperature, die temperature of the liquid cooled ITE, etc. Managing the pump speed will minimize pump power consumption.

The cooling manager could be part of the ITE, Door HX, RPU, or even in a Rack Manager. Sensor data and pump controls will likely be on different devices, so the cooling manager will need a network connection between the devices.

### Hybrid

Fan speed control is typically the same as with a Traditional Door HX.

This implementation has the most complex management because of the need to control the FWS coolant flow to balance the return air temperature from the Door HX, and coolant flow to the CDU.

As with the Air Assisted implementation, the cooling manager could be part of the ITE, Door HX, CDU, or even in a Rack Manager. The FWS cooling manager needs to ensure that the CDU gets adequate FWS coolant flow, and the CDU needs to ensure that the ITE gets adequate coolant flow.

# 10. Summary of Benefits and Limitations

Door HX has multiple applications that enable liquid cooling in facilities with or without coolant piping to the IT racks. Together, the authors believe these applications enable support for near- and long-term ITE and enterprise technologies/hardware. As highlighted in previous sections, designing for your application is critical to maximizing the capability of the Door HX in terms of cooling capacity, energy-efficiency, and other relevant parameters. The following section will highlight key takeaways from this effort.

## Key Takeaways

- Door heat exchangers are a mature technology, with IBM publishing about adoption/applications in the early 2000s [6]. In North America, Door HX solutions have seen adoption in the HPC and enterprise spaces with average lifespan of the product extending anywhere from a few years to over a decade. It is important to note that across all ACS (advanced cooling solutions) technologies being explored under OCP, Door HX has the least impact on hardware/ITE design.
- *AALC application*: This solution focuses on enabling higher component power and rack density through implementation of closed-loop liquid cooling with cold plates in an air-cooled facility. Door HX design influences the temperature of coolant supplied to the IT gear and, in turn, power/temperature of critical components. For example, 30kW of IT load could be supported with a wide range of rack airflows (2500~3500cfm) at supply air temperatures ≤ 30°C. As highlighted in section 7, being specific with the Door HX design can reduce fan power consumption by as much as 55% while reducing rack airflow by 1000cfm and maintaining reasonable coolant supply temperatures to the cold plate loops. Conversely, even higher component powers could be supported by consuming more airflow without the need to reduce the facility's supply air temperature. These aspects aid in extending capability or efficiency of air-cooled data centers and enable smooth transition to facility water-enabled facilities.
- *Traditional application*: This solution aids in simplifying data center or room design for air-cooled hardware by eliminating the need for aisle containment as well as assisting/minimizing CRAC units; enabling higher power racks near low power counterparts. The Door HX is also an option for small deployments, such as edge computing. Purposeful design can minimize the approach temperature, enabling 30°C ambient air with 27°C facility water supply (upper end of ASHRAE W27 envelope).

- *Hybrid application*: This solution excels at maximizing the advantage of facility water supply to racks by cooling critical IT gear components with cold plates (this necessitates TCS loop either within rack or at row/facility-levels) while making the rack thermally neutral to the room, or 100% liquid cooled (from the facility's perspective). Like the traditional application, this implementation simplifies the DC design while maximizing potential for white space footprint optimization by enabling higher rack powers compared to AALC and traditional counterparts. For example, a 30kW rack could be comfortably cooled with 1500cfm and 30°C water supply (assuming the CDU is upstream to the Door HX and at least 50% of the power is capture by the cold plate loops) while maintaining an ambient or rack outlet air temperature of 32°C. Temperature of water to cold plates can be as high at 40°C; this is a result of the Door HX using the minimal amount of coolant needed to achieve the required airside cooling capacity. Lower water temperature to the cold plates could be achieved by increasing the total flow rate, but this would come at the cost of lowering the return water temperature from the rack. With regards to rack-level cooling efficiency, total fan power is only 1.5% of the rack IT capacity which is lower in relation to AALC and traditional Door HX counterparts/implementations. The proportion of rack power distributed between liquid- and air-cooling will influence how liquid flow to the rack (including the Door HX) is controlled.
- *Pushing power density with the Hybrid application*: As stated previously, this solution excels at maximizing power or cooling capacity because of facility water piping to the rack. For example, this study has established that a Door HX with a cooling capacity of 30kW can generate 30°C ambient air with 27°C facility water supply to the rack. An in-rack CDU with a cooling capacity of 50kW could feasibly fit within 4U assuming an approach temperature of 5°C. Thus, a rack with 80kW of IT capacity could be cooled with 27°C facility water supply while delivering a power density of 9kW per square foot and total fan power consumption of 2kW (which is 2.5% of the IT capacity). In the current HPC industry, rack power greater than 100kW is not unheard of, and is predominantly driven by interconnect limitations/density. Beyond the hardware, increasing rack power density could help minimize the footprint of the facility resulting in capital and carbon footprint savings. Other benefits include enabling efficiency at the facility through increased FWS supply temperatures, waste heat recovery or reuse and exploring sustainability or circularity through multigenerational use of an oversized Door HX and other liquid cooling components in the rack.

## 11. Next Steps

Based on learnings from this study, the ACS Door HX and OCP communities may consider exploring the following areas:

- Defining a base specification for a Door HX sized for Open Rack V3 with a focus on performance, energy-efficient and reliable operation, and interfacing with other ORV3 liquid cooling solutions and platform components
- Sustainability or circularity evaluation for a hybrid solution (including ORV3 frame and power systems) exploring carbon and capital cost of the same and determining which components should be targeted for multigenerational use
- Building on this study through harmonization within the Cooling Environments and across other OCP projects to meet longer-term goals of the community and the industry as a whole

## 12. References

[1] "Liquid Cooling Guidelines for Datacom Equipment Centers", 2nd edition, ASHRAE Technical Committee 9.9, 2013

[2] "Water-Cooled Servers: Common Designs, Components and Processes", ASHRAE white paper by Technical Committee 9.9, 2019, https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/WhitePaper_TC099-WaterCooledServers.pdf

[3] "Emergence and Expansion of Liquid Cooling in Mainstream Data Centers", ASHRAE white paper by Technical Committee 9.9, 2021, https://www.ashrae.org/file%20library/technical%20resources/bookstore/emergence-and-expansion-of-liquid-cooling-in-mainstream-data-centers_wp.pdf

[4] "ACS Door Heat Exchanger Requirements for Open Rack", Fernandes, J., Na, J., Djuranec, S., and Thompson, M., 2021

[5] "OSHA Technical Manual (OTM) Section III: Chapter 4 Heat Hazard Assessment", https://www.osha.gov/otm/section-3-health-hazards/chapter-4#heat_hazardassessment

[6] "Maintaining Datacom Rack Inlet Air Temperatures with Water Cooled Heat Exchanger", Schmidt, R., Chu, R.C., Ellsworth, M., Iyengar, M., Porter, D., Kamath, V., and Lehman, B., pp. 663-673, InterPACK 2005.

## 13. About Open Compute Foundation

The Open Compute Project Foundation is a 501(c)(6) organization which was founded in 2011 by Facebook, Intel, and Rackspace. Our mission is to apply the benefits of open source to hardware and rapidly increase the pace of innovation in, near and around the data center and beyond. The Open Compute Project (OCP) is a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure. For more information about OCP, please visit us at http://www.opencompute.org