DIELECTRIC COLD PLATE MODULAR DATA CENTER WHITE PAPER

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Executive Summary

In an age defined by relentless technological advancement, the thirst for computational power has never been greater. From data centers powering the digital realm to high-performance computing systems propelling scientific discovery, the heat generated by electronic components is a formidable challenge. As Moore's Law marches forward, pushing the limits of chip density and processing speed, the need for innovative cooling solutions becomes increasingly urgent.

Traditional air-cooling methods have served us well for decades, but they are now reaching their limits. Enter liquid cooling, a disruptive technology that is transforming the landscape of thermal management. At the forefront of this revolution lies the concept of ZutaCores Dielectric Direct-on-Chip Cooling (DDoCC), a groundbreaking approach that promises enhanced performance, energy efficiency, and environmental sustainability.

This whitepaper explores the dynamic world of liquid cooling, with a particular focus on Direct-on-Chip Cooling, shedding light on its advantages and environmental implications.

The Open Compute Project (OCP) foundation is responsible for fostering, serving and seeding the OCP Community to develop new open solutions that can meet the market and shape the future, hence we believe that presenting the dielectric cold plate modular data center whitepaper to the OCP community may encourage further development of the concepts and result in an efficient sustainable solutions.

I. Liquid Cooling: A Paradigm Shift

Traditionally, electronic devices have relied on air cooling, a passive method that dissipates heat through the surrounding air. However, as the power density of modern chips continues to rise, air cooling struggles to keep pace. Liquid cooling, on the other hand, offers a highly efficient alternative. By circulating a liquid coolant directly in contact with heat-producing components, it provides superior heat dissipation, allowing for higher performance, longer component lifespan, and reduced noise levels.

II. The Direct-on-Chip Cooling Advantage

Direct-on-Chip Cooling takes liquid cooling to the next level. It involves integrating Two phase cold-plate directly onto the surface of semiconductor chips. This approach minimizes the thermal resistance between the chip and the cooling fluid, ensuring rapid and efficient heat removal. As a result, chips can operate at optimal temperatures, pushing the boundaries of computing power without compromising reliability.

When moving to dielectric cold plate cooling, the energy efficiency is embedded in the cooling system efficiency and IT power efficiency. The processors are not cooled by air anymore, which enables the internal air temperature coming to the servers to be higher.

III. Environmental Sustainability

The environmental implications of Direct-on-Chip Cooling are substantial. By directly removing the heat from the source (the high-power chip), it reduces the energy required for cooling, cutting down on electricity used for circulating and cooling the air in the data centers and in the high-performance computing clusters. This translates into reduced carbon emissions and a smaller environmental footprint, aligning with global sustainability goals.

Moreover, liquid cooling systems can utilize environmentally friendly coolants, such as zero ozone depletion, very low global warming, and non-toxic liquids, minimizing the impact on ecosystems. The efficiency gains further contribute to lowering the overall energy demand of the electronics industry, a sector historically associated with high energy consumption.

Moreover, the racks and data center can be more densified, resulting in a smaller space needed hence reduced overall air circulation and cooling as well as a reduction in IT power consumption since the fans in the servers are running at idle speed.

On top of all the power reduction, the ZutaCore solution enables collecting the heat from the servers at a high temperature enabling efficient reuse of the heat, reducing even more the power consumption used for computing.

IV. Future Prospects and Challenges

While Direct-on-Chip Cooling holds immense promise, it is not without challenges. Integration into existing hardware designs, compatibility with various chip architectures, and cost considerations are among the obstacles addressed in this white paper.

Nevertheless, as the world grapples with the imperative of sustainable technology, Direct-on-Chip Cooling emerges as a vital piece of the puzzle. With the potential to revolutionize thermal management, it is a technology that can enable the relentless progression of computing power while simultaneously reducing our environmental impact through improved efficiency and heat reuse.

In this whitepaper, we delve deeper into the science and engineering behind Direct-on-Chip Cooling, examining its potential applications, performance metrics, and real-world implementations. By exploring this transformative technology, we hope to inspire innovation, foster collaboration, and drive the electronics industry toward a more sustainable and efficient future.

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1. Introduction

Cooling loop - ZutaCore direct on chip cooling system consists of a Heat Rejection Unit (HRU) functioning as a condenser, Manifold used for refrigerant distribution and vapor collection, and a dielectric cold plate, based on pool boiling evaporator - Enhanced Nucleation Evaporators (ENE).

Using a direct-on-chip two-phase evaporator-based cooling system will reduce the energy required for cooling and the server power consumption allowing space reduction as well as more computational power to be utilized. Hence servers as an optimal technology to be implemented in a modular data center.

