WHITE PAPER: ADVANCED COOLING CONCEPTS FOR OPEN EDGE SERVERS - MOVING TOWARDS MORE SUSTAINABLE AND EFFICIENT SOLUTIONS

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Executive Summary

Nokia has already contributed the initial Open edge chassis as an OCP accepted product and for a complete solution, Nokia also contributed 1U and 2U air-cooled energy-efficient server sleds and also a front haul gateway sled as OCP inspired products. Already included in the initial release of 2018, the first-generation Open edge solution was designed to support certain environmental requirements, including the NEBS temperature ranges that are relevant for edge and far edge datacenters. As a continuation of this effort, Nokia has started work developing further Open edge servers based on energy efficiency and sustainability. In this whitepaper, Nokia highlights key design specifications for the next evolutionary step of the Open edge server cooling solution.

In this development, the target is to explore alternative advanced cooling solutions, while maintaining compatibility with the well-established air-cooled Open edge servers. Enabling higher power density for newly designed sleds and bringing the possibility of decreasing the power used for cooling the site significantly and in that way reducing CO_2 emissions caused by edge computing. Secondary but equally important, benefits can be found from lowering the acoustic noise generated by the edge data center.

Going beyond the direct advantages of the adoption of advanced cooling solutions, new opportunities for datacenter energy use are enabled, which could increase energy efficiency and consequently move the edge datacenters towards a more sustainable future.

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Introduction

The mission statement of the Open Compute Project Foundation (OCP) is to be a rapidly growing, global community, that designs, uses, and enables mainstream delivery of the most efficient designs for scalable computing. Nokia has contributed to this mission and OCP, since the initial Open edge (OE) chassis as an OCP accepted product and contributed 1U and 2U air-cooled energy-efficient server sleds as an OCP inspired product, already in the initial server release of 2018. Since the first-generation Open edge was designed to support all environmental requirements, like full NEBS temperature ranges that are relevant for edge and far edge datacenters.

Nokia continues to work on OCP contributions, in consonance with the theme for the 2022 OCP Global Summit: Empowering Open. Focusing on how advanced cooling systems can overcome challenges faced by the current air-cooled centered solutions, going beyond the heat transfer properties, but also looking into the overall potential of edge data centers to be more sustainable and energy efficient.

The importance of these initiatives is demonstrated by the considerable energetic and consequent carbon footprint represented by datacenters globally. Some current estimations indicate that the total operational energy consumption by datacenters is between 1% and 2% of the total electricity generated [1] [2], while electric energy production accounts for emissions of 1 495.25 Million Metric Tons of CO_2 equivalent in the US alone (25% of the total US greenhouse gas emissions) [3].

While it is important to account for and recognize the advances already made in the ITC sector, where due to the combination of increased efficiencies and greater virtualization a six-fold increase in server compute instances was achieved, with only a 25% increase in global server energy use [1]. It is also fundamental to start taking the necessary steps toward meeting the commitments under the Paris Agreement, by limiting warming to 1.5°C above pre-industrial levels. In this sense, many OCP technology leaders have already made commitments for 2030 and 2045, to decouple the industry's predicted growth from its environmental impact, which will require the acceleration of existing and future sustainability strategies and solutions [4].

The proposal presented in this white paper is to develop and investigate advanced cooling options, that could be applied to the next generation of Open edge server designs. Also, exploring how advanced cooling technologies could enable heat storage solutions and with that the decoupling of processing power consumption from the cooling power consumption. Allowing a strong integration with renewable (and fluctuating) energy sources, while also reducing the need for chemical energy storage. Which in turn is in sync with the OCP's Sustainability call for climate action [4].