Using pool boiling principle enables providing the amount of cooling needed in every part of the chip, regardless of the chip's structure, whether it consists of one die, multiple dies or even layers. The ENE efficiently moves large amounts of the heat off the chip and provides on-demand responses. The ENE's self-regulated mechanism (patented) supplies precisely the amount of refrigerant needed to cool the heat generated by each component. Thermal energy is efficiently removed from the devices through the generation of vapor, which is then transported to the condenser, where it is removed from the rack via a flow of air or facility water. The ENE enables a single, closed-loop, two-phase, liquid cooling solution.

Hybrid cooling approach is combining liquid cooling with air cooling to maximize efficiency: the Direct on chip dielectric cooling process is cooling the high-power chips and removing ~70% of the server heat. 30% of the heat is generated by multiple low-power chips (such as memory, storage, and power regulators), and is removed by air, using the servers built in fans.

Using our unique cooling system, we propose two options of "**all-in-one**" prefabricated data center in a container. Combining facility structure, IT equipment, power infrastructure, and cooling into one shippable enclosed unit, providing a plug & play computing solution:

1. 1MW liquid cooled data-center configuration - using ZutaCore direct on chip dielectric cooling system, with a facility water distribution, will allow a modular container to contain a 1MW data center using the latest and strongest CPUs with a PUE of 1.12, and even 1.07 when used under climate conditions such as in Denmark.
   Each container will contain 16 racks, each rack will support 63 kilowatts(kW) of IT.

2. 350kW liquid cooled data-center configuration – using ZutaCore direct on chip dielectric cooling system, with free air flow, will allow a modular container to contain a 350kW data center with a PUE lower than 1.07.
   Each container will contain 16 racks, each rack will support 20 kilowatts (kW).

The first configuration, providing 1MW, enables a very efficient operation by densifying the racks while keeping them cooled and with heat reuse option, suitable for example, for the HPCs intense computing needs. Furthermore, this configuration provides a facility water outlet at a constant temperature of 65℃, hence enabling an efficient and cost-effective heat reuse option. Using this solution will require only one modular data center as opposed to, for example, using 90kW modular data centers, that will require using 11 modular data centers. The proposed solution will need only 10% of the space needed for the alternative.

The second configuration providing 350kW, is a cost-effective solution with completely waterless operation, suitable, for example, for Telco providers.

Both configurations can be related as building blocks that can be either incorporated as part of a data center or as a standalone solution.

2. Compliance with Open Compute Project Tenets

2.1 Openness

The suggested configurations in this paper are examples of how to utilize direct on chip two phase liquid cooling to achieve efficient and cost-effective solution servers. The purpose of this paper is also to inspire additional configurations based on the proposed concept with different components.

2.2 Efficiency

Using direct on chip dielectric liquid cooling system increase thermal efficiency, as the cooling is being perform directly on the chip. Moreover, the suggested 350kW configuration provides a cost-effective solution – the cost of the full modular data center including the IT equipment is expected to be less than 4 million euros.

2.3 Impact

The proposed configurations are based on previous OCP compatible modular data center concepts and suggest a way to utilize liquid cooling technology to achieve higher density, better efficiency and increased sustainability.

2.4 Scale

Both suggested configurations can be related as building blocks that can be either incorporated as part of a data center or as a standalone solution.

2.5 Sustainability

The 1MW configuration provides a facility water outlet at a constant temperature of 65°C, hence enabling an efficient and cost-effective heat reuse option, without using heat pumps, helping the modular data center to become more sustainable.

3. Two Proposed configurations of Modular Data Centers

In the following sections we will detail the two proposed modular data centers configurations, including the structure, suggested equipment, cost, rack configuration as well as a diagram of the structure top view.

In addition, we have calculated the power consumption and the PUE for two test cases in different climate conditions to give a sense of the expected operation, energy and cost saving.

A. 1MW liquid cooled Data Center with heat reuse option:

The Structure will be of 15-meter x 3.3-meter modular data center, that will include:

- 16 42Ux110x80cm server racks
- 32 power distribution units (PDUs) (2 for each rack)
- cable trays
- fire detection and suppression system

The IT Equipment will include:

- 1,152 Dell C6620 Server sleds in 288 chassis with 2,304 Intel SPR, 350W CPUs
- 16 top-of-the-rack switches

The total modular data-center **CPU power** will be 806kW and the **total** modular data-center power will be 1MW.

The power supply will consist of:

- Uninterruptible power supply (UPS) with batteries, switchgear/switchboard, transformer, panelboard, and automatic transfer switch (ATS)
- Backup power - external electrical generators, integrated separately (not included)

The cooling system will include:

- 16 X 6U-HRU-W (1 for every rack)
- 16 X RdHX rear door
- 1,152 SPR server kits
- 32 X 36U manifolds (two for each rack)
- Facility water distribution infrastructure and valves
- External 1MW dry cooler (adiabatic cooler)
- External 1MW plate heat exchanger (if heat reuse is planed)

The server configuration will be as follows:

- Dell PowerEdge C6620 8-Port Chassis x 1
- Intel Xeon Platinum 8480+ Processor x 8
- (4x8GB) 1RX8 PC4-21300R x 4
- Onboard S140 SATA Software RAID
- 1TB 7.2K RPM SATA 2.5" Dell Hard Drive x 4
- Dell Broadcom 5720 Dual Port 1GbE BASE-T Network Adapter X 4
- iDRAC9 Express Remote Access Card - Remote Monitoring Functions Only x 4
- Dell 2000 Watt PSU x 2
- Dell PowerEdge R740XD2 2U Post Static Rails

Table 1 details the expected cost of goods for a 1MW modular data center, rack design is demonstrated in figure 1, and figure 2 presents the modular data center containers' top view.

Table 1: Expected cost of goods for Modular 1MW liquid Cooled Data center with SPR 350W CPUs*

Item	#	K$	Total (K$)
Servers	288	35	10,080
Switch	16	25	400
Racks	16	3	48
Total IT cost			**10,528**
Facility water Infrastructure	1	30	30
Construction	45	3	135
RdHX rear door	16	10	160
Adiabatic/ Dry cooler	2	50	100
Chiller	2	60	120
Pumps	2	10	20
Fire system	1	10	10
UPS system	1	400	400
Power System	1	990	990
ZutaCore Cooling system	1	1,070	1,070
Total Infrastructure			**3,035**
Total MDC			**13,563**

*Please note that the figures are for reference only, indicative of high volume.

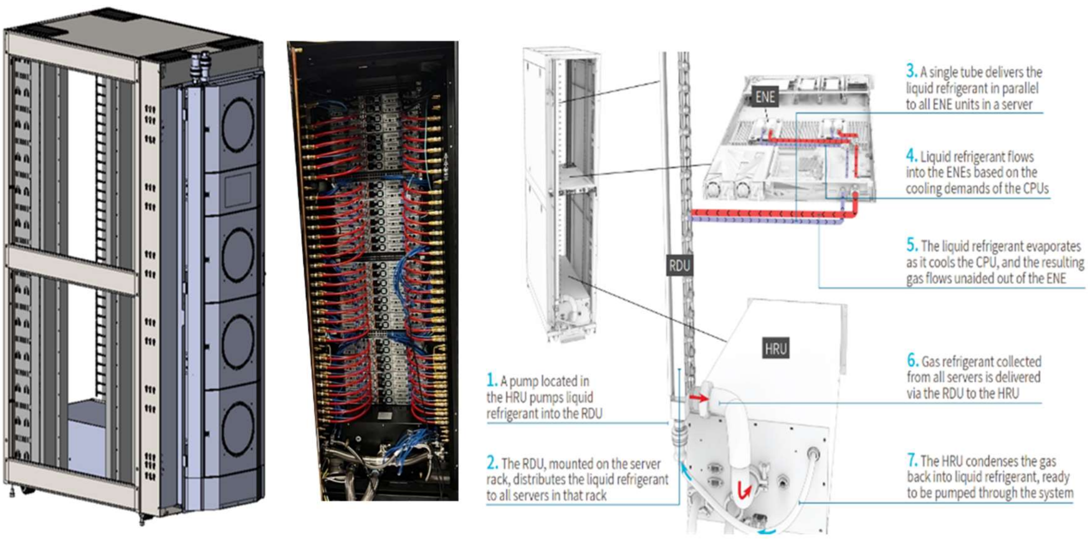


Figure 1: 1MW modular data center rack design