1 Open edge cooling

Open edge server sleds are compliant with key environmental and regulatory requirements, and, fundamentally, any advanced cooling concept developed for the platform is still aligned with these specifications. From the cooling side, some of the key operating conditions are:

- Operating temperature range from -5 to +45°C [ETSI EN300 019-1-3 Class 3.2]
- Short term operating temperature from -5 to 55°C [GR-63-CORE]
- Operating relative humidity from 5% to 95%

This range of operating conditions is wider than the recommended for ASHRAE's class A4 [5]. Additionally, specifications for seismic tolerance (Zone 4 in GR-63-CORE), safety (IEC 62368-1:2014 and GR-1089-CORE), fire resistance (shelf level criteria in GR-63-CORE), and acoustic noise (equipment room criteria in GR-63-CORE), all have an important impact in defining the working conditions that advanced cooling concepts must track.

The cooling of the Open edge server is currently done using an air heat transfer design, with a CPU heat sink and heat sinks for the PPM, as illustrated in Figure 1. The current design is targeted to maximize heat sink capacity in a limited physical footprint, which is most critical for the 1U Open edge server. The present design has the following cooling specifications:

- Airflow of 100 CFM for the 1U server sled, and 160 CFM for the 2U server sled, with fans at maximum speed.
- Airflow is achieved for the 1U server sled using four, dual rotor, 4056 fans; and for the 2U server sled using two, dual rotor, 8056 fans.
- Both front-to-rear and rear-to-front airflow options are supported.
- Fan controls adapt to the environmental conditions, providing adequate cooling with minimum fan power consumption.
- The sled can tolerate the failure of a single fan rotor.
- Power budget for the 1U server sled is 500 W, and for the 2U server, the sled is 800 W.
- Maximum power levels for PCIe cards of 100 W in 1U, and up to 300 W in 2U.

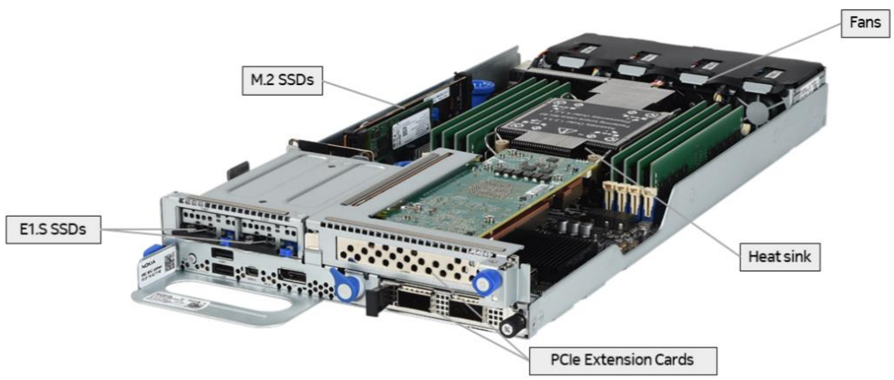
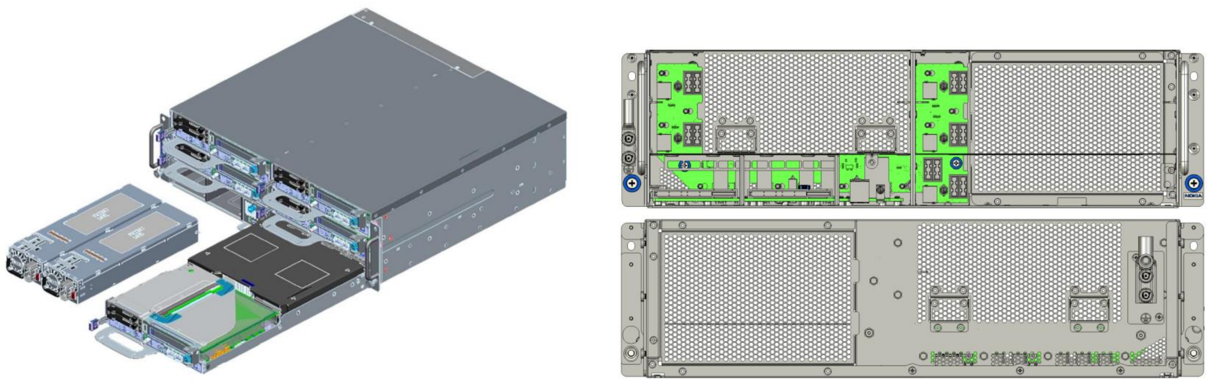