Containers' top view (internal dimensions) **External components**

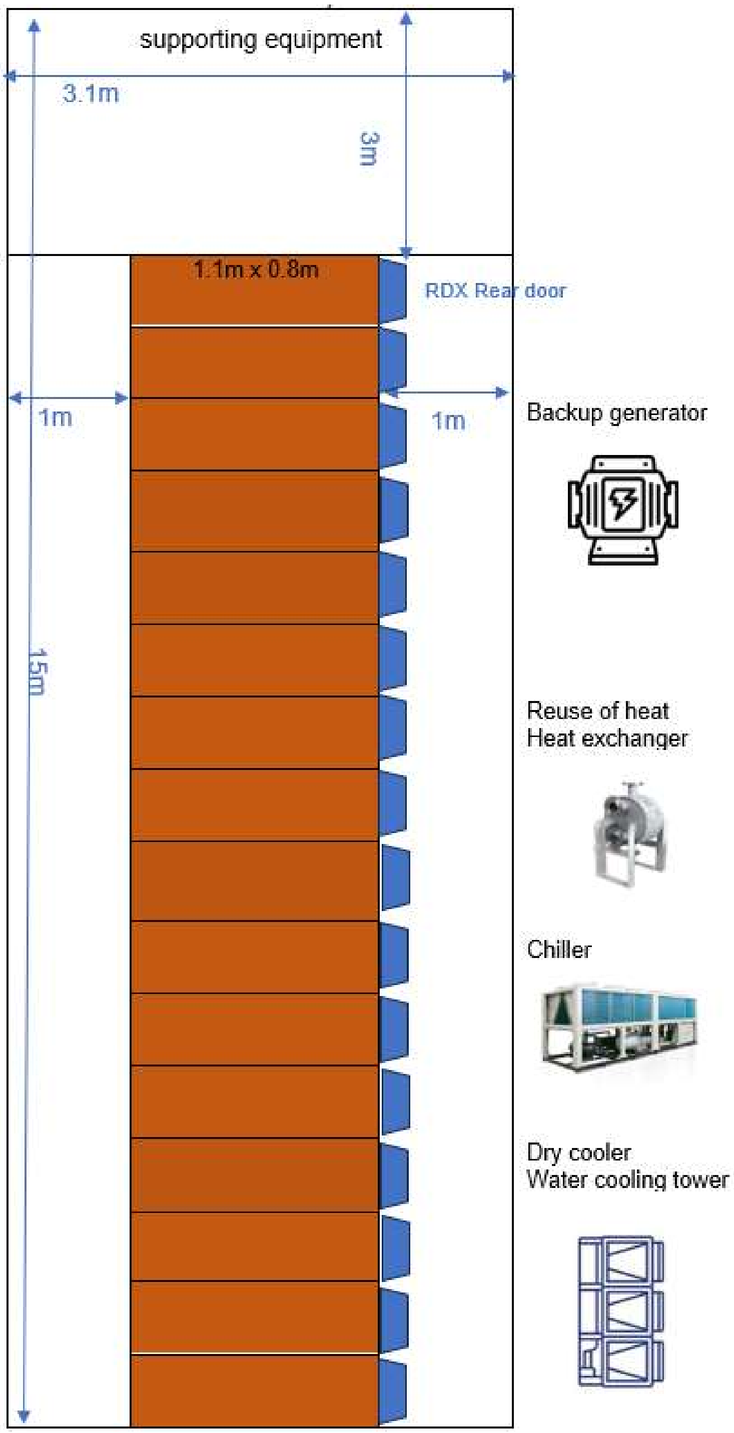


Figure 2: 1MW modular data center containers' top view

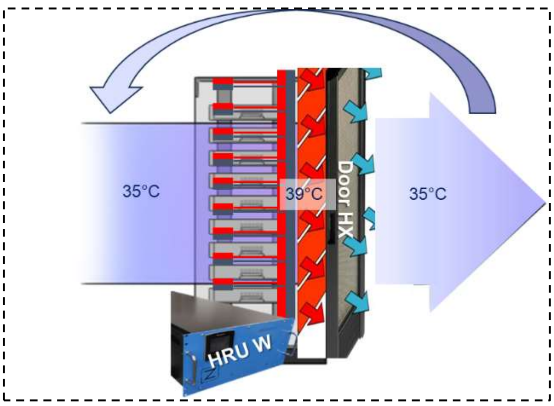


Figure 2.1: air temperature around the rack

1MW modular data center test cases:

TUCSON Arizona USA

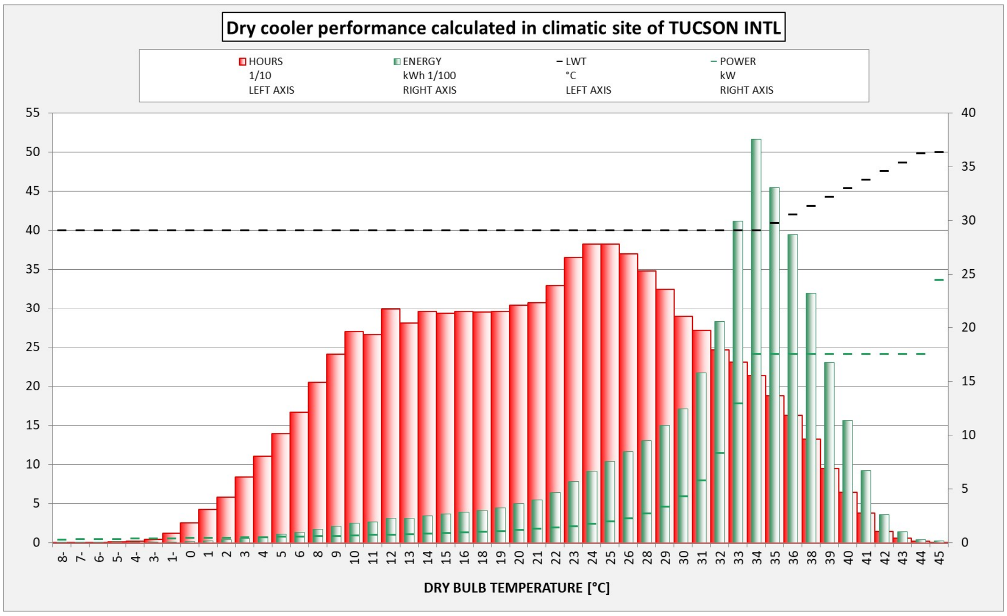
The following calculation in table 3 and table 4, demonstrating a PUE of **1.12** (including 5% for UPS), was performed for a modular 1MW liquid cooled Data Center located in TUCSON Arizona USA, taking into consideration the specific climate conditions and variations (see Graph 1):

Table 3: Power consumption:

Component	kWh
Chiller	70
Pumps	12
Dry Cooler	25
RDX rear door	9
HRUs	6
Servers	1,000
UPS	51
Total	**1,173**

Table 4: Yearly power consumption:

Component	MWh
Chiller	304
Pumps	102
Dry Cooler	33
RDX rear door	77
HRU	53
Servers	8,760
UPS	450
Total	**9,778**



Graph 1: 1MW modular data center - climate conditions and variations in TUCSON Arizona USA

Odense Denmark

The following calculation, in table 5 and table 6, demonstrating a PUE of **1.07** (including 5% for UPS), was performed for a containerized 1MW liquid cooled Data Center located in Odense Denmark, taking into consideration the specific climate conditions and variations (see Graph 2):

Table 5: Power consumption:

Component	kWh
Adiabatic cooler	18
Pumps	4
RDX rear door	9
HRUs	6
Servers	1,000
UPS	51
Total	1,070

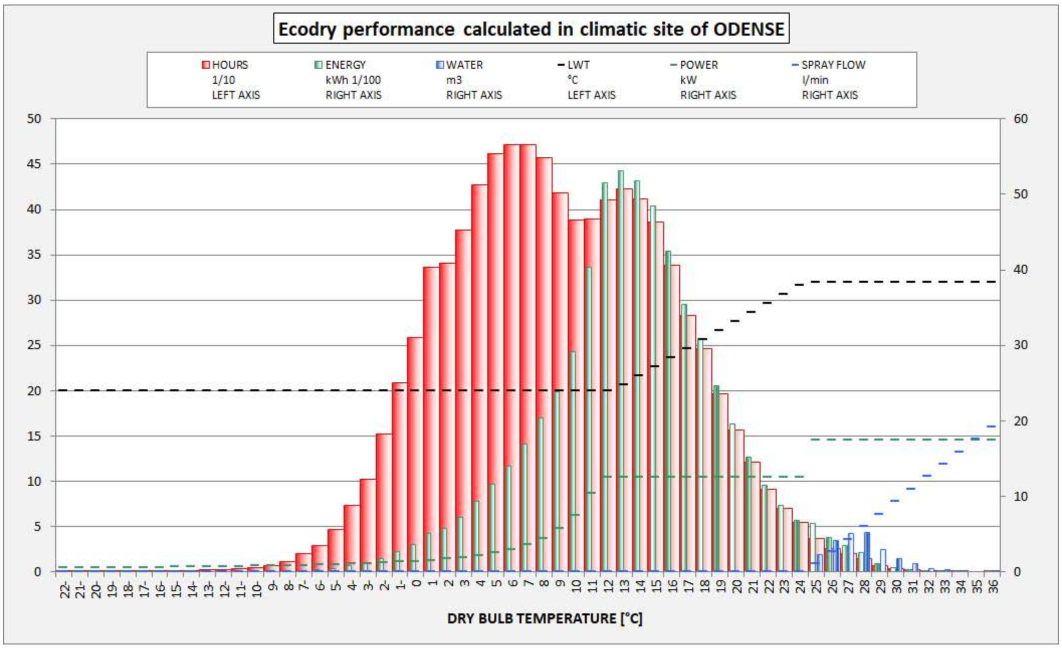
Table 6: Yearly power consumption:

Component	MWh
Adiabatic cooler	18
Pumps	33
RDX rear door	77
HRU	53
Servers	8,760
UPS	446
Total	**9,369**

The heat provided this way is equal to saving 1,446,363m^3 natural gas per year or 8,890MWh per year. The usable heat temperature is 62° C.

PUE=9,369(without adiabatic in case of heat reuse)/8,760=1.070

The Energy Reuse Factor (ERF) is the ratio of the data center energy that is reused elsewhere, and the total energy brought into the data center. In our case, ERF=8,890 (without adiabatic and UPS)/9,369 (without adiabatic in case of heat reuse) = 0.95, indicating 95% of the energy (air and liquid form) is converted to heat for reuse.



Graph 2: 1MW modular data center - climate conditions and variations in Odense Denmark

B. 350kW liquid cooled Data Center:

The Structure will be of 15-meter x 3.3-meter modular data center, that will include:

- 16 X 42Ux110x60cm server racks
- 16 X power distribution units (PDUs) (1 for each rack)
- Cable trays
- Fire detection and suppression system
- Hot air containment by air flow blocker on top of the racks and at the end of the aisle.