Figure 1: Open edge 1U server sled [6]

The OE server sleds are coupled with the Open edge server chassis, as shown in Figure 2, which provides a steel enclosure and mounting brackets for the OE servers, as well as power distribution and grounding. All operations are done at the front side of the chassis, with all units (PSUs, RMC, and sleds) being inserted and removed from the front, as well as all interfaces also in the front. These requirements follow the OCP design principles of centralized power feed, front access, toolless maintenance, and vanity-free design [7].

An Open edge 3U chassis supports up to five 1U, half-width sleds, and a 2U chassis supports up to three 1U, half-width sleds. Also, 2U, half-width sleds are supported in both chassis form factors. In all workable configurations using 3U and 2U chassis, the maximum power budget is 2 kW. More information on the different configurations for the Open edge chassis can be found in [7].



(a) (b)

Figure 2: Open edge server chassis (a), and chassis rear wall backplane in place (b), front view (b – top), and rear view (b – bottom) [7].

The Open edge chassis does not have fans, instead, the fans are integrated on the sleds and PSUs, with the design of the chassis supporting both air flow directions. The rear wall of the chassis, shown in Figure 2. b, is closed by a perforated honeycomb pattern, with a perforation ratio of 64.4% and no integrated air filters. All thermal events are dealt with at the sled level, each sled has its own and independent fan control, the sled must be able to operate at the full specified capacity, within the specified environmental conditions.

The Open edge chassis is mounted to a standard 19” rack, requiring a shelf to provide full support, as the front mounting flanges are not capable of carrying the entire weight of a fully populated chassis. At the rack level, different configurations can be explored, currently, various blueprint rack configurations are available for Open edge [8]. Taking as an example a 36U Open edge rack, it could fit up to eight 3U chassis, which would represent a power budget of 16 kW just for the servers, with the current solution offloading all the thermal load to air heat transfer, and the facilities air handling unit (AHU).

2 Advanced cooling

The continuous evolution of the Open edge platform demands more focus on the selection of server cooling solutions and system-level configuration. This is demonstrated by the CPU development, rapidly increasing processor’s core count and I/O speeds, the increased power needs of memory modules, and the NIC evolution, with more powerful components; all leading to higher power densities and an increased TDP. At the same time, any cooling alternatives must deal with the fixed cooling specifications from the previous OE generations, and with the limited access to the rear side of the cabinet.

These cooling challenges can be compounded by the data center impacts of higher heat loads, especially for edge computing solutions. In the recent past, the best data centers could be expected to deliver cooling airflow of 1900 CFM [9], and until recently, cabinets approaching 30 kW load were considered the ceiling of air-cooling capacity to maintain the servers’ cooling requirements. Although Open edge solutions can operate reliably, the need to move additional airflow and reach higher rack heat loads comes at the cost of increased power usage and reduced cooling efficiencies. This motivates the exploration of advanced cooling solutions that could be implemented within the Open edge solutions environment.

Advanced cooling options for the ITE industry have been a continuous focus of interest for research & development. Although water-cooled servers have been around for more than 50 years, since high-performance mainframes, there are still technological readiness challenges for the full adoption of higher heat density options, as presented in Figure 3.