The IT Equipment will include:

- 576 dell R640 Server with 1,152 SkyLake/Cascade Lake, 205W dual CPUs
- 16 X top of the rack switches
- The total modular data-center **CPU power** will be 236kW and the **total** modular data-center power will be 350kW

The power supply will consist of:

- Uninterruptible power supply (UPS) with batteries, switchgear/switchboard, transformer, panelboard, and automatic transfer switch (ATS).
- Backup power - external electrical generators, integrated separately (not included)

The cooling system will include:

- 16 X 6U-HRU-A (1 for every rack)
- 576 SkyLake/Cascade Lake server kits
- 16 X 38U manifolds (one for each rack) with free air flow

The server configuration will be as follows:

- Dell PowerEdge R640 8-Port Chassis x 1
- Dell Trusted Platform Module (TPM) 2.0 for 14G x 1
- Intel Xeon Platinum 8160 Processor (2.1 GHz, 24C, 33MB Cache) x 2
- 32GB DDR4 RDIMM 2666MT/s x 4
- No Hard Drive RAID Controller x 1
- Dell 200GB SATA 2.5" Solid State Drive x 1
- No RAID Installation
- No SD Card Reader
- Dell Intel I350 Quad Port 1GbE Network Daughter Cardx 1
- Dell Intel I350-T2 Dual Port 1GbE Network Adapter x 1
- No Optical Drive
- iDRAC9 Express Remote Access Card - Remote Monitoring Functions Only x 1
- Dell PowerEdge R230 R330 R430 R630 R640 Sliding Rails x 1
- No Cable Management Arm
- No Bezel
- Dell 13G 14G 750 Watt PSU x 2

Table 7 details the expected cost of goods for a 350kW modular data center, rack design is demonstrated in figure 3, and figure 4 presents the containers', in which the modular data center will be assembled, top view.

Table 7: Expected cost of goods for Modular 350kW liquid Cooled Data center with 205W CPUs*

Item	#	K$	Total (K$)
Servers	576	4.2	2,419
Switch	16	10	160
Racks	16	3	48
Total IT cost			**2,627**
Construction	45	3	135
Fire system	1	10	10
UPS system	1	184	184
Power System	1	400	400
ZutaCore Cooling system	1	472	472
Total Infrastructure			**3,035**
Total MDC			**3,828**

*Please note that the figures are for reference only, indicative of high volume.