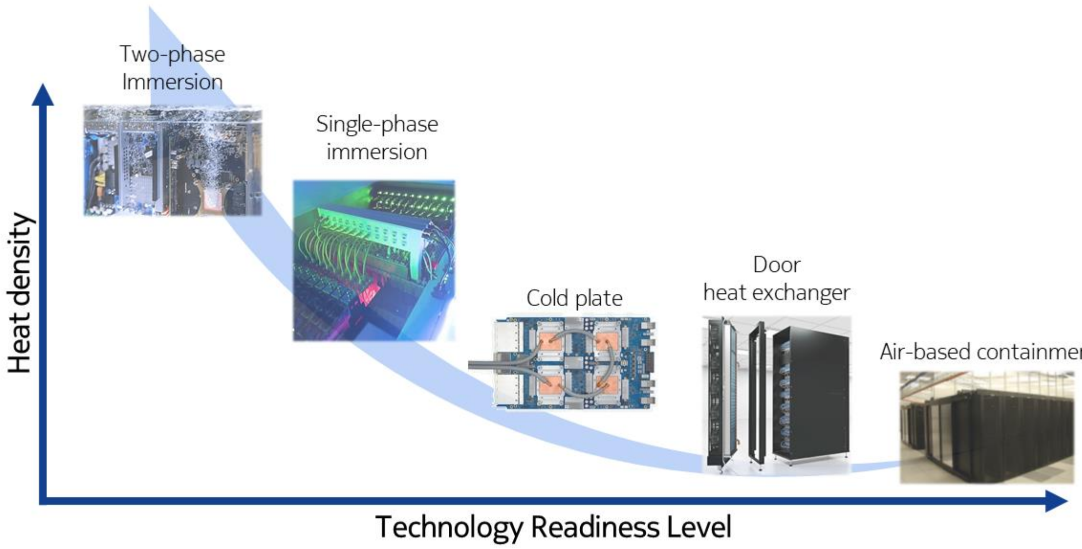


Figure 3: Technological trend for data center cooling options in relation to achievable heat density (Images sources, from right to left, [10], [11], [12], [13], and [14]).

Presently air heat transfer cooling is the dominant form of cooling for ITE. Though this technology might have intrinsic limitations for higher heat density applications, there are a few advances implemented to achieve useful cooling without necessarily increasing airflow. Such as using improved packaging materials for higher heat transfer, designing servers capable of handling increased ΔTs, and adopting efficient best practices in the data center, such as cold aisle containment with reduced mixing between cold air and hot air. Still, there is no escaping the physics limitation of air's reduced heat capacity, and therefore the resulting scaling challenges and the loss of opportunities for sustainability improvements.

Active door heat exchangers are the next step in the evolution of air-based heat transfer designs, in these applications the heat from the ITE is captured by a heat exchanger located inside the rack itself, generally on the rear door. While this implementation prevents hot air from entering the white space and reduces the thermal load for the CRAC, allowing for the increase of the maximum heat removal capacity for the rack (up to 50 kW). These systems are still limited by the air's heat capacity inside each server, and the increase in complexity by the coolant distribution units at the room level is not necessarily compensated by higher heat densities.

To allow the increasing heat densities, that are going to be required by advanced server units, the use of liquid cooling and two-phase options must be considered. For the liquid cooling option, an often cited figure is the comparison of volumetric heat capacity ($C_{p,V}$), in which water has a $C_{p,V}$ that is about 3500 times greater than air, while a more realistic comparison has to take into account the overall heat transfer coefficient (U - $W \cdot m^{-2} \cdot K^{-1}$). This ability of liquids' two-phase refrigerants to carry much larger amounts of heat offers considerable advantages, such as allowing easier transport and management of heat, which provides new opportunities for sustainability improvements.

The two main ways in which liquid and two-phase cooling can be implemented are using cold plates or immersion cooling. The use of direct-to-chip cold plate cooling has been growing rapidly, since these systems can be implemented without radical hardware architecture changes, by replacing the heat sinks used for air-cooled designs, with the use of a proper coolant distribution unit (CDU) and the necessary hoses and connectors. One advantage of using cold plates is that mixed cooling systems can be easily employed, with the main heat-producing elements being liquid-cooled and the rest of the server being air-cooled. On the other hand, immersion cooling alternatives generally require more radical design changes and higher initial investment. Also, system weight, form factor, and serviceability challenges must be considered.

3 Open edge advanced cooling specifications

Considering the present development of advanced cooling options, and the expected increase in the cooling needs for the Open edge servers, we propose a series of specifications to help guide the progress of OE servers towards more sustainable and efficient solutions. This draft proposal has an evolutionary approach, it does not address future revolutionary cooling systems, and is guided by OCP design specifications.

- The servers with advanced cooling solutions (ACS) should maintain full serviceability by IT-trained professionals. With the minimal need for any additional fluid-specific instruction or access to service tools and materials.
- The ACS server must have all the necessary interfaces through the front side of the chassis, any fluid coupling should be able to be aligned and connected without access to the back of the rack.
- The cooling system should be fault-proof for normal operating conditions, given a proper maintenance plan is followed.
- The design must have fail-safe features in all possible components.
- Any faults in the cooling system must be detected and communicated to the Baseboard Management Controller (BMC), generating the proper notifications and alarms.
- Full compatibility must be kept between ACS and the previous generations of OE servers, with the possibility of having ACS servers and air-cooled servers mounted to the same Open edge chassis, and the possibility of swapping ACS servers for air-cooled servers without mechanical modifications.

Following these specifications leads to a solution that is centered around the use of cold plates, with a mixed cooling approach. In this case, the components with the highest heat generations are to be cooled using the advanced cooling solution, and the other components cooled using an air-cooled design (though with a highly reduced power consumption for airflow). Blind-mate fluid connections should be used, and have a flat-face design, non-spill features, and misalignment compensation. A guiding pin and mechanical stop must be included, and any connection forces must be dealt with by the front face locking mechanism of the server.

4 Advanced cooling sustainability opportunities

While the proposed change from the current air-cooled OE server solutions presents challenges, which might demand redesigns and adaptions, notably with the necessity of integrating new thermal and mechanical specialists, it will also present opportunities with untapped benefits. These prospects are presented here as a motivational factor for the adoption of advanced cooling solutions for the OE Servers, even though they are not the focus of this white paper.

One well-known potential advantage is the possibility of implementing heat reuse applications, which is ever more prominent as the data center industry puts sustainability and efficiency as key goals. While heat reuse can be employed using traditional air-cooled data centers, the use of liquid-cooled solutions, in the form of cold plates or immersions cooling, enables the use of liquids at higher temperatures, with liquid cooling class W45 and W+ [5], resulting in waste heat with much greater quality. In this manner, the heat generated by the ITE can be redirected for applications in agriculture (warming greenhouses), swimming pools, and district heating (already implemented with success at Nokia's Tampere data center [15]) [16]. The heat reuse potential has also been demonstrated through the energy analysis of data centers [17], suggesting that there may exist incentives to consider coupling work-consuming devices (ITE which consumes energy), with work-producing systems (power sources, which supply energy), and in this way take advantage of potential synergies, such as collocate data center facilities with alternative energy systems that have a use for the low-grade waste heat, *e.g.* cogeneration systems or waste processing plants.

Although heat reuse might not always be a feasible application for edge datacenters, which have a smaller footprint and therefore reduced waste heat available. Another important benefit is the potential to reduce energy consumption by the datacenters, which in some cases leads to lowering the PUE since the cooling systems tend to be one of the biggest energy consumers. This is also reflected in the overall energy consumption of the datacenter, and the consequent decrease in electrical bills and total cost of ownership.

One final and important benefit to be considered is the potential of decoupling computational power consumption from cooling power consumption. This is particularly relevant for scope 2 of the OCP Sustainability focus area [4], by facilitating the alignment of workloads to current and forecasted renewable energy capacity, as this allows data centers to more readily integrate thermal storage solutions. An example of a data center with such thermal storage is presented in Figure 4, in this case, a central which operates with the use of a dry cooling tower and direct heat rejection is considered, without the use of an external chiller in the cooling system.