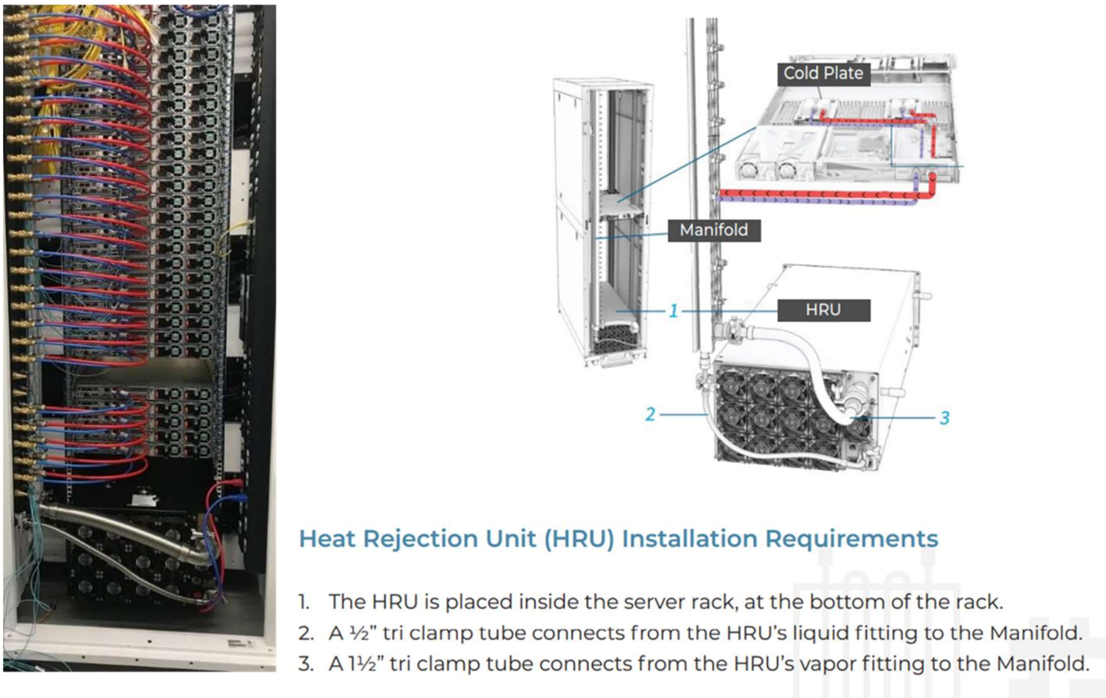
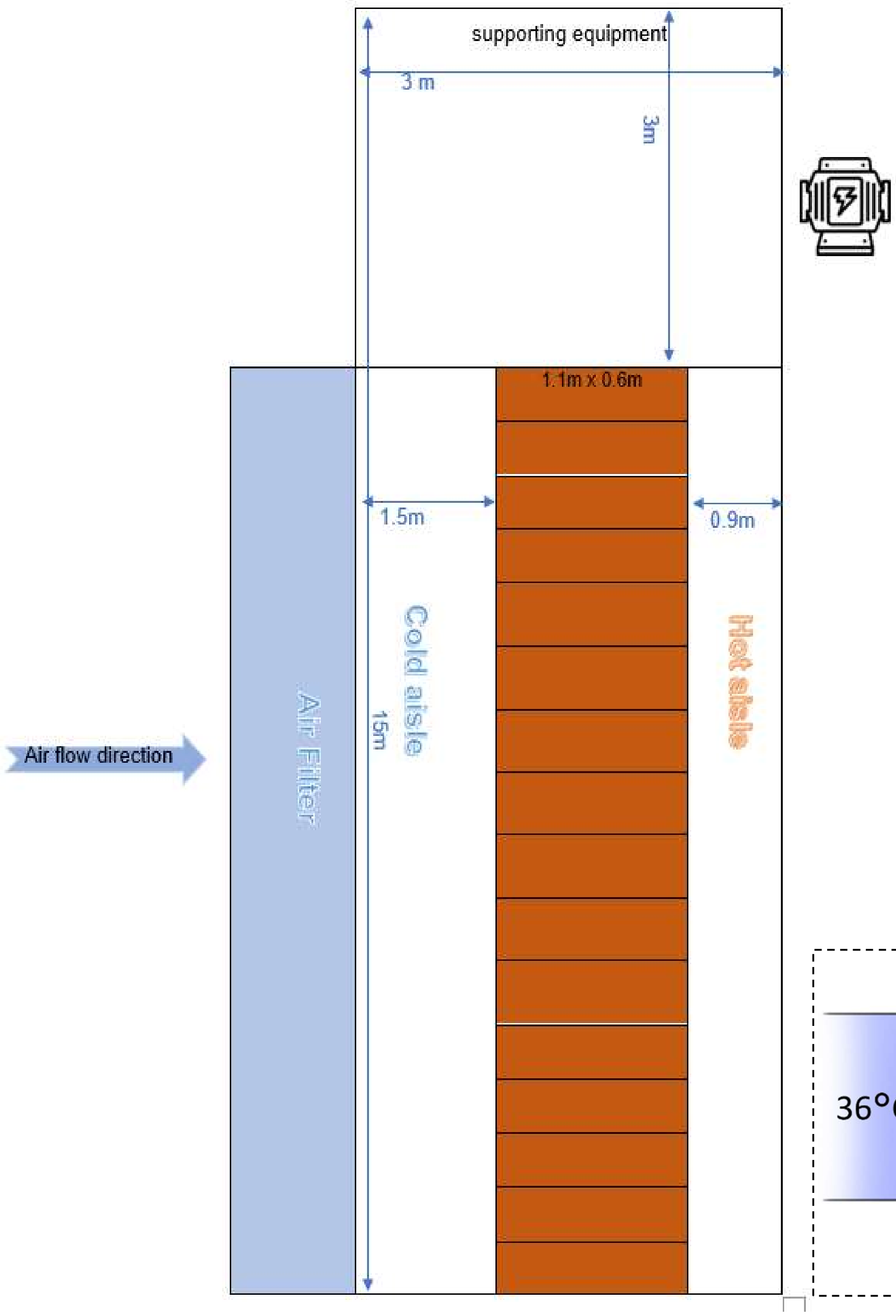


Figure 3: 350kW modular data center rack design

Container top view (internal dimensions)



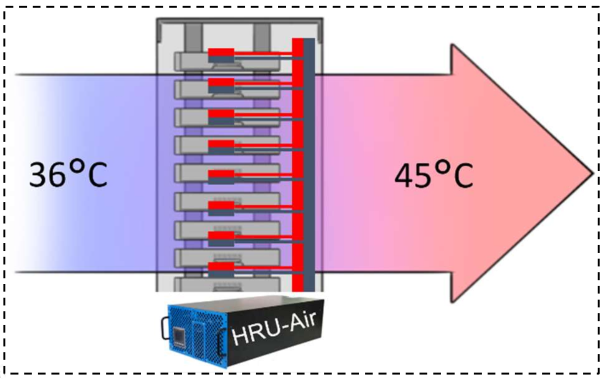


Figure 4: 350kW modular data center containers' top view

Figure 4.1: air temperature around the rack

350kW modular data center test case:

Odense Denmark

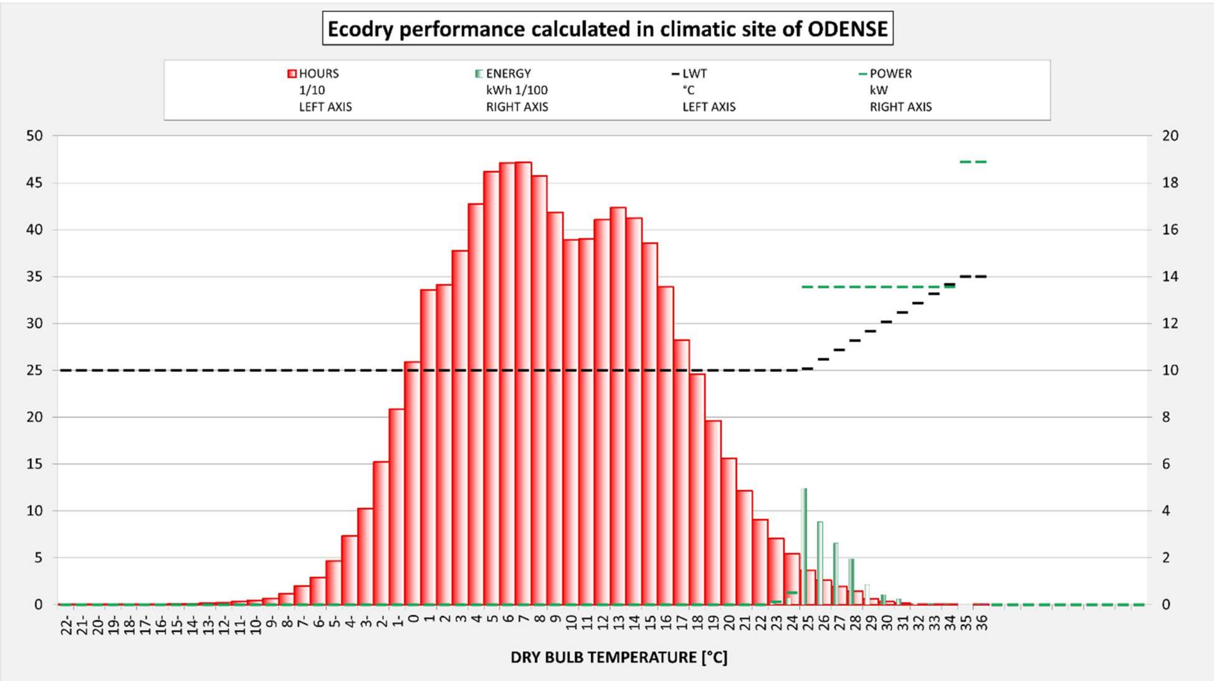
The following calculation in table 8 and table 9, demonstrating a PUE of **1.06** (including 5% for UPS), was performed for a modular 350kW liquid cooled Data Center located in Odense Denmark, taking into consideration the specific climate conditions and variations (see Graph 3):

Table 8: Power consumption:

Component	kWh
HRUs	18
Servers	350
UPS	18
Total	**386**

Table 9: Yearly power consumption:

Component	MWh
HRU	27
Servers	2,923
UPS	161
Total	**3,111**



Graph 3: 350kW modular data center - climate conditions and variations in Odense Denmark

4. Conclusion

As we demonstrated in the two modular data center configurations, dielectric cold plate cooling is highly compatible for modular data center applications. Using this method for cooling enables very efficient and cost-effective operation. Implementing dielectric cold plate cooling method enables racks densification while keeping them cooled, reducing power consumption, as well as reducing costs. Furthermore, when facility water is used to cool the dielectric liquid, water outlet is at a constant temperature of 65°C, hence enabling an efficient and cost-effective heat reuse option. When air is being used to cool the dielectric liquid, a cost-effective waterless operation can be achieved.

Both configurations can be related as building blocks that can be either incorporated as part of a data center or as a standalone solution.

These are just two examples of possible implementations, and we hope it will encourage other OCP members to further develop modular configurations that will allow for a more sustainable operation.

5. Glossary

Term	Definition
DDoCC	Dielectric Direct-on-Chip Cooling
ENE	Enhanced Nucleation Evaporator cold plate
HRU	Heat Rejection Unit - bottom of the rack condenser
PDU	Power Distribution Unit
UPS	Uninterruptible Power Supply
ATS	Automatic Transfer Switch
MDC	Modular Data Center
ERF	Energy Reuse Factor

6. License

7. About Open Compute Foundation

At the core of the Open Compute Project (OCP) is its community of hyperscale data center operators, joined by telecom and colocation providers and enterprise IT users, working with vendors to develop open innovations that, when embedded in product are deployed from the cloud to the edge. The OCP Foundation is responsible for fostering and serving the OCP Community to meet the market and shape the future, taking hyperscale led innovations to everyone. Meeting the market is accomplished through open designs and best practices, and with data center facility and IT equipment embedding OCP Community-developed innovations for efficiency, at-scale operations and sustainability. Shaping the future includes investing in strategic initiatives that prepare the IT ecosystem for major changes, such as AI & ML, optics, advanced cooling techniques, and composable silicon. Learn more at www.opencompute.org.