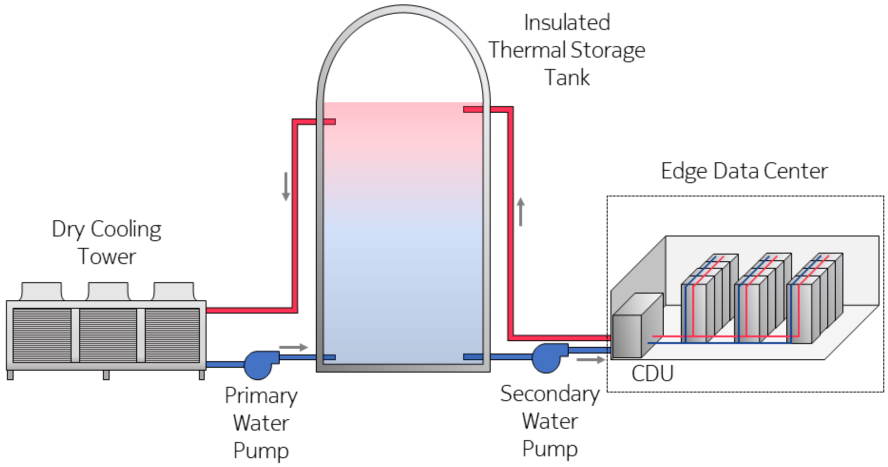


Figure 4: Liquid-cooled OE data centers enable opportunities for thermal storage

In the scenario presented in Figure 4 the thermal storage tank operates as a cold storage system. This kind of thermal storage solution can be thought to operate like a battery, using the combination of cooling equipment and energy storage tank to transfer the cooling production to when the fluctuating renewable energy sources are available (such as sunshine for solar power production). The stored water is used to supply cooling energy during peak hours. This storage cycle can be daily, weekly, or even seasonal, as the thermal storage can be in the form of sensible heat as in liquid water (Figure 4), latent heat as in the use of ice harvesting solutions, or as chemical energy.

In the use of thermal storage, any temperature variations in the facility water system (FWS) tend to happen slowly, as the insulated tank can keep the stored water at a stable temperature. This results in an additional safety feature since any power loss that may occur will not directly impact the cooling capacity of the data center, and with that, the servers could be battery operated with a considerably lower overhead. In this case, any potential fluctuations in the temperature of the supplied chilled water can be compensated by additional control systems in the CDU, by throttling the fluid flow in the heat exchangers and with that keeping a constant ΔT in the technology water system (TCS).

The potential for thermal storage could also be applied for systems that integrate into heat reuse, though operating with higher temperatures (ASHRAE liquid cooling class W45 and W+ [5]), in these cases, there is still the potential of offloading cooling capacity when there is a variable need for the heat produced, as in district heating applications.

5 Conclusion

Advanced cooling options could be applied for the next generation of Open edge servers, as the OE platform continues to evolve and more focus on thermal management is necessary. In this white paper, we presented a high-level view of the present cooling needs for the OE servers and investigated the different technological options for advanced cooling. From this basis, we outlined specifications for the implementation of advanced cooling for OE servers, and considered a possible design pathway, given an evolutionary approach to the implementation of advanced cooling on edge data centers. Finally, we explored a few opportunities generated by the advanced cooling technologies, such as heat reuse and enabling heat storage solutions, from which the decoupling of processing power and cooling power could be achieved.

As computational power continues to evolve, and the pressures for sustainability action increase, the need for innovative solutions for the development of high-density servers becomes ever more evident. The adoption of advanced cooling solutions for the Open edge servers, either through liquid cooling or two-phase cooling, must be explored to address these demands.

6 Glossary

ACS	Advanced Cooling Solution (for the Open edge Server)
AHU	Air Handling Unit
BMC	Baseboard management controller
CDU	Cooling Distribution Unit
$C_{p,V}$	Volumetric heat capacity (SI = $J \cdot K^{-1} \cdot m^{-3}$)
CRAC	Computer Room Air Conditioner
FWS	Facility water system
ITE	Information Technology Equipment
NIC	Network Interface Card
OCP	Open Compute Project
OE	Open edge
PPM	Processor Power Module
PUE	Power usage effectiveness
TCS	Technology water system
TDP	Thermal Design Power

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8 License

9 About Open Compute Foundation

The Open Compute Project Foundation is a 501(c)(6) organization that 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 computing infrastructure. For more information about OCP, please visit us at http://www.opencompute.org